Andreas Pastoors
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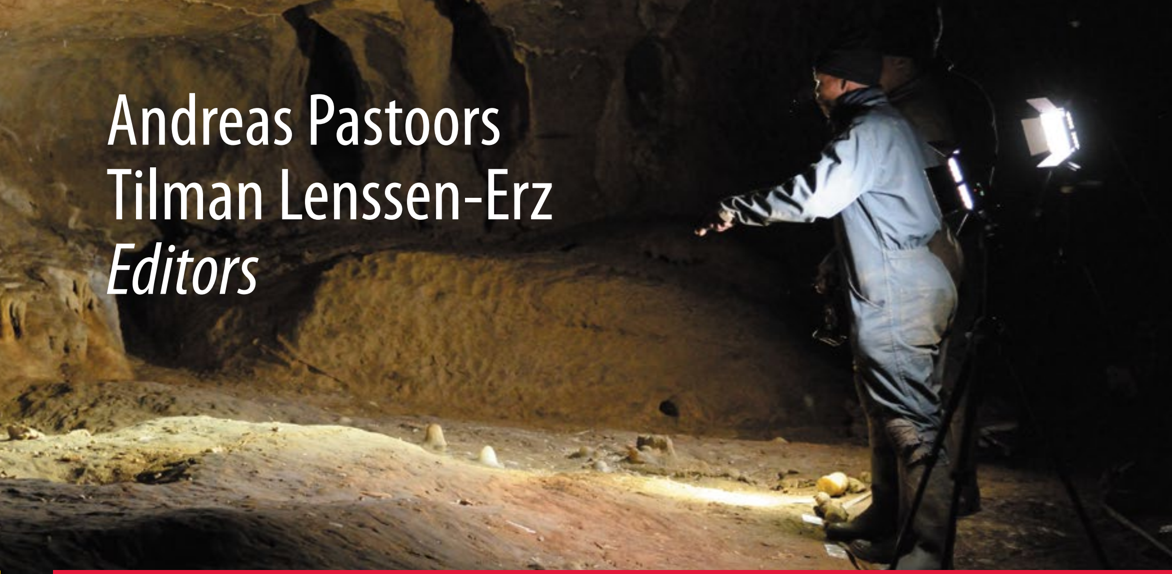
Editors



Reading Prehistoric Human Tracks

Methods & Material

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Foreword

It is a great honour and pleasure for me to congratulate the organizers of this conference and its volume for having brought forward such an innovative approach and topic. It was a fantastic idea to invite expert trackers for an international conference on human tracks, to offer them the possibility to meet other trackers from hunter-gatherer communities around the globe, and to open pathways for including indigenous experts into archaeological research. This shows that there is a kind of knowledge beyond the academic knowledge that is able to enrich science.

This conference was somehow an experiment, but a very successful one. To deal with new categories of knowledge beyond the classical western academic knowledge is extremely challenging, and it is part of the intangible heritage of mankind. The Humboldt Forum in Berlin will become a place where cultures from all over the world shall meet and get into exchange, where a new dialogue between cultures can be developed by cooperation and by co-productions, and where we want to define a new understanding of shared heritage and shared history. This is not only a great challenge, but also a unique chance.

Traditional or indigenous knowledge is so important, because these knowledge systems are embedded in the cultural traditions of regional, indigenous, or local communities, it is knowledge acquired over many generations, it is knowledge mostly about traditional technologies of subsistence, ecological knowledge, traditional medicine, climate etc., and it is generally based on accumulations of empirical observation and on interaction with the environment. This traditional knowledge may distinguish one community from another, it takes on personal and spiritual meanings, and it can reflect the community's interests.

Communities depend sometimes on their traditional knowledge, especially on environmental issues, their knowledge is bound to ancestors and ancestral lands, and it is embedded in a cosmology and therefore has a spiritual component, too. Communities have strong traditions of ownership or custodianship over knowledge, the misuse of knowledge may be offensive to traditions, and they prevent the patenting of traditional knowledge by not expressing consent.

In the broader context traditional knowledge has to be treated in the same way as other traditional cultural expressions. The World Intellectual Property Organization (WIPO) interprets traditional knowledge as any form of artistic and literary expression in which traditional culture and knowledge are embodied. This knowledge is transmitted from one generation to the next, and it includes handmade textiles, paintings, stories, legends, ceremonies, music, songs, rhythms and dance.

During the preparation of the Humboldt Forum in Berlin, it is interesting that the inclusion of indigenous knowledge becomes more and more important and interesting. Years ago we started the project “Sharing knowledge” with the Indigenous University of Tauca in Venezuela, which in the meantime expanded into neighbouring regions of Brazil and Colombia. This cooperation makes visible the dynamics and presence of indigenous perspectives on ethnographic objects, it helps in writing the history of the collections again by including the indigenous perspective. Through an online-platform the future visitor of the Humboldt Forum gets first-hand knowledge from the indigenous perspective on the objects, and not ethnologists or anthropologists are speaking for the indigenous, but the indigenous speak for themselves, what we call multivocality. Ethnologists and anthropologists remain only in an intermediate position. This is a way of decolonizing perspectives by sharing the power of interpretation.

In these days we talk a lot about decolonizing museums and also decolonizing the archaeological practice. These questions are addressing issues of power of science and control of archaeological interpretation. We need participatory approaches, and we have to develop new methodologies and strategies of community participation. This kind of community engagement can be a new path into the future of archaeology in Africa and beyond. It also can help in reacting towards rapid environmental changes affecting ecosystems by engaging communities throughout all levels of research.

But local communities demand to get something back, e.g. the San people in Southern Africa, Inuit in Alaska, First Nations in Canada, or Aborigines in Australia. They defined codes of ethics for researchers wishing to study their culture, their knowledge, their genes or their heritage. They have to be treated respectfully without publishing insulting information, communities wish to read and check results before publication to avoid misunderstandings, and they have to have free access to research data.

Dealing with indigenous knowledge can help us a lot to learn more about a distant past, but it is also a unique chance to broaden our understanding of the plurality of cultures today, and that there are very different categories of knowledge. More knowledge, however, is an important step towards more tolerance and respect for other cultures and different traditions, what maybe today is more important than ever.

President of the Stiftung Preussischer Kulturbesitz, Berlin, Germany
December 2019

Hermann Parzinger

Preface

In May 2017 a conference was hosted at the University of Cologne and the Neanderthal Museum that covered the topic of prehistoric human tracks in a truly global perspective: it convened experts from five continents as well as from various disciplines for scientific presentations. Besides the usual academic presentations in a lecture hall a full day was dedicated to discussing with and listening to indigenous tracking experts from Australia, Canada and Namibia – around a fire outside. These talks and practical demonstrations of track reading by the indigenous tracking experts on a track field with human footprints aimed at enabling western scholars to get a glimpse of the methodological basics of expert tracking. For indigenous trackers it is common practice not only to discriminate male from female footprints but they can also distinguish age classes of adult persons – a differentiation western science including orthopaedics is unable to achieve. This knowledge now entered into a discourse with scientific approaches to glean information from human footprints.

Nearly all projects worldwide investigating human tracks in archaeological context were present at the conference, covering a time span from the earliest footprints in Laetoli to Neolithic ones on the Danish coast. Methodological aspects presented a range from collaboration with indigenous trackers to visualizations based on state of the art scanning technology. This extraordinary meeting with its first time ever encounter of all kinds of human ways of knowing on an archaeological source material – an under-researched one at that – called for an dissemination beyond the closed circle of experts who were present at the conference. The idea of capturing all this knowledge in a book was cogent and in the process of production it showed that further aspects that were not represented at the conference, should still be included so that here we also present authors who did not contribute to the conference. Through this selection of authors for the first time the most important sites which were found worldwide, will be published in a single publication.

This and the broad scope of methodological diversity will make the book a rewarding read for readers from a wide range of fields of knowing. The analysis of human tracks by representatives of anthropological, statistical and traditional approaches feature the multi-layered methods available for the analysis of human tracks and will appeal to students, scholars and also laypeople with an interest in archaeologies, anthropology, social anthropology, palaeontology, cognitive science, cultural science, ichnology and sports science. This book is to show that progress in science and enlightenment on the one hand requires the development of ever new methods in order to enhance the ability for fine resolution in measurement and interpretation of phenomena, but on the other hand it also shows that recourse to knowledge and skills that may have been our human toolkit throughout out species' history can point out where we should get at with our scientific approaches.

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Erlangen, Germany Andreas Pastoors

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February 2020

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Part III Experiences with Indigenous Experts

Chapter 1
Introduction

Andreas Pastoors and Tilman Lenssen-Erz

Abstract This book explains that after long periods of prehistoric research in which the importance of the archaeological as well as the natural context of rock art has been constantly underestimated, research has now begun to take this context into focus for documentation, analysis, interpretation and understanding. Human footprints are prominent among the long-time under-researched features of the context in caves with rock art. In order to compensate for this neglect an innovative research program has been established several years ago that focuses on the merging of indigenous knowledge and western archaeological science for the benefit of both sides. The book composes first the methodological diversity in the analysis of human tracks. Here major representatives of anthropological, statistical and traditional approaches feature the multi-layered methods available for the analysis of human tracks. It second compiles case studies from around the globe of prehistoric human. For the first time the most important sites which have been found worldwide are published in a single publication. The third focus of this book is on first hand experiences of researchers with indigenous tracking experts from around the globe, expounding on how archaeological science can benefit from the ancestral knowledge.

Keywords Prehistoric human tracks · Methodological diversity · Indigenous tracking

Prehistoric human tracks entered into archaeology on a side track more than 100 years ago when human footprints from the Ice Age were discovered in 1906 in the Palaeolithic cave of Niaux in southern France (Cartailhac and Breuil 1907: 222, 1908: 44; Pales 1976):

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> Ajoutons qu'en deux points épargnés par les pieds des visiteurs modernes, nous avons noté, à la surface d'un sol analogue, mais un peu moins ferme, l'empreinte des genoux nus d'un homme qui avait rampé sous une voûte basse, et celles de nombreux pieds également nus, appartenant à des adultes et à des enfants. (Cartailhac and Breuil 1907: 222)[1]

But the interest in these sources was a rather modest one since only Bégouën (1928) and Vallois (1928, 1931) made scientific studies on them, while many tracks in other sites were destroyed without recording. Archaeologists treated the remaining tracks similar to most other sources they deal with: measuring, recording, copying and casting were the means applied to get at a deepened understanding. Tracking, i.e. reading of tracks, was not applied so that this realm of knowledge made its first appearance in academia only in 1990 with Louis Liebenberg's book *The Art of Tracking, the Origin of Science* – and yet the insights of this book remained a dormant potentiality for unjustifiably long time. It was only from the first decade of the twenty-first century onwards when more and more scholars and projects turned their attention towards prehistoric human tracks thus attempting to catch up with ichnology which for a long time had developed as a specialized field of research, mainly coming from the analysis and interpretation of dinosaur tracks (Lockley 1999). Interpretation of tracks in criminal forensics had taken its own, isolated development (Matthews David 2019) before archaeologists and forensic specialists pooled their accumulated knowledge and experiences (Bennett and Budka 2019). With these turns in research strategies, it was acknowledged that human tracks are an important contextual source for the understanding of people's behaviour in the past which previously had mainly concentrated on the sensational footprint finds at Laetoli in Tanzania (Leaky and Harris 1987). Besides learning from these earliest footprints about the development of bipedal locomotion the understanding of human behaviour was of particular interest in the Palaeolithic caves harbouring masterpieces of prehistoric art such as Niaux, Pech-Merle, Tuc d'Audoubert or Chauvet-Pont d'Arc Cave. But also many other sites around the globe with fossilized human tracks gained growing attention (Lockley et al. 2008, 2016; Pasda 2013) and experienced the application of state-of-the-art technology for documentation and analysis (Bennett et al. 2009, 2016; Crompton et al. 2011). However, scientific methods do not attain much deeper insights than concluding the body height of a person, where the footprint length represents 15% of body height (the formula is virtually unchanged since Topinard 1877), but as Bennett and Morse (2014: 148) point out, there lies vast fuzziness in these results. Nevertheless this estimated size is from which an educated guess of the age of the person is made (Bennett and Morse 2014: 152–154). Because of these shortcomings of scientific methods, some projects turned to involve indigenous trackers in prehistoric human spoor interpretations (e.g. Webb et al. 2006; Pastoors et al. 2015), and this confirmed the known but hitherto neglected ability to glean deeper information from footprints (Liebenberg 1990; Biesele and Barclay 2001; Lowe 2002; Gagnol 2013; for the reliability of

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[1] "Let us add that at two points not affected by the steps of modern visitors, we noted, on the surface of a similar but slightly less firm ground, the bare knee prints of a man who had crawled under a low arch, and those of many equally bare feet, belonging to adults and children" (translated by the authors).

indigenous track reading see Stander et al. 1997. Wong et al. 2011). Wherever indigenous specialists were involved as ichnologists, they were able to considerably augment the insights about human behaviour at a site thus showing the rich potential of information resting in these sources, if adequately well preserved. Expectable critique of these analyses and interpretations points out the lack of testability and validation (e.g. Bennett and Budka 2019: 155), but scientific methods, for their part, are presently unable to provide dependable falsification with their proper methods, which would demonstrate their supremacy. Instead, interpretation with a large team of scientists of complex tracks seemingly remaining from human/animal interaction (possibly a hunt) in the Pleistocene (Bustos et al. 2018) eventually has to turn to speculation about intentions and behaviour of humans and animals in order to find a cogent narrative for what the tracks preserve of an event.

Examples of Indigenous Spoor Interpretation

The list of prehistoric sites mentioned in this volume (Happisburgh, Bàsura Cave, Formby Point, Laetoli, Le Rozel, Calvert Island, Vârtop Cave, Ciur-Izbuc Cave, Aldène, Theopetra Cave, Ojo Guareña Cave system and Willandra) where scientific methods have been applied clearly shows that the identification of the trackmakers by morphometric analyses is not sufficient to capture the potential of the dynamic processes stored in the spoors. At each of these sites, more or less complex events were hypothesized but as was to be expected their accuracy and scope varies due to the personal experience of the respective authors. This procedure constitutes the unspoken application of the pre-iconographic description in western art according to Panofsky (Panofsky 1962). Practical experience (familiarity with objects and phenomena) is an absolute prerequisite for a successful application of the pre-iconographic description, from which a positive correlation between experience and descriptive accuracy can be derived. In the Tracking in Caves project carried out in Tuc d'Audoubert, the outstanding experience in reading tracks by indigenous ichnologists was used (Pastoors and Lenssen-Erz 2020; see Lenssen-Erz and Pastoors Chap. 6; Pastoors et al. Chap. 13). Their expertise was applied not only to the prehistoric spoors in Tuc d'Audoubert but also in the caves of Niaux, Pech-Merle and Fontanet.

In Niaux Cave (Ariège, France) 38 footprints are known in a small diverticule. Western academic analysis found some order in an initially seemingly chaotic distribution of footprints by identifying two to three subjects with an age of 9–12 years (Pales 1976: 92–93). The indigenous ichnologists saw an unequal number of footprints and identified a girl (7–13 years; age classes according to Martin 1928) as their sole trackmaker. The spoors were executed in a controlled, not a chaotic manner and in an upright body posture, which is a puzzle since the ceiling is too low to stand upright (Pastoors et al. 2015).

The cave of Pech-Merle (Lot, France) reveals a total number of 17 footprints. Last western academic analysis interpreted the spoors as the result of one single trackmaker, a big child, adolescent or a small adult (Duday and García 1983). The indigenous ichnologists identified five subjects with an age between infans II (7–13 years) to maturus (41–60 years) (Pastoors et al. 2017). They saw four adults, two male and two female and one younger male (7–13 years) crossing the location separately – independent of each other. Furthermore, they detected two events deviating from normal walking: subject S5, a female adult, carried additional weight, and subject S3, a boy of 9–10, turns left abruptly.

The third cave that has been briefly surveyed by the indigenous ichnologists is Fontanet (Ariège, France). Due to various circumstances, the exact number of prehistoric spoors is unknown. In any case, no complete western academic analysis has yet taken place. Currently Lysianna Ledoux is working on a complete inventory of the spoors. First results are available for three track fields of different sizes (Ledoux 2019). Accordingly, on the largest of the three areas, plage 1, 62 tracks were inventoried (identified and measured). Beside footprints there are some handprints and especially numerous slipping marks. The number of trackmakers is assumed to be between two and six subjects, including children, on the basis of metric analyses. In addition to recording the identity of the trackmakers, Ledoux is also concerned with the identification of events. As an example, three tracks suggest a squatting position, extending on the feet, and the left hand resting back against the ground (Ledoux 2019: 253). The indigenous ichnologists counted on 2 study areas (plage 1 and plage 3 at Ledoux 2019) in Fontanet a total 28 prehistoric human traces (27 footprints and one knee) of 17 subjects that could be combined to a total of 8 trackways, which made up 15 events (Pastoors et al. 2015). Among them there are six men on plage 1, two women, one boy, three girls and one unspecific male (covering altogether an age from infans I to maturus). On plage 3 there are four subjects, all male, between juvenis (14–20 years) and maturus (41–60 years). In addition to the information on the identity of the trackmakers, the experienced trackers were able to identify some special events apart from normal walking. On plage 1 subject S5 had slipped, subject S6 was going fast and subject S10 was kneeling. Then a group consisting of four subjects was identified, who were walking together. These are subject S1, female adultus, subjects S2 (male infans II), S3 (female infans II) and S4 (female infans I). In addition, plage 3 was exclusively identified as an area of normal walking. No footprint shows a direct relation to the results of the drawing activities carried out on the ground.

What we have here are results of an analysis by indigenous experts that is part of a daily practice in many pre-industrialized societies. Information on contemporaries, their whereabouts and their doings, in these societies is independent of self-observed evidence or reporting and information. What those who grew up in industrialized societies with paved and tarred surfaces in most of their life-world may read from the face of a person (known or unknown) is also frozen in footprints, irrespective of the wearing of shoes or not (pers. comm. Kxunta; Gagnol 2013; see Gagnol Chap. 19) and therefore readable for those with developed tracking skills. Since there can be no doubt that this depth of information gleaned from tracks is being disclosed not by trancing, dreaming, hallucinating or vision but instead by a positivist approach to the analysis of hard data – i.e. an immediate intuitive assessment of complex measures and textures as well as of biological, zoological, hydrological, meteorological, pedological, cultural, social, sedimentological and physical context – it should in the long run also be detectable by scientific means. Tracking is a parascientific process implying reasoning in an analogous way to western sciences, using induction, deduction and abduction in order to generate new knowledge (Liebenberg 1990). While western morphometric approaches restrict themselves to inductive methodology, indigenous trackers, whose approach can be labelled morpho-classificatory, can imply induction, deduction or abduction depending on data quality, as was mentioned above.

With this book we want to fathom how far scientific and indigenous ichnology have advanced towards their meeting point where both can fully and competently assess the results of the other. Since tracking does not take recourse to alien types of rationality, logic or causality and by no means includes any esoteric facets, practitioners of scientific ichnology may find a useful guide in this book for the recognition of and the advancement towards indigenous ichnology which shows the potential of what can be gleaned from tracks, while still continuing exchange with colleagues from around the globe.

On this Book

Tracks are probably the oldest element of human perception that has been the object of expert analysis ever since humans hunt. *Homo sapiens* is not a born successful hunter of any sizeable game since we have a comparatively poor eyesight (also missing the *Tapetum lucidum* that makes many animals seeing well in the dark), a rather poor sense of smelling and we would be too slow, clumsy and harmless for successful hunting – if not intelligence came into play. Everything beyond a turtle poses a true challenge if we want to get it alive. Therefore reading tracks will probably during the whole human history have been an important means and advantage for the procurement of fresh meat; it would have been an existential necessity for every adult person to acquire solid knowledge in all disciplines of environmental sciences. Consequently Liebenberg (1990) identified tracking as the origin of science.

Adding to this first appraisal of the analytic and even epistemic value of the human ability to read tracks, we want this book to provide a state-of-the-art collection of chapters that represent the best contributions to the field of track analysis at the beginning of the third decade of the twenty-first century. In this digital epoch, there are sophisticated technological solutions to grasp all attributes that characterize tracks, and contributions from around the world show how these are being implemented in many places. Besides this welcome development and enrichment, there is another, paradoxical development in which many indigenous traditions are on the verge to disappear, while it is only now that western science understands that these traditions harbour irretrievable treasures of knowledge for the understanding of certain archaeological source. The patron of the conference on Prehistoric Human Tracks in Cologne and Mettmann 2017, Hermann Parzinger, expounds in his foreword to this book on this point, emphasizing that indigenous knowledges belong to the toolkit with which people master living – not only survival – in all kinds of environments, based on accumulated knowledge inherited from the ancestors, a topic to which the new Humboldt Forum in Berlin will dedicate considerable space.

It is the aim of this book to give a comprehensive overview of the investigation of human footprints in terms of methods and of locations and enriching these with perspectives on tracks from various indigenous groups. Addressing the main sessions of the conference on Prehistoric Human Tracks, this book is divided in the three parts:

- Part I – Methodological diversity in the analysis of human tracks
- Part II – Case studies from around the globe
- Part III – Experiences with indigenous experts

Part I, the methodological part of this book, covers three principal aspects of archaeological research with chapters on technical means, on experimental archaeology and on the attempt to open research towards new knowledge systems. Bennett and Reynolds give a welcome overview of the technical means that are developed today and additionally provide a useful array of different ways of how to visualize data or evidence on tracks (Chap. 2). Meritoriously they also provide a checklist for running field research on tracks.

Among the ultimate goals and challenges of the various digital methods is the ability to discriminate tracks of an individual from those of co-occurring individuals. As McClymont and Crompton point out in their following chapter, two imprints of a foot of one person are never identical so that the fuzziness of an imprint needs to become part of the formula by which an individual can be pinned down by his or her footprint transposed to data (Chap. 3). Besides the information on an individual, footprints also freeze information about locomotion processes and about the character of the locomotion.

Important means of archaeology to generate insight into processes and phenomena are experimental renditions. From the working group of Cussac Cave in southwestern France Ledoux and her co-authors report about their endeavours to better understand taphonomic processes inside a karst cave (Chap. 4). Importantly they focus on the effects of intermittent floodings which are a common phenomenon in caves. McLaren and co-authors also describe experiments by which they not only re-created footprints in clayey ground but also controlled how plant remains and macrofossils became imprinted in the ground by stepping on (Chap. 5). By covering the footprints with sand and excavating them experimentally, inferences about the depositional conditions in the Late Pleistocene were corroborated.

The final chapter of this first part of the book by Lenssen-Erz and Pastoors takes an encompassing epistemological view of the art of tracking as parascientific practice (Chap. 6). Doubts in indigenous experts' inferences would be very obvious and justified should they arrive at results that contradict any reasonable expectations of which people may have entered the caves and how they behaved there. However, the tracking experts simply augment the depth of exploration of the data, i.e. they interpret the track with its visible attributes, refining the results and expectations of scientific researchers. This cannot be characterized as being unscientific simply because no scientific discipline presently has the means to disprove them, but instead it is a lack of series of measurements which the sciences will keep on suffering from before they arrive at an equally dependable resolution.

Part II of the book, dealing primarily with prehistoric track sites from around the globe, opens with an instructive chapter by Trinkaus and co-authors about how to analyse and interpret various elements on skeletal foot remains (Chap. 7). It is through the combined assessment of these accumulated details which makes the authors conclude that many imprints of bare feet, which are the normal case in prehistory, yet retain the markers to identify the consistent use of protective footwear. While this chapter covers a wide range of periods of human evolution, the following chapters are ordered chronologically, beginning with the hominin footprints of Laetoli. Being the prototype of prehistoric human tracks, it is a welcome contribution of Cherin and co-authors that they review the rather long history of research on these tracks, connecting it to the present where digital methods and scanning have become state of the art in research (Chap. 8). What Laetoli is for Africa, Happisburgh is for Europe, but even though they are considerably younger, they were an ephemeral phenomenon. While they could not be preserved in place due to tidal activities, their preservation and afterlife, as it were, are not only secured in archaeology but also in the arts, as Ashton exemplifies with citations from a poem and a popular book on walking (Chap. 9).

The four human footprints of Theopetra Cave in Greece, according to the authors Kyparissi-Apostolika and Manolis, are the oldest European tracks that arguably could be either of Neandertal origin or early *Homo sapiens* (Chap. 10). They seem to originate from two young children of whom one is assumed to have worn footwear, thus supporting the postulate of Trinkaus and co-authors. More and undisputed Neandertal tracks are reported from Le Rozel from French Normandy by Duveau and co-authors (Chap. 11). The sheer mass of more than 250 footprints at this site, sided by a number of handprints, makes this an exceptional site for the understanding of Neandertal behaviour and group life of about 80,000 BP. Only some 13,000 years younger and therefore also of Neandertal origin are footprints that Onac and co-authors present from Vârtop Cave in Romania – together with a plethora of younger footprints of *Homo sapiens* found in Ciur-Izbuc Cave, also in the Carpaths (Chap. 12). A cave with an equally large number of Pleistocene footprints is Tuc d'Audoubert in the French Pyrenees, presented by Pastoors and co-authors (Chap. 13). In this cave the track reading of indigenous trackers was practiced most meticulously (only the cave of Aldène received equally intense investigations, but this is still unpublished) and the results, presented in a systematized scheme, allow to follow, as it were, certain individuals through the cave. They seem to have undertaken a one-time exploration of the cave system during which some of them procured certain materials, e.g. bear teeth. Interestingly also in the Late Pleistocene, a similar one-time visit into a deep cave was paid by a small group of individuals to Bàsura Cave in Italy, as presented by Avanzini and co-authors (Chap. 14). And again, same as in Tuc d'Audoubert, here, too, not only adults but also adolescents and even very small children were part of the exploring group. Another parallel between the two cave visits is that even difficult passages where crawling or dangerous climbing is required did not prevent the groups from bringing the small children, and none of the visitors in either group who left imprints wore shoes nor leg clothes. A well comparable case to the two mentioned ones is reported by Galant et al. from the Mesolithic period from Aldène Cave in Hèrault region of southern France (Chap. 15). Again, visitors of all ages and both sexes left their imprints and all seem to have been in the cave only once – apparently for the purpose of exploration only. Interestingly, conditions in the cave have preserved many traces of the lighting management that the Mesolithic explorers had to implement. Since with regard to lighting they had no technological advantage over the Late Pleistocene, this practice can be taken as a potential model for comparable explorations during earlier periods. These insights will in the near future be associated with the results of the investigations by indigenous experts in this cave.

More evidence on secular behaviour in the Mesolithic comes from the footprints at Formby Point on the English Coast on the Irish Sea on which Alison Burns expounds (Chap. 16). Here human and animal tracks are mixed, and this appears to reveal consciousness of the tracks in the people who thus articulated in behaviour their relationship to animals and to the landscape. As other track sites on coasts, the Formby tracks were bound to disappear once they had been exposed whereas caves can preserve footprints for millennia. This is the case to a large extent in the huge Ojo Guareña Cave system in northern Spain, presented by Ortega and co-authors (Chap. 17). While this cave preserves evidence from the Upper Palaeolithic onwards, tracks are dated to the Chalcolithic period at around 4300 calBP and that is why this chapter concludes the chronologically ordered part of the book. The partially sandy sediment on the floor shows far more than 1000 human footprints in various places, which constitute vast areas that cannot be explored without destroying tracks. In some parts of the cave system, tracks show again a one-time exploration as the purpose of the visit, while other parts convey clear evidence of several visits – apparently relating to the dark zones of the cave as symbolic and social landscape.

Part III of this book intends to encourage an opening of discourse from a closed academic environment to other ways of knowing in that besides the conventional realms of academic exchange we also aim at presenting experiences of researchers from their encounters with indigenous experts, be they hunters or herders. The chapters clearly show that such encounters instil a rather personal and emotional but also humble relationship between experts from different worlds of knowing – perhaps partly because the close insight of western scholars into a special field of knowledge in a culture without books and formal teaching shows that meticulous analysis and understanding of phenomena in our world with the human sense can surpass any technological apparatus. While tracking usually works with the optical sense for the analysis and interpretation of visual signs, Lye in her contribution on Batek from the Malayan rainforest shows that the hearing sense can take precedence over seeing should the environment require this (Chap. 18). But as in visual tracking, hunters tracking sounds with the ear reach a fine resolution that seems virtually impossible to the layperson. In addition, in the rainforest also olfactory traces need to be carefully included. Since the human tracking ability typically has a connotation with spoor recognition by hunter-gatherers, the contribution of Lye is a welcome broadening of scope regarding the senses that can be involved.

Another broadening of scope comes from the second chapter of this part by Gagnol who looks at the tracking abilities of nomadic pastoralists of the Sahara, where he has done tracking research (Chap. 19). This is the first source (based on Gagnol 2013) where the same stunning tracking abilities – that are known from hunter-gatherers – are well and comprehensively documented among peoples with other subsistence strategies. Just as with hunter-gatherers, the camel herders of the Sahara, too, have equally sophisticated tracking skills regarding animal or human tracks. For the latter the particularly skilled experts maintain that even social aspects can be read from tracks. In addition, Gagnol independently found out that expert tracking also requires the mastering of abductive reasoning (cf. Liebenberg 1990), labelled hodological strategy in his chapter, thus providing unprejudiced corroboration of Liebenberg's postulate that tracking at least partly is based on a scientific mindset.

Other quasi-epistemological aspects of tracking are raised in Biesele's chapter that draws on her decades of experiences with and living among hunter-gatherer trackers in the Kalahari (Chap. 20). She can report, inter alia, from her observations on how these experts reach dependable results when reading tracks which – as an exchange of personal insights – is embedded in their sharing ideology. But Biesele also reports on how challenging it was in the beginning to integrate western and San analytical practice in the Tracking in Caves project.

A pioneering project of the integration of scientific and indigenous knowledge is the topic of Webb's chapter who after the discovery of the Pleistocene footprints in the Willandra Lakes in southern Australia was the first to call indigenous experts to help understand an archaeological source (Chap. 21). The success of this collaboration is an inspiration to other projects because it showed that the interpretations of the Aboriginal track experts were completely plausible and generated information "that we could not have obtained in any textbook and even a lifetime in archaeology".

With this Willandra project and the since 2013 ongoing Tracking in Caves project, practical collaboration between scientific and indigenous experts has gone some way together, but they had to design routines and practices without having established models at hand. Therefore the concluding chapter by Zwischenberger reviews the characteristics of western and indigenous expertise and how such different knowledge traditions can collaborate on eye level (Chap. 22). Based on this review and on the analysis of various ethical protocols of indigenous groups, she compiles guidelines for the collaboration of scientific and indigenous experts. Thus a circle closes back to the first chapter in part I where Bennett and Reynolds provide a checklist for the practical encounter with tracks as archaeological source which Zwischenberger's contribution complements with an analogue list comprising points that need to be observed when investigating such sources with indigenous support.

Reading prehistoric human tracks constitutes a perhaps unique kind of discourse not only for archaeology but for our knowing of the world in general. With the most sophisticated means of analysis and computing, we of today try to understand and explain the very same sources, aiming at the very same results as we as a species will have done millennia ago: we find tracks of conspecifics, and we want to know who was here before me, what did she or he do and how did she or he feel. Admitting that whatever apparatus we use, our results remain wanting, we of today fortunately can call the support of indigenous experts who master reading tracks without the help of any technology and yet arrive at much deeper understanding. They allow us to get a glimpse of which information our prehistoric ancestors would have had access to when encountering human tracks. With reading prehistoric human tracks, we can liaise our epistemological procedures not only with experts from other cultures but also with the knowledge even of our Pleistocene ancestors.

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Part I

Methodological Diversity in the Analysis of Human Tracks

Chapter 2
Inferences from Footprints: Archaeological Best Practice

Matthew R. Bennett and Sally C. Reynolds

Abstract Animal footprints are preserved in the archaeological record with greater frequency than perhaps previously assumed. This assertion is supported by a rapid increase in the number of discoveries in recent years. The analysis of such trace fossils is now being undertaken with an increasing sophistication, and a methodological revolution is afoot linked to the routine deployment of 3D digital capture. Much of this development has in recent years been driven by palaeontologists, yet archaeologists are just as likely to encounter footprints in excavations. It is therefore timely to review some of the key methodological developments and to focus attention on the inferences that can and, crucially, cannot be justifiably made from fossil footprints with specific reference to human tracks.

Keywords African palaeoecology · Mammalian ichnology · East African fossil record · Laetoli · Hominin sites · Pliocene · Ichnology

Introduction

Every contact an animal makes with the ground has the potential to leave a trace, as set out in Locard's famous exchange principle. The average moderately active person, for example, takes around 7500 steps a day, and if maintained over a lifetime of 80 years, then they will have left the order of 216,262,500 steps with each step having a theoretical potential for preservation. Contrast this with the 206 bones in the human body, and it is not surprising that we frequently uncover fossil footprints. In fact, it is surprising that we don't find more. Something we would argue is due to the lack awareness and prospection, rather than any particular rarity in the geological or archaeological record. There is a well-documented recent examples where footprints of *Homo heidelbergensis* have been recovered (Altamura et al. 2018) but were not

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recognised by earlier excavators who destroyed tracks in their quest for more conventional archaeological materials. Increasing awareness of archaeologists of the potential to find footprints in excavations of all ages is an important endeavour, as is drawing attention to the convergence of methodological approaches, standards of recovery and best practice. Much of this best practice has been driven in recent years by the palaeontological community, and it is therefore timely, we believe, to review these developments for the benefit of all, especially for archaeologists.

There has been a rapid growth in recent years in the discovery of human fossil footprints around the world which questions the long-held and much-stated assumption that footprint preservation is a freak geological event (Bennett and Morse 2014). To give a flavour of the recent discoveries, in 2016 we saw the publication (Masao et al. 2016) of additional footprints at the famous 3.66-million-year-old footprint site at Laetoli in northern Tanzania first reported in 1979 by Leakey and Hay (1979). Not far from Laetoli, a Late Pleistocene site on the shores of Lake Natron was reported with hundreds of visible tracks (Balashova et al. 2016; Liutkus-Pierce et al. 2016; Zimmer et al. 2018). In 2018 the publication of children's footprints in association with butchered hippo carcasses was reported from Ethiopia (Altamura et al. 2018), and there are reports of human tracks in association with giant ground sloth in North America (Bustos et al. 2018). Footprints preserved in peat have been found on the Pacific Coast of Canada (McLaren et al. 2018), and a new footprint site in South Africa is reported by Helm et al. (2018). Footprints have been found in a diverse range of environments (Fig. 2.1a), and improved awareness by excavators, continued prospection and a revolution in digital techniques for their capture and analysis are perhaps responsible for the increasing discovery of new sites. There is much more to do however.

The aim of this contribution is explore modern tools for the capture and analysis of fossil footprints and to emphasise some of the challenges archaeologists face in making inferences from human footprints in particular. We have structured this review along three stages in what we see as the ichnological pipeline: (1) digital capture and documentation, (2) analysis and (3) inference. To aid cross-disciplinary convergence, the key terminology used in vertebrate ichnology is provided in Table 2.1.

Digital Capture, Documentation and Stratigraphic Context

A quiet revolution during the last decade has transformed human ichnology from an essentially descriptive discipline into one that is now both data- and hypothesis-driven. This transformation started with the introduction of optical laser scanners to capture 3D tracks and has been completed with the routine availability of Structure from Motion-based photogrammetry (Bennett and Budka 2018). While 3D documentation is not necessarily new, having been applied in the late 1970s to the Laetoli tracks (Day and Wickens 1980; Leakey and Harris 1987), it has now become routine for all modern practitioners, although there remain situations where it has not been

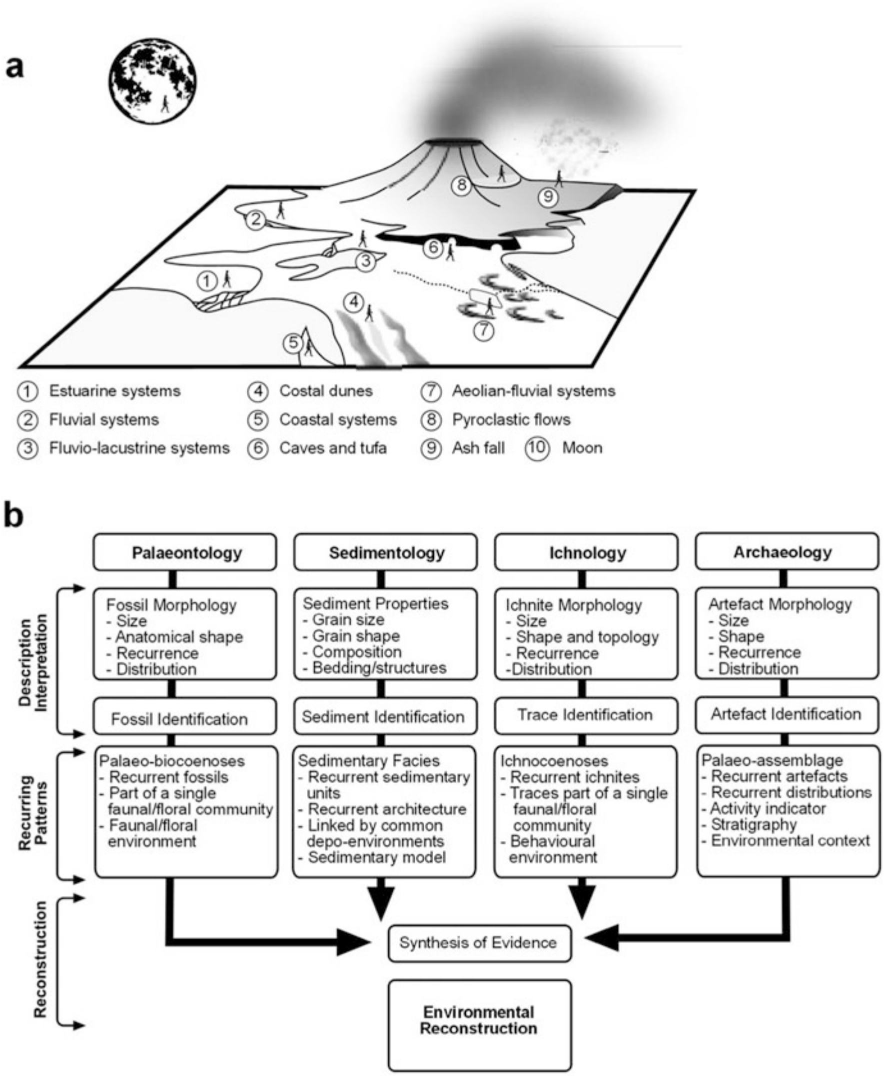


Fig. 2.1 (**a**) Sketch showing the typical types of location in which fossil footprints have so far been found after Bennett and Morse (2014); (**b**) the power of independent lines of investigation leading convergence and/or corroboration

successfully applied or has failed due to environmental conditions (e.g. Ashton et al. 2014). Collecting 3D data allows the user to test assumptions and inferences that previously were made simply by assertion, as exemplified by the work of Roberts et al. (1996). There are those that argue that assertions made by expert trackers (Pastoors et al. 2015, 2016) provide a valid alternative, and while the skill of the

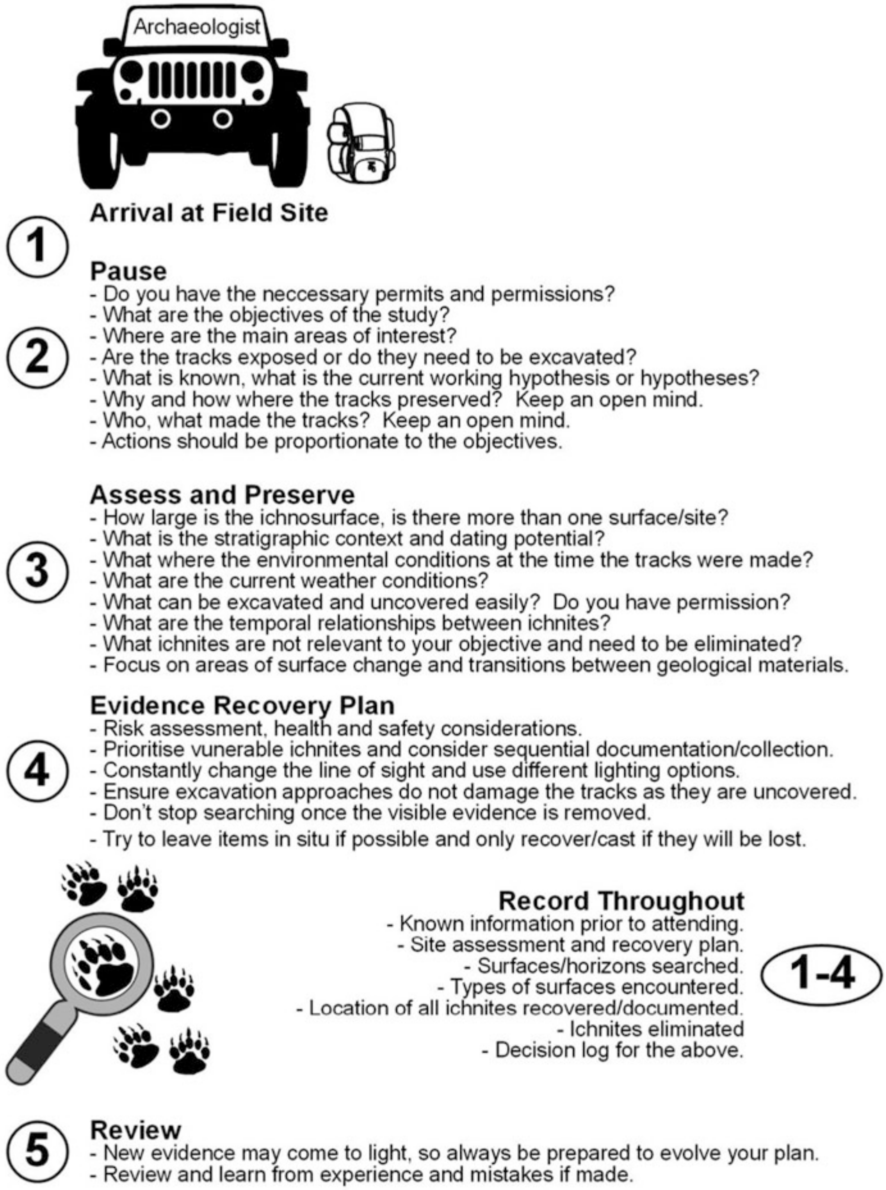
Table 2.1 Commonly used terms with respect to footprint or footwear impression. After Marty et al. (2009)

Term	Definition
Track	A single footprint or partial impression made by the foot of shod or unshod animal or human
Trackway	A series of tracks made by a single individual
Trail	A series of signs or objects left behind by the passage of someone or something. In this context it might be multiple tracks left by one or more individuals, forming a path, for example
Trackmaker	The animal that made the track
Tracked surface	The surface on which the trackmaker walked/moved
Over-printing	Caused by an individual or animal over-printing an original track
Displacement rim	A marginal rim to a track formed by the upward displacement of sediment, sometimes referred to as a push-up structure or a bourrelet
Track ejecta	Material ejected by the removal of the trackmaker's foot from a track. This often forms a debris trail in front of a track
Plantar surface	The base of the trackmaker's foot or shoe
Ichnosurface	A surface with multiple tracks which may have either formed in an isochronous (synchronous) or diachronous (time-averaged) fashion

trackers is not in dispute, the inability of a reader to question and/or test those assertions themselves limits the scientific credibility of such approaches.

The authors have developed, along with colleagues, freeware (www.digtrace.co.uk) that enables the capture of tracks in 3D using the open source software OpenMVG (Bennett and Budka 2018). Not only can you create 3D models, but the freeware provides a series of analytical workbenches with tools specific to the analysis of footprints. Commercial alternatives exist in the form of such things as PhotoScan by Agisoft (http://www.agisoft.com), and while they create excellent 3D models, they do not provide analytical tools specific to footprint analyses, and the user has to rely on expensive 3D modelling software or freeware tools such as MeshLab (www.meshlab.net) or CloudCompare (www.danielgm.net/cc). Structure from Motion relies on multiple oblique digital photographs from which individual pixel clusters are placed in 3D space. Almost any digital camera can be used provided its sensor size is known or can be calculated (Bennett and Budka 2018).

The archaeologist who arrives at a field site or encounters a series of footprints for the first time needs a plan. Figure 2.2 lists some of the key elements of any plan and reviews the things that need to be considered. Assuming that one has the necessary permits and permissions, the first step is to consider whether the tracks can be preserved or whether it is a case of conservation by rescue. Preserving soft-sediment footprints is challenging, if not impossible (Bennett et al. 2013), and 3D digital capture is often the only way to create a permanent record of the tracks (Bennett and Morse 2014). This is especially true of those tracks preserved in coastal exposures (Bennett et al. 2010; Falkingham et al. 2018; Wiseman and De Groote 2018) or where the act of excavation disturbs a fragile surface, thereby allowing erosion.



Arrival at Field Site

Pause
- Do you have the neccessary permits and permissions?
- What are the objectives of the study?
- Where are the main areas of interest?
- Are the tracks exposed or do they need to be excavated?
- What is known, what is the current working hypothesis or hypotheses?
- Why and how where the tracks preserved? Keep an open mind.
- Who, what made the tracks? Keep an open mind.
- Actions should be proportionate to the objectives.

Assess and Preserve
- How large is the ichnosurface, is there more than one surface/site?
- What is the stratigraphic context and dating potential?
- What where the environmental conditions at the time the tracks were made?
- What are the current weather conditions?
- What can be excavated and uncovered easily? Do you have permission?
- What are the temporal relationships between ichnites?
- What ichnites are not relevant to your objective and need to be eliminated?
- Focus on areas of surface change and transitions between geological materials.

Evidence Recovery Plan
- Risk assessment, health and safety considerations.
- Prioritise vunerable ichnites and consider sequential documentation/collection.
- Constantly change the line of sight and use different lighting options.
- Ensure excavation approaches do not damage the tracks as they are uncovered.
- Don't stop searching once the visible evidence is removed.
- Try to leave items in situ if possible and only recover/cast if they will be lost.

Record Throughout
- Known information prior to attending.
- Site assessment and recovery plan.
- Surfaces/horizons searched.
- Types of surfaces encountered.
- Location of all ichnites recovered/documented.
- Ichnites eliminated
- Decision log for the above.

Review
- New evidence may come to light, so always be prepared to evolve your plan.
- Review and learn from experience and mistakes if made.

Fig. 2.2 The basic structure of an ichnological field survey plan, modified from Bennett and Budka (2018)

Interestingly, recent work using geophysics (magnetometry and ground-penetrating radar) shows promise with respect to how tracks may be prospected for without surface disturbance or excavation (Urban et al. 2018).

The basic information that is required is (1) spatial information showing the relative position of one track to another (i.e. some form of map); (2) detailed 3D models of all or a selection of individual tracks; (3) detailed vertical photographs, written observations and measurements; (4) facies descriptions of the containing sediments both vertically and spatially; and (5) detailed sampling for datable materials both below and above the tracked layer. Spatial mapping can be achieved in a variety of different ways, although traditional field survey techniques, coupled with low-level aerial photographs, are now the norm. Traditionally plastic sheets have been placed over tracked surfaces, and footprint outlines have been traced onto them. These have to then be reduced to make them manageable, the advantage of vertical images is that, if the surface is not horizontal, contours can be added using photogrammetry or portable LiDAR devices. Working at White Sands National Park (WHSA), Bustos et al. (2018) used Agisoft's PhotoScan to produce photomosaics of large areas, supplemented with detailed 3D models of individual tracks made with DigTrace.

Tracks need to be documented individually, or in combination. Deciding what the sampling strategy should be is critical here. For example, how many tracks should be excavated out of the total population? What proportion should be conserved, if any, for future investigators? This clearly depends on the total available track count, but at sites like those described by Morse et al. (2013) and Bustos et al. (2018) where there is a surplus of tracks and excavation limits long-term preservation, then these are real questions for which there are few definitive answers. As working principle excavating/disturbing the minimum number of tracks is usually the general practice, unless the site is at risk. Sampling strategies are not necessarily relevant where there are a small number of endangered tracks. Anything and everything that is excavated needs to be captured in 3D. Where a whole surface has been scanned, or a 3D mosaic created, there is a temptation to simply crop this down to create individual track models. Large-scale models do not always have the resolution, however, for detailed topological study and rarely deal with undercut edges well. It is therefore advisable to also make close-up models where lines of sight can be improved. It is also worth noting that photogrammetry, or laser scanning for that matter, is not always a perfect solution especially where the tracks are deeply incised in soft ground. The use of an endoscope can help with this, but it may be necessary to adopt alternative strategies. For example, Altamura et al. (2017) excavated deep hippo tracks and then infilled these with plaster before excavating the surrounding surface to reveal the cast. The casts can be laser scanned subsequently, if required. Once the individual tracks have been documented, it is then necessary to describe and sample the tracked units and surrounding lithofacies, using standard procedures.

Analytical Tools in Ichnology

Traditionally good science requires a separation between description and interpretation. The description will always stand if done well, but the interpretation may change with time and new ideas or discoveries. In the context of a track, this is the separation between describing a track's topological properties and making inferences about the trackmaker from them. There are lots of examples where a trackmaker is inferred without such description (e.g. Musiba et al. 2008). In describing and/or measuring a track of whatever origin, we have three main independent properties to consider. Firstly, we have size defined by a single, or more usually, a combination of linear measurements. Typically these include measures of length, area and volume. Secondly, we have shape or form which describes how the track is defined by intersecting lines, edges or textural boundaries. For example, do the edges define a triangle or square? Finally we have topology which is the geometrical properties, and their spatial relationships to one another, such as the spatial disposition of different component shapes and depth variations. The morphology (or anatomy) of a track is the sum of the above properties, and all three dimensions need to be considered when describing a track (Fig. 2.3a).

Separating aspects of shape and size is an important part of any anatomical description and is usually achieved by the superposition and transformation of geometric forms such that size is removed. This is a standard part of most geometric morphometric analysis and is commonly attained via some form of Generalised Procrustes Analysis (GPA; Zelditch et al. 2012; Gómez-Robles et al. 2008; Friess 2010). Berge et al. (2006) pioneered the application of GPA to human tracks, an approach adopted and refined by Bennett et al. (2009) in their analysis of the Ileret footprints and used by others since (e.g. Wiseman and De Groote 2018). All the above require the placement of some form of homology-based landmark, that is, a landmark that relates to a biologically or anatomically homologous structure and crucially one that can be recognised consistently by observers. Even a single linear measurement of length requires landmarks to be placed at the start and finish of the measurement line. Defining landmarks consistently across different studies and operators is a source of error especially where linear properties such as length are not clearly defined (Bennett and Morse 2014).

Concern over landmark placement lead Crompton and his team at the University of Liverpool to develop a whole-foot comparison method in which tracks are co-registered allowing measures of central tendency to be determined for entire track populations. Taking their lead from the mathematics behind the analysis of magnetic resonance imaging (MRI), they developed pedobarographic statistical parametric mapping (pSPM). It was designed to co-register multiple pressure records obtained from individuals walking on a treadmill, once co-registered pixels in similar anatomical positions are compared (Crompton et al. 2012). By substituting depth for pressure, one can apply it to tracks, although it requires the removal of all marginal structures for automated registration since it can only match recurrent plantar surfaces. Manual registration gets around this problem, but in doing so the

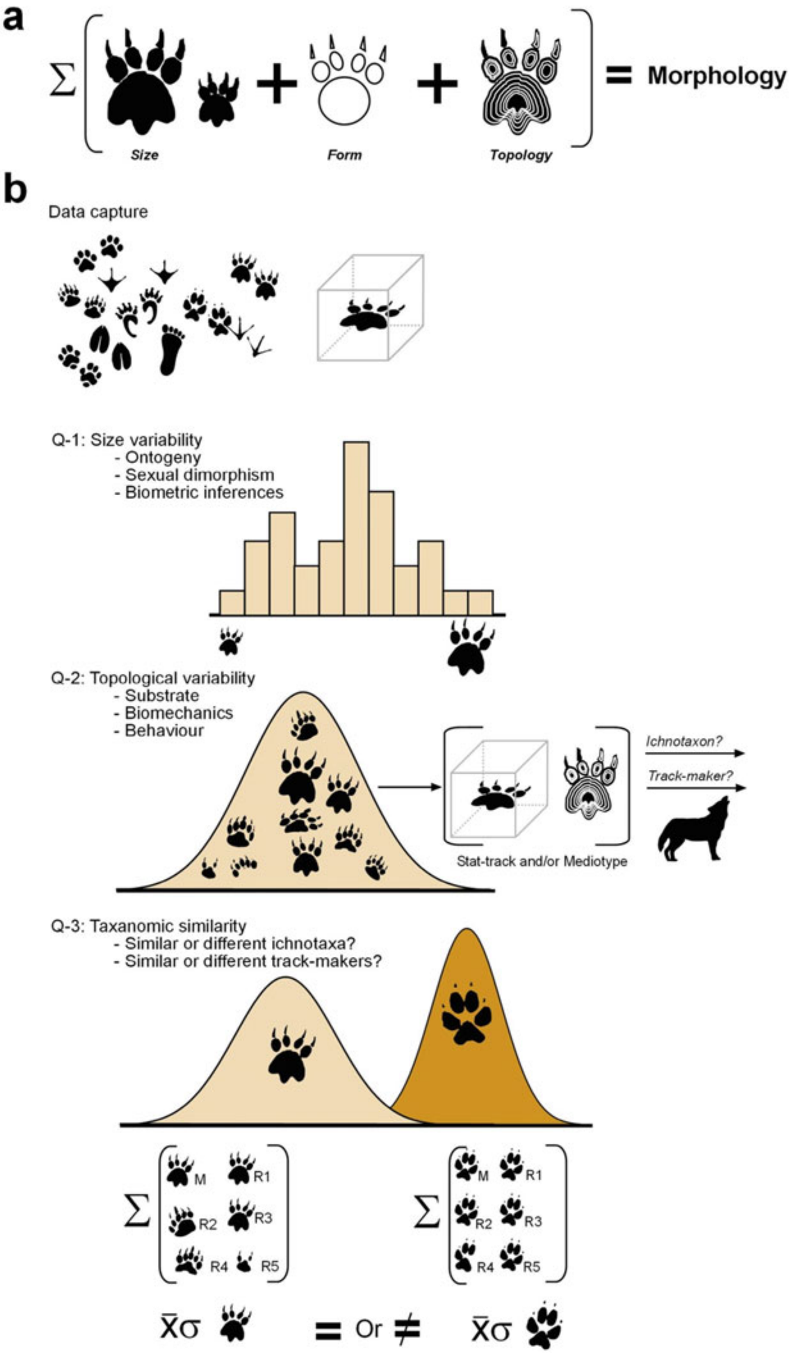


Fig. 2.3 (**a**) Components of track morphology; (**b**) analytical questions that can be addressed by quantitative analysis when 3D digital data is collected

objectivity obtained by auto-registration is lost. It is important to note that marginal deformation structures are as equally valid as the plantar surfaces in interpreting tracks.

Bennett et al. (2016a) use an alternative approach in which tracks are co-registered by matching common structures, via placed landmarks. These matched points are then used to guide the registration, and this approach has the advantage of being driven by a simple user interface. Whichever approach is used to register a population of tracks, once co-registered, one can create measure of central tendency, pixel by pixel, in the form of a mean/median track and measured of statistical variability around this (Crompton et al. 2012). This allows both dimensions of track variability to be explored, namely, (1) intra-trackway variance, that is, the variation between different tracks made by the same trackmaker in a trackway due to variation in substrate and inter-step biomechanics, and (2) inter-trackway variance, that is, the difference between two different trackways that may, or may not, have been made by the same individual. Both are critical to determining whether a set of tracks were made by the same trackmaker or not. If the intra-trackway variance is greater than the inter-trackway variance, then you have a problem in making a definitive qualitative or quantitative distinction between them. Belvedere et al. (2018) introduce two new terms, the stat-track and the mediotype (Fig. 2.3b). The former refers to any statistically produced measure of central tendency for a population of tracks, while the latter refers specifically to a mean or median track created from those holotype specimens. They also provide a range of examples of how whole-track methods can be used to help formalise the description of formal ichnotaxa (Marty et al. 2009, 2016).

Types of Inference from Human Footprints

The discovery and/or excavation of a fossil trackway can be an exciting process, revealing as it does a captured moment in time when the foot of a human made contact with the ground. Tracks lead to a range of analytical questions (Fig. 2.3b), and there are four broad areas of inference that can be drawn from such discoveries: (1) the trackmaker, their pedal anatomy and inferences about size and body mass; (2) locomotion style and speed from the depth distribution which is assumed to be a proxy for pressure; and (3) the palaeobiology of the track assemblage. Different preservation conditions favour different types of inferences as illustrated in Fig. 2.5 and discussed below.

Anatomical Inferences

An individual track, or more reliably a population of morphologically similar tracks (Fig. 2.3b), preserves anatomical information about the trackmaker, such as the shape of the foot and/or the number of digits. This information is inclusive of the soft tissue that surrounds the bones, material that is rarely preserved and yet essential to anatomical description and locomotory behaviour. A given animal may produce a range of different track topologies depending on functional interaction with the sediment and the sediment itself (Bennett et al. 2014). The next logical step is to name the trackmaker, although this is not always as simple as it sounds. Within the Plio-Pleistocene at least the starting point for such interpretation is the palaeontological record or a modern animal track guide. Over-reliance on the palaeontological record provides an ever-present risk of missing a species known only by its tracks at a given site. In a similar way, reliance on modern tracking guides or local/native trackers when dealing with Pleistocene track sites (Pastoors et al. 2015, 2016) assumes a similarity that is not always warranted between past and present communities. The tendency to fit tracks to a known template is also an ever-present risk. Good science comes from good building blocks forming safe foundations, and in the case of ichnology, this consists of good topological, quantitative, 3D descriptions of individual tracks and their topological variability as a population of tracks. This should occur independently of any assessment of the sedimentary facies and associated palaeontology (Fig. 2.1b).

Assuming the trackmaker can be deduced, the next stage is to consider what biometric inferences are possible for that given animal. Empirical relationships between foot size and height are well known for humans and some animals (Fig. 2.4). For example, Roberts et al. (2008) describe an elephant trackway dated to around 90 ka from Still Bay in South Africa in aeolinites. The tracks are attributed to the African elephant (*Loxodonta africana*), and, interestingly, Roberts et al. (2008) use the track dimensions to infer both shoulder heights and ages for the trackmakers using the empirical relationships of Western et al. (1983). There is good data about the ontology of African elephants (Western et al. 1983; Lee and Moss 1995; Shrader et al. 2006) allowing biometric data to be inferred. It is an approach that has been applied elsewhere to mammoth tracks in Canada (McNeil et al. 2005) and Miocene Proboscidea tracks in the United Arab Emirates (Bibi et al. 2012). The idea is based on fitting a growth curve such as a von Bertalanffy growth function, to available empirical data, despite the fact that the trackmaker's sex cannot normally be determined from a track alone and that the presence of sexual dimorphism complicates such inferences. To what extent this approach could be applied to other animals is uncertain but has the potential to be an interesting line for future research. It has been applied to dinosaur tracks where there are clear morphological variations with size (e.g. Avanzini and Lockley 2002), and some data on the ontology of ungulate tracks does exist (e.g. Miller et al. 1986; Musiba et al. 1997; Cumming and Cumming 2003; Stachurska et al. 2011; Parés-Casanova and Oosterlinck 2012a, b).

In terms of humans, there is a wealth of empirical relationships for different ethnic/racial groups which relate foot size to stature (and refs therein: Bennett and Morse 2014). The founding data is based on different measurement protocols and either 2D foot imprints or direct foot measurements. As a consequence the value of this huge body of data to fossil footprint studies is more limited than sometimes

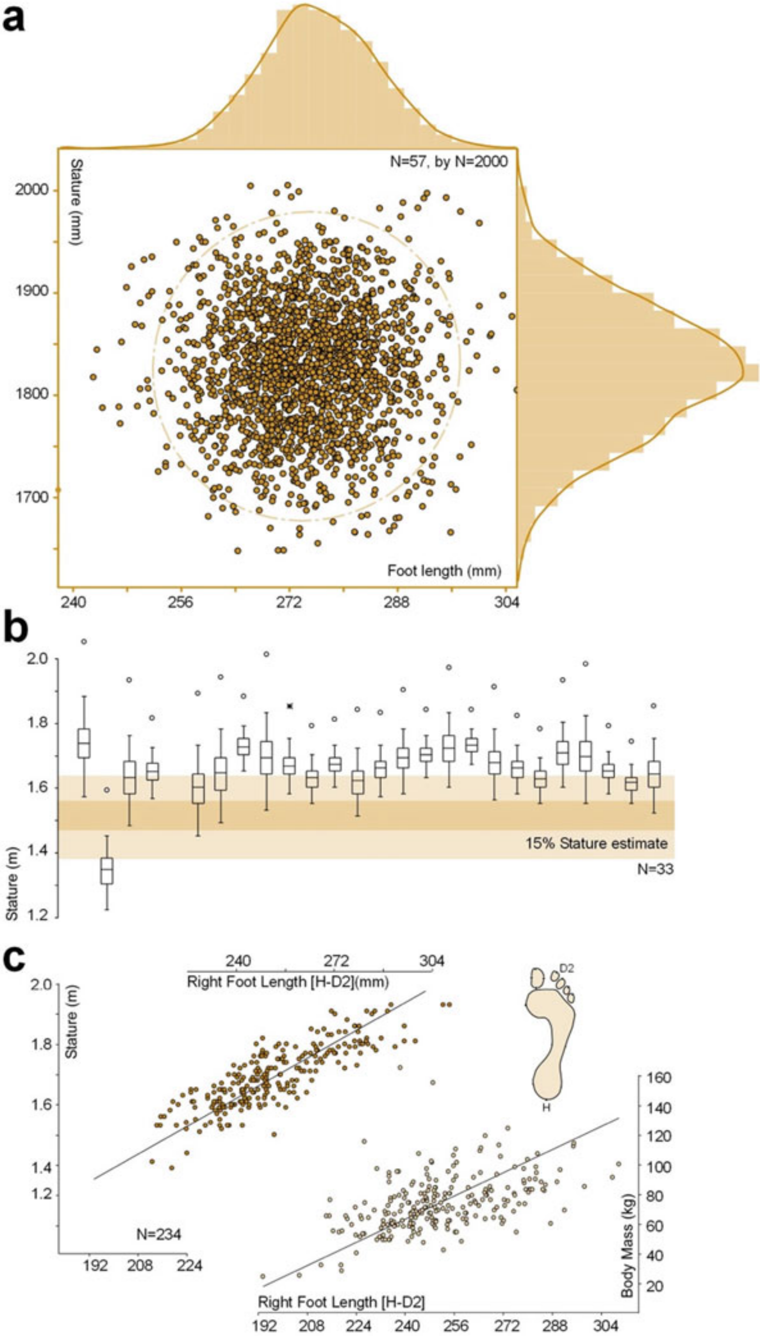


Fig. 2.4 Stature and body mass inferences from footprints; (**a**) data from a beach showing variation in foot length due to intra-step variability. A total of 57 tracks where used and then boot-strapped to give the 2000 data points shown. The 95% confidence ellipse is shown by the dashed line; (**b**) stature estimates using a range of different published stature equations for a single Holocene trackway in Namibia N = 77. A fuller description of this analysis is provided in Bennett and Morse (2014); (**c**) foot length, stature and body mass estimates for a sample (N = 234) of 3D footprints for a Bournemouth University staff/students

assumed. The first issue is that foot length varies considerably along a trackway due to substrate, biomechanical inter-step variability and chance. Consider the data in Fig. 2.4a which shows the length variation of a single individual walking on a beach and the potential height variations obtained using a simple 15% foot length to stature ratio. Similarly for a fossil trackway, you don't normally know the ethnicity/race, sex or age of the trackmaker, and you are left to make a series of assumptions in selecting an empirical relationship to model stature from foot length, and this is even more problematic when dealing with extinct human ancestors. Figure 2.4b shows a series of height estimations made from the same trackway of 77 tracks in Namibia (Morse et al. 2013) using different empirical equations. They give a range of estimates which are generally higher than the more conservative 15% rule of Topinard (1877). While they give a greater sense of scientific rigour, this is perhaps an illusionary, and the results depend on the empirical relationship chosen (Fig. 2.4). Empirical relationships to body mass are available (Fig. 2.4), but they are much weaker than those for stature, and, while some more sophisticated modelling has been attempted (e.g. Dingwall et al. 2013; Masao et al. 2016), again the reliability of such estimates has to be questioned (Bennett and Morse 2014). Finally, while modest levels of sexual dimorphism are evident in human track length, it is possible to separate genders on the basis of track measurements within controlled populations (Bennett and Morse 2014). However, there are simply too many unknowns to do so in the fossil record. Where small adult tracks exist, it is perhaps possible to tentatively suggest that they may be those of women, but the possibility that they are adolescent males can never be ruled out definitively. Despite this, implicit and explicit gender assignment of footprints is common within the literature. The other issue to be considered is how representative are size estimates of a population as a whole. Sampling by substrate and sampling by activity are all issues that are relevant here (Kinahan 2013). The harsh reality is that unless a large number of tracks are present, clearly made by different individuals, it is hard to make reliable inferences. True demographic reconstructions from the basis of human footprints have yet to attempted, not least because the number of sites where it can be applied is limited. In terms of track abundance, there is also a fine line between too many tracks leading to multiple partial impressions due to over-printing and too few to do anything other than to give data on an individual (Fig. 2.5).

Biomechanical Inferences

As the foot makes contact with the ground, if the shear strength of the substrate is exceeded, it will deform leaving a record of that interaction (Hatala et al. 2018). Implicit in all biomechanical inferences from tracks is the idea that distributions in depth across the surface of a track provide a measure of the plantar force applied by the foot in different locations and phase of stance. The experimental work of Bates et al. (2013) shows that there is greatest correlation between plantar pressures and depth for shallow tracks and that this relationship holds less for deeper examples.

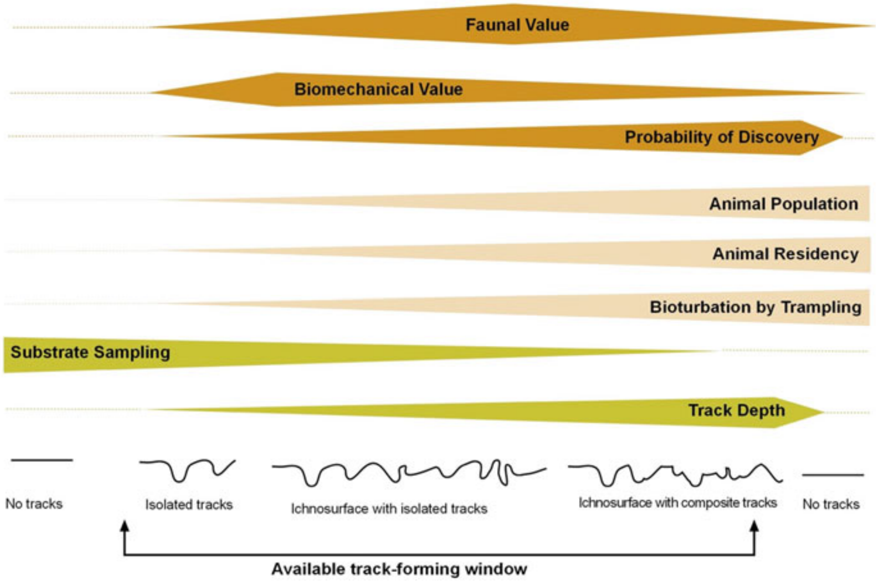


Fig. 2.5 Factors that control the nature of an ichnosurface and its scientific value

Given that the preservation potential is greater for deeper tracks, this may limit biomechanical inferences from some types of fossil track site (Fig. 2.5). Speed estimates are possible using step and stride length records and the empirical relationships developed by Alexander (1984). Biomechanical inferences on hominin tracks have been extensive and fiercely debated (e.g. Meldrum et al. 2011; Bennett et al. 2016a, b; Hatala et al. 2016b) and, as such, are not considered further here.

Palaeobiological Inferences

Lockley (1986) argues that tracks provide palaeobiological data, ranging from the taxonomic identification of the trackmaker, placing them at given location and time, to providing information on faunal biodiversity where evidence of multiple trackmakers is present. This can be used to contribute data on the palaeogeographic range of a species, its demography and/or population dynamics. Interestingly, in contemporary environments track density maps are used to assess population numbers of specific species, most notably carnivores, and perform better than some other census methods (e.g. Prins and Reitsma 1989; Silveira et al. 2003; Gompper et al. 2006; Funston et al. 2010; Moreira et al. 2018). The problem with fossil tracks is one cannot constrain the time interval over which tracks are preserved, and faunal sampling usually influences the results. This subject is explored further below.

Inferences from track assemblage with respect to the behavioural ecology of trackmakers, such as the composition of herds, tendency toward gregarious habits and even prey-predator relationships, are, in theory, possible. Martin and Pyenson (2005) argue that trackways contain evidence of an array of behaviours, such as shifts in speed and direction, lateral movements, obstacle avoidance as well as gregarious movements. Ostrom (1972) and several others have used directional data of dinosaur trackways, for example, to argue for gregarious behaviour, while Bibi et al. (2012) argued for evidence of social structure in Miocene Proboscidea in the United Arab Emirates on the basis of trackway patterns. Working at Ileret (Kenya) track site, Roach et al. (2016, 2018) argued that hominin tracks show similar states of deterioration and typically do not cross-cut one another and as such can be considered at best to be contemporaneous and at worst penecontemporaneous. They suggest that the parallel hominin trackways (1.5 Ma), with individual tracks of similar size, indicate that the trackmakers moved as part of male hunting groups (see also Hatala et al. 2016a, 2017). Altamura et al. (2018) point to the co-association of child tracks with stone tools and the remains of a butchered hippo carcase from which they infer a more pastoral scene in which young children are present (0.7 Ma) and presumably learning. Perhaps one of the best examples, however, of behavioural inference is provided by Bustos et al. (2018). In this work they show that the tortuosity of trackways made by extinct giant ground sloth from the terminal Pleistocene increases in the presence of human trackmakers. In fact the trackways show evidence of evasion with sudden changes in direction and speed. Bustos et al. (2018) suggest that human hunters were stalking and harassing sloth, presumably as part of a hunting strategy. The higher the density of tracks and the more extensive they are in space, the greater the potential to infer palaeobiological information (Fig. 2.5).

Critical to all these inferences are two fundamental questions which are referenced in passing in most track-based publications but rarely developed in detail. They are issues of faunal sampling and of demonstrating co-association within a track assemblage. Both issues are underpinned by the geological context of the site and are explored further here due to the fundamental importance of these issues.

Faunal Sampling

Essentially this distils down to the question that troubles all palaeontological studies eventually, which is to what extent does a proxy count, for example, of the number of bones or tracks mirror the original faunal population from which they are derived, in terms of composition and abundance, and to what degree do taphonomic processes distort this reflection? In the context of tracks, these issues were explored in the seminal papers by Cohen et al. (1991, 1993) which provide one of the few

Table 2.2 Factors influencing track survivorship after Cohen et al. (1993)

Substrate susceptibility (strain)	Track loading (stress)	Secondary reworking rates
Sediment properties (texture, sorting, bulk density, organic content)	Pedal anatomy and animal body mass (mass/shape/force)	Vertebrate trampling/foraging (+)
Water content (+/−)	Biomechanics (including manus vs pes variations)	Invertebrate bioturbation (+)
Degree of cementation inclusive of salts and algal mats (−)	Kinematics (e.g. direction, acceleration and deceleration)	Surface disturbance such as waves, run-off, deflation, desiccation (+)
		Algal stabilisation/cementation (−)
		Salt blooms (−/+)
		Surface desiccation (−/+)
		Burial (−)

The positive and negative signs refer to the direction of a potential influence. These three grouped variables are plotted on ternary diagrams in Fig. 2.6

modern analogue studies (neoichnology) relevant to the interpretation of Plio-Pleistocene track sites.

Cohen et al. (1993) recognise three basic variables at play in track preservation (summarised in Table 2.2), namely, (1) animal load (force/area) (2) sediment susceptibility (strain/stress) and (3) secondary reworking. These three summary variables are not completely independent of one another. For example, a surface with a high susceptibility to deformation will also be one that is easily reworked. However, it does provide a means of exploring the interplay of these variables in track formation and the immediate taphonomy of those tracks. Here we conceptualised these variables on a ternary diagram to define a track-forming window for a given animal (load), at a specific time and place (Fig. 2.6). It defines the Goldilocks track-forming zone, as modelled numerically by Falkingham et al. (2011). These variables and the track-forming windows they define vary spatially across a site such as a lake margin, or river, and temporally, as pore water and surface water conditions change over time. The track-forming window, present at one location and moment in time, samples the fauna that passes; too little fauna and it won’t be sampled, too much and it will not be preserved at all due to self-inflicted bioturbation (Fig. 2.5). Take the example shown in Fig. 2.7, which shows a hypothetical model based on a lake or river margin. Rainfall events are linked to rises in water level, and track preservation occurs primarily during falls in water levels when the maximum printable surface is revealed. Animals are not continuously present but visit periodically, as indicated by the green bars. For tracks to be preserved, there need animals to be coincident with a track-forming window. The site is effectively trackmaker limited, and the tracks preserved do not reflect the whole faunal community, simply part of it (Fig. 2.7).

The corollary to the track-forming window is the surface relaxation time. That is, the time it takes for the surface structure (i.e. track topology) to decay through surface reworking, whether due to bioturbation or by surface processes, along with

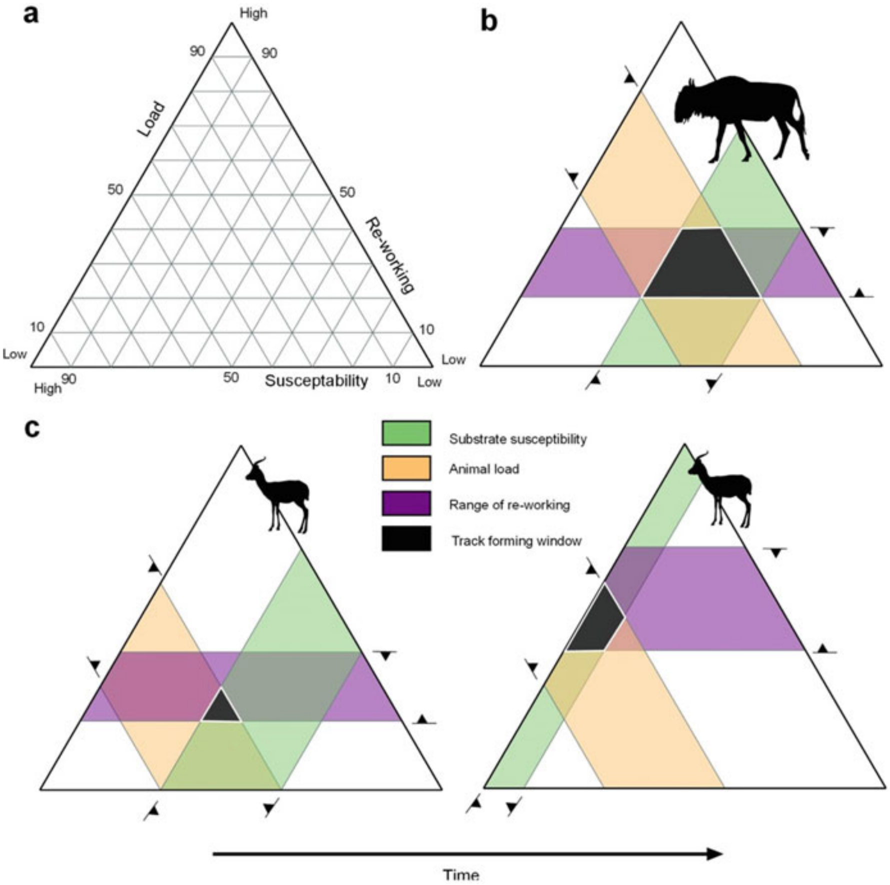
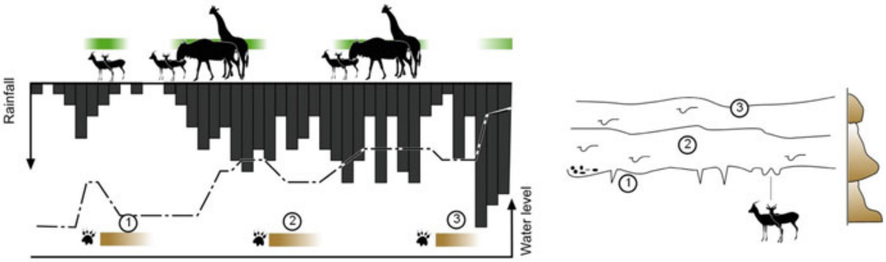


Fig. 2.6 Track-forming window as defined by the interplay of animal load, substrate reworking and substrate susceptibility. Different animals have different track-forming windows. For example, compare (**b**) to (**c**) while track-forming windows may vary through time, as shown in (**c**)

sediment plasticity during enhanced moisture or brecciation caused by desiccation. Brecciation of desiccated tracks was documented in modern analogue studies from Amboseli (Kenya) by Bennett and Morse (2014) and is discussed by Cohen et al. (1993). There are factors which can delay relaxation, such as the growth of algal mats, associated sediment trapping (Marty et al. 2009) and cementation by salts. The distribution of track-forming windows will vary spatially around a given environment. On the margins of the saline Lake Manyara (alkaline flats) in Tanzania, Cohen et al. (1991, 1993) recognised three ichnological zones:

- Zone One: This was an onshore zone where the sediment is dry at the surface and subject to salt blooms and associated deflation. Insect bioturbation is limited, and biotic reworking is achieved by animal trampling. While groundwater fluctuations do occur, the surface is sufficiently firm to only take the tracks of the



Trackmaker Limited

Fig. 2.7 Hypothetical model of a lake or river margin. For tracks to be preserved as shown on the right, animals need to be coincident with a track-forming window. The isolated tracks shown are associated with occasional preservation during water level rises, while the broader ichnosurfaces are revealed during water-level regression

heaviest animals when groundwater rises. Desiccation often renders tracks indistinct, and they are infilled by breccia and wind-blown mud. Long-term survivorship of tracks can be high.

- Zone Two: This is the shore zone where sediments are usually wet and salt crusts are minimal. Insect bioturbation is pronounced, as is animal reworking, groundwater fluctuations and shore face reworking. The soft sediment in this zone is ideal for the preservation of small mammals and birds in conjunction with larger ones, but survivorship, and therefore preservation potential, is far less.
- Zone Three: This is the subaqueous zone where the sediment is saturated and often, as a consequence, unstable. Larger animals may leave abundant tracks in this zone, but they quickly become indistinct and have low survivorship potential.

The way in which animals traverse these zones, and thereby leave their tracks, depends in part on water quality. In the case of Lake Manyara, most of the trackways follow the shoreline due to its salinity. No animals drink here. At less saline lakes, animal trackways may be more perpendicular to the shore, and carnivores (including humans) may adopt a more shore-parallel strategy in order to intersect prey (Roach et al. 2016). The point here is that each zone has different track-capturing properties and will sample the fauna differently, and different zones also have different preservation potentials. Clearly the deeper tracks in Zone One may have greater preservation potential than those in Zone Three. Small mammals and birds, for example, may be under-represented in some faunal samples.

Animal behaviour in each of these zones may also be relevant; one animal repeatedly walking in a small area can generate a lot of tracks! Cohen et al. (1993) make a distinction between faunal estimates based on milling and directional behaviour, tracks left by the former greatly inflate animal abundances, and they suggest that randomly orientated tracks should be avoided in making abundance estimates. Similarly, game trails may be recognisable at some sites, but because of their composite nature, they speak only to the presence of multiple animals, not to the exact number, even if individual ichnotaxa can be discerned (e.g. Ashley and

Liutkus 2003). In terms of broad time-averaged faunal assessment, the risk of sampling across diachronous surfaces is unlikely to be a significant issue, unless we are dealing with large time intervals; after all, skeletal and tool assemblages are time-averaged phenomena. However, demonstrating co-association is an issue for inferences around behavioural ecology.

Problems of Co-association

That a track assemblage was imprinted in close temporal association is an assumption that is implicit at most footprints sites but one which should, in truth, be demonstrated every time. We can explore some of the issues by theoretically modelling lake-level fluctuations around a lake such as Lake Manyara. Figure 2.8 shows a water-level curve, deduced from a stacked sequence of lithofacies, with tracked surfaces marking lake-level regressions. Lake regressions create the maximum spatial track-forming window; transgressions will tend to erode tracks, as shore process advances over an area and may compress the space for track-forming zones. This may correspond, however, to different rates of regression, when the data is re-plotted with time as the vertical (Fig. 2.8). Only one of the ichnosurfaces shown is isochronous, being associated with a rapid fall in lake levels, while the others record diachronous assemblages. On the margins of this hypothetical water body, the rates of sedimentation and therefore track burial will likely vary seasonally, and multiple track-forming windows may become superimposed (Fig. 2.9). We can develop the model first presented in Fig. 2.7 to explore this further, although in this case animal abundance is continuous (i.e. track formation is window limited). In the first

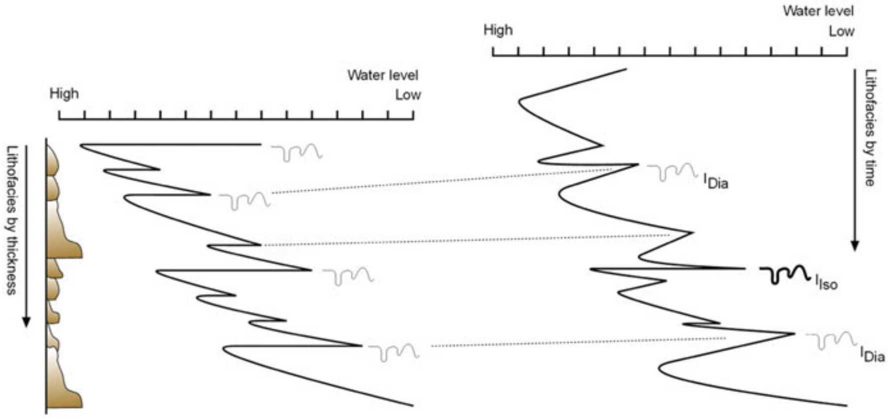


Fig. 2.8 Hypothetical model of lake-level fluctuations around a lake or river margin with available trackmakers. The lithofacies associated with such a scenario is indicated on the left. These are likely to be fining-upward sequences, associated with the transgressions, with tracks on the unconformities associated with regression. When time is substituted for depth on the right, the importance of a rapid fall in water level in creating an isochronous faunal track sample is indicated

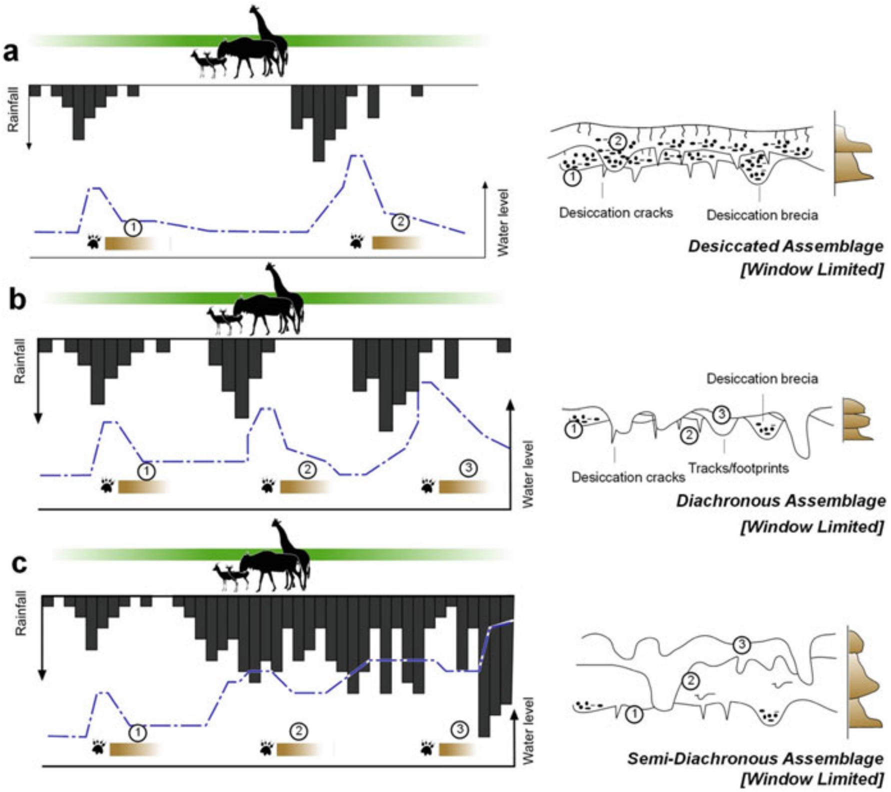


Fig. 2.9 Three hypothetical scenarios around the margin of a lake or river, with a link between rainfall and water level. Animals are present throughout the time shown, and we assume that the optimum track-forming window occurs during a lake-level fall and that with exposure, the tracks degrade through desiccation and brecciation; (**a**) in this scenario only the deepest tracks (Zone One) will be preserved; (**b**) in this scenario the three track-forming windows are essentially superimposed on one another to form a diachronous assemblage; (**c**) finally, in this scenario, the rising lake level is assumed to be associated with sedimentation, and the tracks become more separated. With greater rates of sedimentation, separation between the track-forming surfaces will increase. The presence of isolated tracks represents the possibility of deeper tracks being preserved during a transgressive episode. Note the use of window limited and trackmaker limited in Fig. 2.7

scenario, periodic water-level highs are separated by desiccation events, leading to a tracked assemblage dominated by desiccation, in which only the deepest tracks, associated with the heaviest animals, are preserved, and then only poorly (Fig. 2.9a). In scenario two, we have shorter periods of desiccation between track-forming windows, but little sedimentation and the resulting tracks are superimposed one into the other, such that the surface is really a composite of several track-forming windows. This is typical, for example, of some of the assemblages at Ileret. Only in the third scenario, where rising water levels and associated sedimentation are assumed, do we get tracked surfaces that separate out one from another and verge toward being isochronous (Fig. 2.9c). Only on these types of surfaces is there potential to deduce behavioural interactions.

Co-association is usually argued for on the basis of cross-cutting relationships between different trackways and on similar levels of track freshness. That is, tracks which show a similar degree of degradation are assumed to be penecontemporaneous, especially if they are associated similar deformation structures (i.e. rim and sub-track structures) indicating similar pore water conditions. The ever-present risk is that a track-forming surface may have been reactivated several times. These models demonstrate that, in truth, there is no simple answer to the issue of co-association, other than care is needed when making such assumptions. These assumptions need to be justified and explained more clearly than is often the case in the literature. Ultimately the only way of demonstrating true co-association is to look for evidence of behavioural interaction between one or more trackmakers (e.g. Bustos et al. 2018). If two animals where present on the landscape at the same point and moment in time, there should be some interaction, either active (i.e. prey-predator) or passive (i.e. scenting or avoiding via trackway adjustment).

Conclusions

The study of human ichnology, along with other associated animals, is rapidly advancing with the discovery of new sites. The advent of 3D digital capture allows increasing research sophistication with quantitative hypothesis-led testing. There is much to do to replace the assertion-based approaches of the past with data-driven observations and inferences. In this review, we have explored some of the issues associated with the ichnological pipeline from data collection to the inferences that can be made, advocating throughout for the power of 3D digital data capture and analyses. In the later part of the review, we have emphasised the importance of geological context to the interpretation of track-based assemblages, and to assumptions of co-association, and around issues of faunal sampling. There is greater rigour needed here in ichnological research, and we would argue that the geological context of an assemblage is critical to its interpretation, regardless of the level of sophistication of the tools used to document it.

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Chapter 3
Repetition Without Repetition: A Comparison of the Laetoli G1, Ileret, Namibian Holocene and Modern Human Footprints Using Pedobarographic Statistical Parametric Mapping

Juliet McClymont and Robin H. Crompton

Abstract It is traditionally held that early hominins of the genus *Australopithecus* had a foot transitional in function between that of the other great apes and our own but that the appearance of genus *Homo* was marked by evolution of an essentially biomechanically modern foot, as well as modern body proportions. Here, we report the application of whole foot, pixel-wise topological statistical analysis, to compare four populations of footprints from across evolutionary time: *Australopithecus* at Laetoli (3.66 Ma, Tanzania), early African *Homo* from Ileret (1.5 Ma, Kenya) and recent modern (presumptively habitually barefoot) pastoralist *Homo sapiens* from Namibia (Holocene), with footprints from modern Western humans. Contrary to some previous analyses, we find that only limited areas of the footprints show any statistically significant difference in footprint depth (used here as an analogy for plantar pressure). A need for this comparison was highlighted by recent studies using the same statistical approach, to examine variability in the distribution of foot pressure in modern Western humans. This study revealed very high intra-variability (mean square error) step-to-step in over 500 steps. This result exemplifies the fundamental movement characteristic of dynamic biological systems, whereby regardless of the repetition in motor patterns for stepping, and even when constrained by experimental conditions, each step is unique or non-repetitive; hence, repetition without repetition. Thus, the small sample sizes predominant in the fossil and ichnofossil record do not reveal the fundamental neurobiological driver of locomotion (variability), essentially limiting our ability to make reliable interpretations which might be extrapolated to interpret hominin foot function at a population level. However, our need for conservatism in our conclusions does not equate with a conclusion that there has been functional stasis in the evolution of the hominin foot.

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Introduction

The origins and evolution of human striding bipedalism have long been a focus of human palaeontology and evolutionary biomechanics. However, the fossil evidence for the evolution of the postcranial skeleton has not been an unambiguous source of information. Claims that morphological features taken as human adaptations for terrestrial bipedalism reduce effectiveness in arboreal climbing are challenged by the combination of both capabilities in several indigenous modern human populations (Venkataraman et al. 2013a, b). This is a clear demonstration of neurobiological degeneracy (Seifert et al. 2016) and the high variability necessary for dynamic systems (Davids et al. 2003). These two theories underpinning biomechanical movement and locomotor adaptation are reviewed in the references provided but are not discussed in great detail here due to the nature of this publication. Briefly, however, both concepts can be illustrated by the everyday phrase, "there are many ways to skin a cat". Thus, the long femoral necks and small femoral heads together with flaring iliac crests found in many australopiths (McHenry 1975) (but due to high biological variability, emphatically not all), versus large femoral heads and short femoral necks with sigmoid, non-flaring iliac crests in ourselves, must be interpreted as reflecting naturally high variation in biological forms. Undoubtedly, the mechanics of hip adduction and abduction must have been different in some australopiths; however, variation in morphology may act to achieve the same biomechanical effect on joint systems in different ways. Take, for example, clear evidence of facultative upright bipedal behaviour in *Gorilla gorilla* (see, e.g. Watson et al. 2009). Gorilla morphology isn't designed specifically for upright bipedalism, but natural biological variation permits it. Very few papers in primatology, hominin palaeontology and human and non-human ape ichnopalaeontology address variation in bone morphology and footprint topology within the context of the locomotor system. Small fossil samples are often described as key for understanding human locomotor evolution or morphofunctional behaviour. Such relationships are often claimed from the evidence of a single individual without including either morphological variation or facultative capabilities. It is more reasonable to recognize that high natural intra-individual facultative variation elicits high inter-individual morphofunctional variation at a population level and vice versa. Both are a consequence of complex neurobiological evolution in biological systems. A noteworthy exception to a general lack of investigation of variability, however, is Dunn et al. (2014) on the *Gorilla* talus.

Leading cognitive and ecological motor skills specialists address biomechanical variation anchored by the theoretical paradigms of dynamical systems (Thelen 1995, 2005; Davids et al. 2003; Bartlett et al. 2007) and neurobiological degeneracy (Edelman and Gally 2001; Seifert et al. 2016). These paradigms have been increasingly influential in biomechanics, especially sports science. However, hominin palaeontology has not yet taken these advances on board, while further being hampered by small sample size, which make it difficult to incorporate an understanding of the impact on variability in biological systems on evolutionary interpretations. For example, the biomechanical complexity involved in taking a step begins at the hip joint, a simple, single ball joint articulation, while the knee joint comprises the biarticular joint between femur and tibia and a third, sliding joint between the tibia and fibula. Thus, the knee joint is kinematically complex, with sliding (essentially planar), as well as rotatory motion. However, the structure predominantly concerned in transferring forces to the substrate (whether ground, branches or any other surface) is the foot. Here we face 26 bones (excluding sesamoids) which form 33 joints and are controlled by over 100 muscles, tendons and ligaments. Thus, given variation in the complexity of biomechanical forms, and a shortage of fossils, it is no wonder that functional interpretations of the evolution of the foot have been and still are interpreted in different and contradicting ways.

For example, the OH-8 *Homo habilis* foot has been described as (non-human) ape-like in some joints but not others (e.g. Kidd et al. 1996; and see Harcourt-Smith and Aiello 2004) but elsewhere more or less entirely humanlike in function (e.g. Day and Napier 1964). What humanlike in function implies for gait is obvious (habitually upright, striding steps), but what is the significance for gait of describing a foot as a mosaic of non-human ape-like and humanlike joints, when there are 33 joints to consider? In engineering parlance, such a complex system is described both as functionally redundant (there are many neuromechanical pathways to achieve a consistent motor pattern) and that its determinacy is low (it will be difficult to predict how the system will act in different iterations of the same task). Perhaps the most accessible review of these concepts as applied to biological systems can be found in Alexander (2003).

Since foot structure is so complex, and redundancy therefore so high, our confidence in eliciting functional information at a population level about species gait from comparisons of individual foot bones (e.g. Jungers et al. 2009; Ward et al. 2011) must be fairly low. There is some potential however to interpret biomechanical variability retrospectively from topological features of fossil footprint trails.[1] The basis of this potential is that a natural relationship between forces exerted on the ground by the foot, to balance, propel and control walking, and the consequent deformation of the ground could logically exist, given that

$$p = \frac{F}{A}$$

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[1] A *caveat* is required for the present paper: given our brief discussion here on variability and sample size, interpretations of the variability presented herein are made purely for the trackmaker as they took the 11 steps in this sample and cannot be extrapolated to predictions regarding a population locomotor mode. Furthermore, this is not an assessment of functional variability as would be required for inferring stability and balance behaviour: that would require thousands of steps. For an excellent tutorial on functional variability, equations and analysis techniques, see Bruijn et al. 2013.

where pressure (p) equals the amount of force (F) (the scalar of which is measured in Pascals (Pa)), acting per unit area (A) (Giancoli 2004). However, substrates, no matter their composition, will always reach a point at which maximum body weight is fully supported, and thus, the substrate stops deforming even though pressure is still being applied. Substrate composition at and below ground surface, substrate moisture content, even the electrical charge at the surface of substrate particles and a host of other factors can, however, be expected to interact with deforming forces delivered by the plantar surface of the foot. Thus, the shape of a footprint does not mirror the foot that made it due to substrate effects. We explored some of these interactions in Bates et al. (2013) (and see Supplementary Material) and concluded that the relationship of foot pressure and print depth varies with substrate compliance: substrate moisture and presence and depth of subsurface compaction levels, but also the mechanical requirements at toe off, influencing print topology.

A crucial recent discovery that of StW 573 *Australopithecus prometheus*, 3.67 Ma, which is over 90% complete (see e.g. Clarke 2019; Crompton et al. 2018) crucially, closely similar in date to the Laetoli footprint trails. The best known and most complete early human ancestor was *Australopithecus afarensis*, represented by the diminutive AL-288-1 Lucy skeleton, 3.4 Ma. Thus, despite her relatively late date, most locomotor interpretations of the Laetoli footprint trails have been based on the AL-288-1 Lucy skeleton (e.g. Crompton et al. 1998, 2012).

Since discovery of this partial (circa 30% complete) skeleton, her combination of humanlike knees with reconstructed limb proportions that were thought to indicate long arms and short legs, and her clear digital curvature, has fostered a long-term dispute on her locomotor behaviour. Some (e.g. Stern and Susman 1983, 1991; Stern et al. 1984) assert that these traits would have compromised her terrestrial bipedalism, so that she would have walked with a bent hip and knee (BHBK) posture and even a somewhat shuffling gait. Opposing are those who argue that she was an effective terrestrial biped and that the arboreal features are simply retained anachronisms (Latimer et al. 1987; Latimer and Lovejoy 1989; Latimer 1991).

Computer simulation and experimental studies have since shown that even her proportions as first reconstructed with effective fully upright bipedalism (e.g. Crompton et al. 1998; Kramer 1999; Kramer and Eck 2000) and that a BHBK gait in humans causes an unsustainable rise in core body temperature within 5 min of walking (Carey and Crompton 2005). Given the general similarity of muscular physiology in placental mammals, and all other things being equal, forwards dynamic modelling has, similarly, predicted BHBK gait to near double the metabolic costs of transport in *Au. afarensis* (Sellers et al. 2005; Nagano et al. 2005). More recently, other partial skeletons of this species, most notably KSD/VP 1-1 from Woranso-Mille (Lovejoy et al. 2016), but also other isolated bones or partial material from Afar (including material referred to AL-333, see, e.g. McHenry 1986), have shown that Lucy's small stature and long forelimbs are the exception rather than the rule. In fact, analysis of the StW 573 longbones now suggests that AL-288-1 probably did not have particularly short legs in relation to arm length (Heaton et al. 2019). *Au. afarensis* now appears to be a very variable species both in stature and postcranial morphology, and this is further attested to by KSD/VP 1-1 being assigned to this species by Lovejoy et al. (2016).

To gain further enlightenment on the mode of locomotion in *Au. afarensis*, several groups have analysed the penecontemporaneous Laetoli footprint trails, holding that on the basis of the above-cited equation, footprint depth and topographical features must at the very least reflect foot-ground interactions. Early attempts focussed on features of single footprints chosen from the clearer G1 trail, and some declared that the footprints are essentially modern in character (Day and Wickens 1980; White 1980). Others argued that features such as a relatively abducted hallux with limited hallux print depth support a BHBK model for gait (Stern and Susman 1983). However, White and Suwa (1987) regard these features as taphonomic artifacts. This more than 30-year-old debate continues today.

Although it is now broadly accepted that selection of single prints for study is inappropriate, Meldrum and colleagues, as late as 2011, claim that a line in one footprint shows a chimpanzee-like mid-tarsal break, so claiming that *Au. afarensis* lacked a medial longitudinal arch (Meldrum et al. 2011). An opposing argument based on discussions with the chief taphonomist of the Laetoli footprint trails (pers. comm. Craig Feibel to RHC) suggests that this topographical feature is simply a product of natural sedimentological fracture in the substrate over time although this would require micro-sedimentological analysis to confirm. Statistical and biomechanical approaches to the Laetoli footprint trails have predicted the stride length, foot shape, body proportions and speed of the trackmaker (Alexander 1984; Reynolds 1987; Raichlen et al. 2010), and spatio-temporal characteristics of the same trail have been used as an analogy to predict speed of walking and energetic costs in *Au. afarensis* (to date, primarily AL-288-1) (Kramer and Eck 2000; Sellers et al. 2005).

Hatala et al. (2016) compared just 5 of the 11 taphonomically usable footprints from Laetoli G1 using an inappropriate regionalized (and hence anatomically biased, see, e.g. Pataky et al. 2011) topological analysis, to prints made by modern humans and bipedally walking chimpanzees. The authors concluded that topological features from the Laetoli G1 prints are evidence for a functionally unique locomotor mode. Specifically, the authors claim to be able to identify kinematic distinctions in foot and lower limb function and that the trackmaker probably walked with a more flexed knee posture, describing it as a form of bipedalism that was well developed but not equivalent (Hatala et al. 2016) to that of modern humans. Raichlen et al. (2010) found that a simple whole foot statistical comparison of heel and toe depths in the 11 usable prints indicated a fully upright posture. Crompton et al. (2012) used a rigorous combination of topographical whole foot statistical analysis and computer modelling to compare the mean tendency of the 11 usable G1 prints, predicting foot pressure in upright and BHBK gait. The authors conclude, similarly to Raichlen and colleagues, that they cannot have been made by an individual walking BHBK and were more likely left by an upright striding biped. Raichlen and Gordon's (2017) preliminary statistical comparison of heel and toe depth confirms these findings for the more extensive Laetoli S series, which were made by individuals of greatly varying stature.

Recently, Bennett et al. (2016) made a broader comparison of the Laetoli G1 trail both to prints from Ileret, made presumptively by early African *Homo erectus* and to Holocene pastoralist footprints from Namibia. On the basis of footprint depth, substrate conditions at the time of footprint formation of the Namibian trails, which cross from drier sandy bank sediments, through muds, and back to drier bank deposits in an ancient streambed, bridged those at Laetoli (relatively shallow and only slightly moist) and Ileret (deep and wet muds). The Namibian trackways, made in the Holocene age, were made by presumptively habitually barefoot individuals, and given the alteration that footwear induces in human plantar pressure, they are an invaluable control. Using third-party open-source code to derive mean and median tendencies of the tracks, they conclude that there is functional stasis between the 3.66 Ma (Crompton et al. 2012) Laetoli G1 trails and the circa 1.5 Ma (Bennett et al. 2009) Ileret trails. Inasmuch as this implies a fully upright gait at the time of footprint formation at Laetoli G1, this study is in accord with both that of Raichlen et al. (2010) and Crompton et al. (2012). Each of these studies used at least twice as many G1 footprints as did Hatala et al. (2016), raising the possibility that sample size, and further possible loss of variability between footprints due to their subjective selection of only five footprints, could account for their very different interpretations.

Because of this contradiction, an extended statistical analysis of variability in footprint topology using pedobarographic statistical parametric analysis (pSPM) of the Laetoli G1, Ileret and Namibian fossil footprint trails in comparison with experimental modern human plantar pressure records is presented here.

Methods

We employ the robust method of statistical parametric mapping (SPM), a topographical statistical approach first developed by Friston et al. (1995) for functional brain imaging and extensively validated by that group (open source). The algorithms have been further developed for foot pressure studies and incorporated into our open-source software pedobarographic statistical parametric mapping (pSPM), which has been further and extensively validated (e.g. Pataky 2010; Pataky and Goulermas 2008; Pataky et al. 2008, 2011). In its analogous extension to footprint depth, statistical comparison of the samples also uses pixel-level pairwise t-tests (Pataky and Goulermas 2008; Pataky et al. 2008) but here after normalization by plantar surface maximum depths. Methods follow Crompton et al. (2012) and Bates et al. (2013) except that we now employ automated registration where possible and use an enhanced method for isolating and normalizing prints. These changes and a full description of the method are presented in Supplementary Material (Fig. 3.4, data processing prior to registration. Figures 3.5, 3.6, 3.7 and 3.8 diagramatically illustrate, registration and re-registration), together with all data processing and methodological sensitivity checks.

Results and Interpretations

Figure 3.1 presents the mean footprints and the results of topological statistical comparisons of 11 prints from the G1 trail at Laetoli (Leakey and Hay 1979; Leakey and Harris 1987), with 9 prints from the upper surface at Ileret (FwJj14E; Kenya) (Bennett et al. 2009), a 32 print sample from the Holocene trail at Walvis Bay, Namibia (Kinahan 1996; Morse et al. 2013), and a modern Western (thus habitually shoe wearing) dataset collected on a treadmill (N = 100 pressure records registered to create one mean print each from 10 individuals).

Habitually shod Western modern and presumably habitually unshod Holocene modern human footprints (Fig. 3.1a) show no areas of significant difference. The Ileret dataset differs significantly from that for modern Western humans ($p = 0.000$), (Fig. 3.1b) showing a deeper medial arch. The Laetoli mean shows significantly deeper medial arch and anterior heel impressions than the modern Western human mean (Fig. 3.1c) and significantly shallower hallucal impressions. The Ileret footprints are significantly different from the Holocene modern human mean (Fig. 3.1d), having a shallower medial arch and deeper distal toes, albeit under a small area in the midfoot ($p = 0.044$) and restricted to print edges. The latter could be the result of imperfect registration due to minor overall shape differences in the two populations or the subject dragging the foot from where it would have been sunken into the soft sediment. Most notably, the Holocene modern humans from Namibia and Laetoli means differ significantly (Fig. 3.1e) in only a very small area under the hallux.

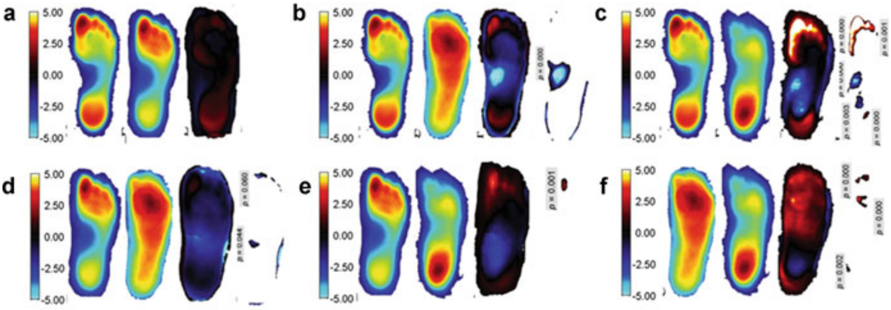

Fig. 3.1 Statistical whole foot comparison of four footprint populations. The first and second footprint images in each comparison (a–f) are the mean image from the two species being compared. The third footprint image is the comparison of the two population means. The fourth footprint image is the inference plot determining the pixel-level locations of statistically significant differences between the two populations being compared; (**a**) habitually shod anatomically modern *H. s. sapiens* vs. habitually unshod *H. s. sapiens*; (**b**) habitually shod *H. s. sapiens* vs. early African *Homo erectus* footprints from Ileret; (**c**) habitually shod *H. s. sapiens* vs. Laetoli footprints; (**d**) presumptively habitually unshod (Namibia) *H. s. sapiens* vs. Ileret *Homo erectus* footprints; (**e**) habitually unshod *H. s. sapiens* vs. Laetoli footprints; (**f**) Ileret *Homo erectus* vs. Laetoli footprints. Inference plots represent the probability values for areas with statistically significant differences in footprint depth and are represented in the far-right column of each comparison. This column is blank in (**a**) designating no statistically significant differences in topology in this comparison

Finally, statistically significant differences between the Ileret and Laetoli means (Fig. 3.1f) exist in deeper impressions under small areas of MTH1, the hallux and the posterior medial heel.

Visual inspection of the experimental footprints provided in the contribution by Hatala et al. (2016) reveals that similarities in the forefoot and hallux depths of their modern human and selected Laetoli footprints more than exist with their selected chimpanzee footprint. The statistically significant deeper medial midfoot impression in Laetoli ($p = 0.000$) than in Western modern humans (Fig. 3.1c), also reported by Hatala et al. (2016), could be attributed to the effect of habitual shoe wearing in Western modern humans, creating a higher medial arch in this group (Stolwijk et al. 2013). We have shown through experimental studies of the relationship of footprint depth to footprint morphology (Bates et al. 2013) that there is a clear tendency for deeper prints to have relatively deeper forefoot impressions. It is therefore likely that the statistically significant differences between Laetoli and Ileret (Fig. 3.1f), and Ileret and Holocene modern human footprints (Fig. 3.1d) sampled here, are attributable to the greater overall footprint depth at Ileret. (The Laetoli sample showed a mean of 31 mm, range 26–37 mm; for Ileret the mean maximum plantar depth was 49 mm, the range 24–94 mm; see Supplementary Material in additional footprint discussion.) Here, moisture content was likely higher, based on sidewall suction against the foot producing long narrow tracks; by this interpretation, the moisture content likely weakened the sediment in which the tracks were made (Craig 1997; Bennett et al. 2016). Similarly, the relatively greater number of deep prints from Holocene modern humans (from a wetter substrate, mean maximum plantar depth was 45 mm and range 23–77 mm) compared to Laetoli could readily account for deeper hallux impressions in Holocene human footprints. Crompton et al. (2012) used computer modelling to simulate contact pressures under the foot in upright and flexed knee walking. They showed that bent knee or flexed knee walking produced higher forefoot than hindfoot pressures because of the anterior shift of the centre of mass (CoM). Their analysis of a larger dataset including all of those prints analysed by Hatala et al. (2016) revealed consistently deeper hindfoot than forefoot impressions, indicating full extension at the knee during upright walking (Ferris et al. 1998; see Crompton et al. 2003, 2008 on the relationship between the heel-strike transient and extended knee postures in orangutans). While any comparison of human and *Au. afarensis* postcrania strongly suggests that the locomotor systems of the Laetoli trackmaker and modern humans form biomechanically distinct kinematic chains, this does not necessarily imply dramatically different external ability and function (Bock 1965, 1994; Laland et al. 2015; Seifert et al. 2016). This interpretation follows the expectations from effects due to high functional redundancy (Latash et al. 2002) and high degrees of freedom in the foot (e.g. Wolf et al. 2008), both natural and essential components to be considered in analyses of fossil footprint trails and explaining the difference between prints and between populations via high variability.

Figure 3.2 represents all prints in the Laetoli G1 sample used in this analysis alongside 11 consecutive p-images collected during treadmill walking from a healthy human at 1.1 m/s (McClymont et al. 2016). This figure is not a statistical

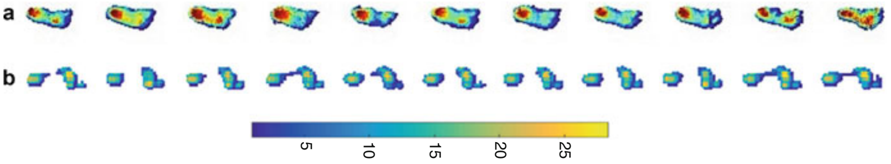

Fig. 3.2 A visual representation of the variability in relative foot print depth (**a**) and plantar pressure (**b**); (**a**) footprint of whole foot pixel-level statistical topographical depth map of the Laetoli footprints used in this analysis, showing variable distribution of maximum depth step-to-step. Greatest depth is evident in combinations of heel, lateral midfoot and the lateral MTH5-2 step-to-step; (**b**) 11 consecutive registered whole foot pixel-level statistical pressure images collected from a treadmill walking trial at 1.1 m/s in *H. s. sapiens*. Areas in yellow are areas of highest variability (mean square error (MSE)) step-to-step. Greatest pressure is consistently evident in combinations of heel and lateral MTH4-1

comparison of relative depths (Laetoli) and plantar pressures (modern human) as the two samples were collected under completely different conditions. It is simply presented to visually demonstrate the variability in each step or fluctuations in foot-ground interactions during just 11 steps. While there are undeniable differences in foot shape and topography, they share similar variation in topology step-to-step. The Laetoli prints (Fig. 3.2a) are consistently deeper under the heel and lateral forefoot with steps 10 and 11 showing deeper depth under the whole forefoot than in previous steps. The human prints (Fig. 3.2b) despite being more consistent step-to-step due to the normalizing effects of the treadmill (Kang and Dingwell 2008) also show consistently high variability in pressure under the heel and MTH4, 3 and 1. We should note that the human subject does not represent the most variable subject from our Western human sample but instead the average. Again, this figure is not intended as a statistical comparison of relative depths and variability in pressure between the two subjects or across deep time. It is simply presented to visually illustrate the step-to-step variability of foot-ground interactions during locomotion despite two very different substrates and in a relatively tiny interpretive sample of only 11 footprints out of the thousands the individual took the day they were made. Tudor-Locke et al. (2017) showed that the average 20-year-old American male walks between 2247 and 12,334 and females 1755 and 9824 steps per day. This underlines the requirement of steps necessary to interpret the natural and characteristic patterns of variability that contribute to morphofunctional interpretations of the individual making fossil footprint trails.

The variation in relative depth in the sequence of 11 footprints reflects similar and thus normal biomechanical variation in stride dynamics in both the G1 trackmaker (Fig. 3.2a) following Alexander's (2003) work (and see Wainwright 1991; Wainwright et al. 2002) and reflecting Bernstein's (1967) classic description of human movement as 'repetition without repetition'. That is, each movement task (e.g. step) is driven by a unique set of neural and motor patterns, temporarily assembled to produce a task outcome (Latash et al. 2002) based on the unique mechanics of each step and the substrate upon and environment in which it is taken. Thus, while each step is programmed by the suit of bipedal evolutionary traits, each step is unique. Thus, not only have we shown that there is intra-species variation in foot pressure within the great apes, sufficient for both Asian and African apes (orangutan and bonobo) to overlap in midfoot pressure patterns with habitually shoe-wearing humans (Bates et al. 2013), but our interpretations here are founded on intra-individual variation step-to-step, as predicted by Bernstein (1967) and Latash et al. (2002).

As mentioned earlier a very serious limitation in the analysis of fossil footprint data is sample size. Figure 3.3 (below) simulates the possible effects of Hatala et al.'s (2016) subjective selection of just 5 G1 footprints, by sampling the first, middle and last group of 5 prints from the 11 used here and available for ready analysis (Raichlen et al. 2010; Crompton et al. 2012). Indeed, as Hatala et al. (2016) observed, modern humans consistently have a deeper impression in the forefoot than that of the Laetoli hominin, irrespective of which sample is selected. However, the last final comparison in set (Fig. 3.2c) shows (considerably smaller) areas of the midfoot and anterior heel, where it is the Laetoli prints which are deeper. Thus, interpreting topological differences between the G1 prints is not immune to a subjective choice of prints, raising concerns about the conclusions of Hatala et al. (2016). On the assumption that footprints are correlated with foot pressure, even given the interactions with substrate characteristics alluded to above and which we dealt with in detail in Bates et al. (2013), our concerns are very deeply amplified by new data concerning the sample size required to reliably characterize human gait. Arts and Bus (2011) recommend only 12 steps per foot for clinical assessment of plantar pressure. Sample sizes of as little as 10, and at most 50, are commonly used to assess gait parameters including pressure and kinematics in clinical practice. The higher value of 50 slightly mitigates the effect of step-to-step variability that would otherwise perhaps lead to false interpretations, due to the high variability step-to-step (McClymont et al. 2016). Owings and Grabiner (2003) however have demonstrated that sample sizes of over 100 steps are needed to reliably characterize an individual's kinematics, to within 95% confidence. Equally, McClymont (2017) showed through a Monte Carlo subsampling analysis of random samples of >2000 footprints per subject that the individual trial N typically collected in plantar pressure studies in the literature (N = 10–50 *p*-images) produces MSE ranges that are more than 50% higher than from when sampled from a larger total individual N of >500. At N = <10 records this increases to more than 75%, indicating a high probability that such a small individual trial N would not reflect either the range of variation or the habitual mean pressure that would be represented by a larger dataset of consecutive foot print records. Acquiring a sample of more than 500 is clearly unfeasible for footprints and even for foot pressure in the infirm. However, samples of 100–138 would deliver around 95% confidence and might be achievable in the future at Laetoli S. But even assuming a close link between pressure and footprint depth, a sample of five, as used by Hatala et al. (2016), offers well under 25% confidence of assessing pressure characteristics, i.e. a probability of unreliable assessments. Indeed, our own sample of 11 would allow no better than 50% reliability; however, we are accounting for the effects of variability in our interpretations and not making confident claims for a new locomotor mode, from what we know to be a biomechanically unsatisfactory sample size.

Discussion

Based on only very minimal statistically significant differences (just a few pixels) between Laetoli and unshod (Holocene) modern humans (Fig. 3.1e), and the commonality of stride-to-stride and step-to-step fluctuations illustrated in the Laetoli G-1 trail and the modern human example (Fig. 3.3a, b), we cannot find any evidence that the Laetoli trackmaker utilized a flexed knee posture at the time of formation of the prints examined, supporting previous results (Sellers et al. 2005; Raichlen et al. 2010; Crompton et al. 2012). The extended evolutionary synthesis (EES) (Laland et al. 2015), and the unifying theory of dynamical biological systems (Davids et al. 2003) and neurobiological degeneracy (Seifert et al. 2016), all predict high variability in adaptive biological systems, permitting rapid evolutionary change (Laland et al. 2015) and stable, functional movement (Bernstein 1967; Seifert et al. 2016). The high redundancy present in the anatomically complex structure of the foot is likely to be employed to control step-to-step dynamic variability in walking (Dingwell et al. 2010), and activation patterns are substantially subject to stochastic processes, reflecting neurobiological degeneracy (Seifert et al. 2016). We (Pataky et al. 2013) also found in a large sample of foot pressure records ($N = 5243$) that autocorrelation in maximal plantar pressure between steps is very weak, such that statistical power calculations found that a null hypothesis that local plantar pressure values are uncorrelated in short gait bouts is likely true with an average probability of 78.9%. This is both consistent with dynamical systems theory and very worrying for the analysis of short/discontinuous trails such as those at Ileret and similarly for the Hatala et al. G1 sample of five. While we have not attempted to quantify dynamic behaviour here, when pressure is taken as analogous to, but not equivalent to, depth in the Laetoli footprints, we can infer a flexible, upright hominin gait variably resisting perturbations to stabilize the CoM across the hot, damp ash (Dingwell et al. 2010). Recent evidence from a variety of substrates found that forefoot depth increased with moisture content in a modern human sample (Bates et al. 2013), leading to a requirement for increased forefoot forces to clear the foot from the substrate. We conclude that the differences in relative forefoot depths are a product of substrate, specifically of high moisture content in the modern human experimental sample, Ileret, and part of the Walvis Bay trail, versus relatively low moisture content (Craig 1997) at Laetoli.

Further visual inspection of the experimental footprints provided in the contribution by Hatala et al. (2016) reveals similarities in the forefoot and hallux depths of modern human and Laetoli footprints, more so than with the selected chimpanzee

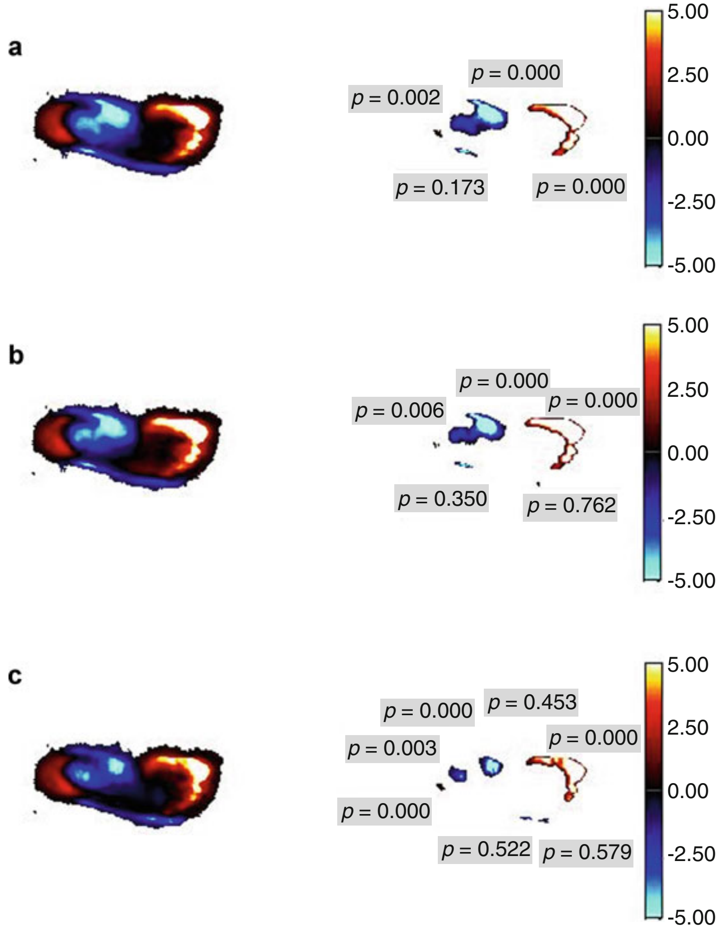

Fig. 3.3 Subtraction of the *H. s. sapiens* mean p-images from the dataset collected in soft sandy sediments from Bates et al. (2013) and 3 alternative set means of 5 registered prints from the 11-print dataset of the Laetoli G1 trail; (**a**) the first set of five Laetoli footprints registered and the mean image compared with *H. s. sapiens* mean p-images following registration; (**b**) the second set of five Laetoli footprints registered and the mean image compared with *H. s. sapiens* mean p-images following registration; (**c**) the third set of five Laetoli footprints registered and the mean image, compared with *H. s. sapiens* mean p-images following registration

footprint. The relatively deeper experimental toe depths observed in the human and chimpanzee prints are likely due to the substrate effects described extensively by Bates et al. (2013), while the human and Laetoli hallucal impression indicating toe off is also clear. While not directly measuring dynamic behaviour, the unique case of fossil footprint trails is a reflection of dynamic behaviour that occurred at one time.

The reliability of assessment, putting aside substrate characteristics, is a major issue in interpreting gait from footprints: very loosely, Raichlen et al. (2010) and

Crompton et al. (2012) have at best a 50% chance that their conclusions that the G1 trackmaker walked upright are correct, and similarly Bennett et al. (2016) have at best a 50% chance that their conclusion of functional stasis between Laetoli and Ileret is correct. Hatala et al. (2016) have at best a one-in-four chance of having drawn a correct conclusion in claiming that the five prints chosen shown that the G1 trackmaker walked with a more flexed posture than ourselves. But, should Masao et al. (2016) discover more extensive footprints at Laetoli S, we may well get 50 continuous steps and up to near 90% reliability (again always given a good relationship of footprint depth with foot pressure), which would make the analysis of gait from footprint depth much more meaningful and promising.

The reconstruction of gait from the postcrania of early hominins however will require a different and more indirect strategy, as even in single bones, and not taking into account the functional redundancy of distal segments, we can expect high intra- and inter-taxon variability of trait morphology, some of which variation will not be functional (Bock and von Wahlert 1965), since motor control patterns adapt locomotor behaviour step-to-step based on each interaction between the body and the environment (Bernstein 1967; Riley and Turvey 2002). This is a primary tenet of dynamical systems theory, which has now matured into the concept of neurobiological degeneracy (see, e.g. Seifert et al. 2016), on which current biomechanical studies of gait variability are now almost always based. The prediction of overall gait patterns in early hominins such as *Au. afarensis* from morphology of proximal bony elements such as long-bone shaft and femoral neck cross-sectional geometry, as attempted by Ruff et al. (2016), is hazardous enough unless dynamic modelling is used to assess summed forces applied to the foot.

Conclusion

Based on the lack of statistically significant differences between Laetoli and unshod modern humans from Namibian footprint trails (Fig. 3.1e), and considering the commonality of stride-to-stride and step-to-step fluctuations in both trails (Fig. 3.1a, b), we find no evidence from this analysis that indicates the Laetoli trackmaker utilized a flexed knee posture beyond the range of variation in modern humans today (given the sediment characteristics and small sample of footprints). This supports previous findings for footprint analyses (Sellers et al. 2005; Raichlen et al. 2010; Crompton et al. 2012) and is consonant with studies showing that *Au. afarensis* was biomechanically capable of, and therefore likely to have performed, erect bipedality. It is possible that some or most australopith populations engaged in substantial arboreality, as suggested for AL-288-1 Lucy (Ruff et al. 2016), based on cross-sectional geometry of her long bones and femoral neck. It does not however follow that selection for arboreal activity reduced effectiveness in terrestrial bipedalism in australopiths. We have shown that footprints in the habitually unshod Holocene Namibian population and in the maker of Laetoli G1 could be very similar.

The primary theoretical argument underpinning our conclusions is that this is possible due to high degrees of variability expected in all aspects of morphology and locomotor behaviour across all biological species, and quantifiable by functional variability during movement (Bruijn et al. 2013). However, as is typical of paleontology, we are restricted by small sample sizes, and hence unable to capture the full biomechanical variation in movement which would have been present in the trackmaker at the time footprints were made. Thus, without the inclusion of, or reference to, the known variability in fossil populations, and the functional variability in locomotion in analogous, extant non-human ape populations, interpretations should only be made for the trackmaker and not used to predict species level behavior, or to suggest unique locomotor modes at he species level. Variability in morphology and behavior, and ontogenetic plasticity, although challenging for our understanding of human and non-human ape fossils, should equally be seen as key to our success in dealing with environmental change and expanding into a very wide range of new environments. Plasticity, in a real sense, is key to evolutionary biological success of all species.

Acknowledgements We dedicate this contribution to Mr. Russell Savage, our dear friend and colleague, who contributed extensively to this work before his sudden and untimely death in late 2016.

We thank Drs. Karl Bates and Todd Pataky for their contributions to core analysis of footprint depth and pressure. We thank Dr. Craig Feibel for his advice on the taphonomy of Laetoli G1, and the extent and identity of usable G1 prints, and Prof. Ronald Clarke for related advice from his perspective as one of the chief excavators of Laetoli G1. We thank our senior colleague Prof. Michael Day for his kindness in entrusting his photogrammetric records of G1 and G2/3, made shortly after excavation and prior to subaerial erosion, to RHC. We thank Prof. Matthew Bennett for giving us access to his Namibia and Ileret data. The participation of JMcC in both excavations at Ileret and Walvis Bay, Namibia, has enabled us to work on these scans with confidence. The research was funded by the Leverhulme Trust, the UK Natural Environment Research Council and the Institute of Ageing and Chronic Disease at the University of Liverpool.

Supplementary Material

Detailed Materials and Methods

Ileret prints used in this analysis are from the upper footprint surface at FwJj14E (4° 18′ 44″ N; 36° 16′ 16″ E) and include five prints from the longest trail (FUT1-1, FUT1-3, FUT1-5, FUT1-6, FUT1-7), two prints from a shorter trail, (FUT3-1, FUT3-2) and four individual prints (FUI1, FUI2, FUI6, FUI7). They were imprinted in fine-grained tuffaceous silt and fine sand deposited as overbank flood deposits and assigned to *Homo erectus* on the basis of biometric inferences of body mass and stature (Bennett et al. 2009). The Laetoli prints (Leakey and Harris 1987) (Trail G1) used here are scans of first-generation casts of the Laetoli G1 prints at the National Museum of Kenya, laser-scanned using a Konica Minolta VI900 with a vertical resolution of 90 μm. Access to Day's photogrammetric data provided a vital check on print morphology. Prints G1/28 and G1/30 were omitted due to excessive erosion and vegetation damaged and also G1/38 as the posterior heel imprint is missing through faulting (Crompton et al. 2012). On the edge of the Namib Sand Sea (Walvis Bay, Namibia), unshod footprints from the Holocene (11,500 ka) (Kinahan 1996; Morse et al. 2013) occur on silt surfaces, deposited as overbank flood deposits from the Kuiseb River and exposed between sand dunes (23° 00′ 25″ S; 14° 29′ 26″ E). These prints were excavated in 2010 and scanned using a Konica Minolta VI900 (Morse et al. 2013). The print makers are assumed to have been habitually unshod due to their African context and date, as well as the presence of skin (callus) texture visible in the footprints (Kinahan 1996; Morse et al. 2013). If footwear was worn on occasions, it is unlikely to have been laterally constrictive. Optical laser scans of 100 prints from 10 living, Western individuals, made in a laboratory tray filled with fine, moist sand, were recorded using an LDI PS-400, and the 10 subject means combined into an overall modern human mean (Crompton et al. 2012). Photographs and stereopairs of individual Laetoli prints are available in the Laetoli monograph (Leakey and Harris 1987), scans of both the Laetoli and Ileret prints have been previously published (Bennett et al. 2009; Crompton et al. 2012), and the prints from Namibia have also been well documented (Kinahan 1996; Morse et al. 2013). Consequently the replication of individual print images here would be redundant. Many are freely available online via Bennett's Bournemouth University website.

All footprint scans were rectified to the orthogonal plane and cropped so that only the plantar surface of each footprint was retained (Fig. 3.4). After removal of any additional surrounding sediment, the data was imported as XYZ point clouds into Matlab and processed using Liverpool's in-house software pedobarographic statistical parametric mapping (pSPM) (Pataky and Goulermas 2008; Pataky et al. 2008). This software was designed to compute measures of central tendency across multiple foot pressure images (Friston et al. 1995; Pataky and Goulermas 2008); however, by substituting pressure for depth, it has here been applied to footprint trails (Crompton et al. 2012). This substitution does not imply that we believe the relationship between foot pressure and footprint depth to be linear, permitting a direct and simple (yet biomechanically incorrect) interpretation of gait from footprint depth. Nevertheless, a natural relationship must exist given $p = \frac{F}{A}$, where pressure (p) is the amount of force (F) acting per unit area (A). Following this nomological premise, we trust this analogue to more robustly underpin interpretation from statistical comparisons and inferences on multiple records.

The pSPM software co-registers the entire plantar surface of a sample of footprints such that each pixel (footprint depth) corresponds to the equal anatomical location in all co-registered images. To achieve standardized comparisons, all point clouds were down-sampled into images of 1 mm^2 pixel dimensions. To enable standardized comparison of footprints of different absolute depths, each image was normalized by its own maximum depth such that pixel values ranged 0–1, with 0 corresponding to shallowest depth and 1 the point of maximum depth of the footprint as in our previous study (Bates et al. 2013). Registration of images within pSPM can be undertaken using a number of automated algorithms or through

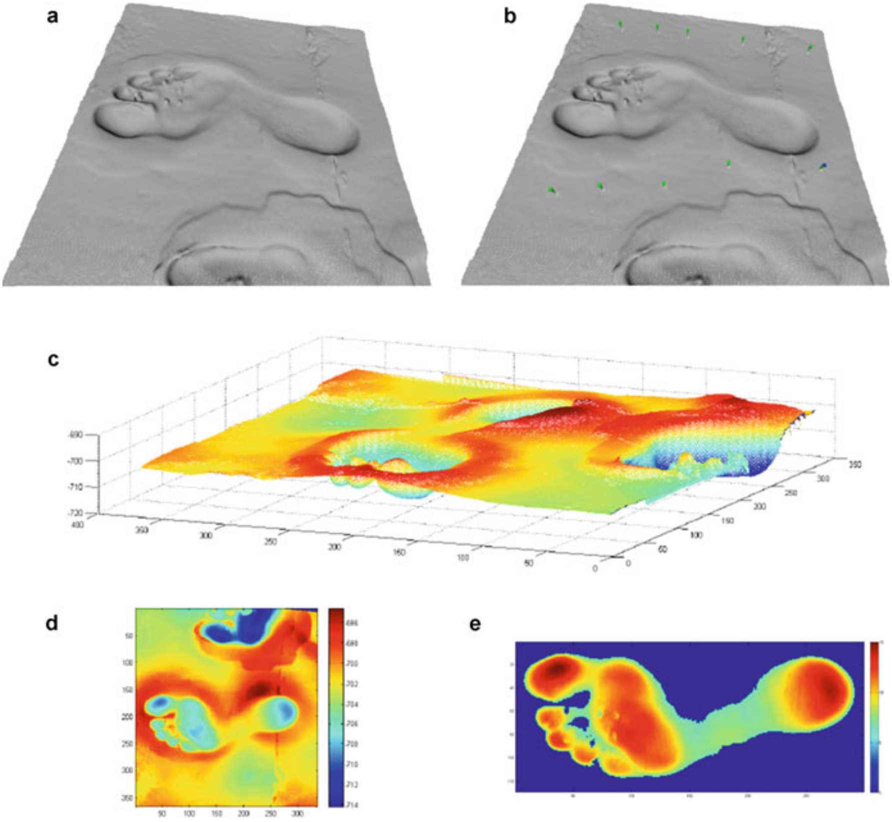

Fig. 3.4 Diagrammatic explanation of the data processing carried out prior to registration and topological statistical analysis; (**a**) surfaced laser scan of modern human footprint; (**b**) ten points were selected on the under-formed surface surrounding the print (i.e. outside any displacement rims, fractured areas, etc.). A plane was subsequently fitted through these points, and (**c**) the rotation required to align this plane with the horizontal was applied to the footprint, thereby aligning print depth with the vertical axis; (**d–e**) the same horizontal plane was then lowered until it reached the highest topological point (i.e. shallowest depth) on the plantar surface of the footprint. All pixels above this plane were then cropped out leaving only the plantar surface (occasionally small surrounding areas of sediment were manually removed). Depth normalization was then carried out using the range of depths present across the plantar surface, culminated with a scaled depth range of 0–1, with the shallowest point (within the midfoot in e) having a value of 0 and the deepest point (in the hallux in e) having a value of 1

manual manipulation that involves the rotation and scaling of individual images to a common template image (Pataky et al. 2008). A previous study tested the accuracy and repeatability of manual registration and showed that it produces comparable and in some cases better results than various registration algorithms (Pataky et al. 2008). Where a higher level of divergence in topology occurs, such as with inter-species comparisons, manual registration has been found to give better results (Crompton et al. 2012).

In this analysis topological variation required that the 9 Ileret prints were manually registered to each other, as were the 11 prints used from the G1 trail (Crompton et al. 2012). The Walvis Bay and modern human footprints were internally registered using an automated algorithm that minimized the root mean square error of pixels globally across pressure images (Pataky and Goulermas 2008). Registrations between populations of prints, facilitating cross-site (i.e. cross-species) comparisons were all performed manually. Here, all manual registrations were repeated three times to observe any impact of operator subjectivity on subsequent statistical tests.

Once registered, measures of central tendency can then be calculated to create statistical parametric maps (SPMs) and compared pixel by pixel using pairwise t-tests. Statistical comparison between print populations (i.e. different trails) is possible since probability values are available for every pixel in the SPM. Pixel-wise two-sample t-tests can be used to create a statistical image known as an "SPM {t}" (Pataky and Goulermas 2008; Pataky et al. 2008; Crompton et al. 2012) that provides a statistical comparison between two print populations. The large pixel numbers pose a potential problem since large t values (e.g. $t > 3$) are likely to occur simply by chance, and in a footprint or plantar pressure (which are the product of interaction between two continuous media) neighbouring pixels are clearly not independent.

However, neighbouring pixels tend to behave in a similar way due to the smooth outline, or boarder, of a print, and their t values form a generally smooth SPM, which can be shown to be topologically characteristic of a thresholded SPM (e.g. cluster size, number of clusters, etc.). Specifically, random field theory (RFT) is used to determine the t-threshold at which alpha = 5% of the pixels would be expected to reach, simply by chance, based on the smoothness and on the foot shape which is parameterized by pixel connectivity with the plantar surface. Shape information is necessary because a square field, for example, would be expected to produce fewer suprathreshold clusters than would a long, narrow rectangular field of the same area and same smoothness. The SPM is then thresholded based on this critical t value, and one is left with some suprathreshold clusters of pixels that have survived the threshold. RFT then uses analytical probability density functions to compute the likelihood that clusters of the given size could have been produced by chance (Friston et al. 1995; Pataky and Goulermas 2008).

Figure 3.1 presents the mean footprints and the results of statistical comparisons of 9 prints from the upper surface at Ileret (FwJj14E; Kenya) (Bennett et al. 2009), with 11 prints from the G1 Trail at Laetoli (Leakey and Hay 1979; Leakey and Harris 1987), a 32-print sample from the Holocene trail at Walvis Bay, Namibia (Morse et al. 2013), and the modern Western, habitually shoe-wearing dataset (N = 100 footprints from 10 individuals). The first two images in each set are the site means, the third is their subtraction to show where they differ, while the fourth identifies those areas where the difference is statistically different using pixel-level pairwise t-tests

(Pataky and Goulermas 2008; Pataky et al. 2008) after normalization by plantar surface maximum depths and their probability level These tests were carried out using the same methods used in previous studies (Crompton et al. 2012; Bates et al. 2013).

Additional Footprint Discussion

Comparison of footprint topology between sites with different substrates and geological properties is potentially difficult since the biomechanical signature of a trackmaker is mediated through the geotechnical properties of the substrate, and the substrate may also influence taphonomic modification (Craig 1997; Ditchfield

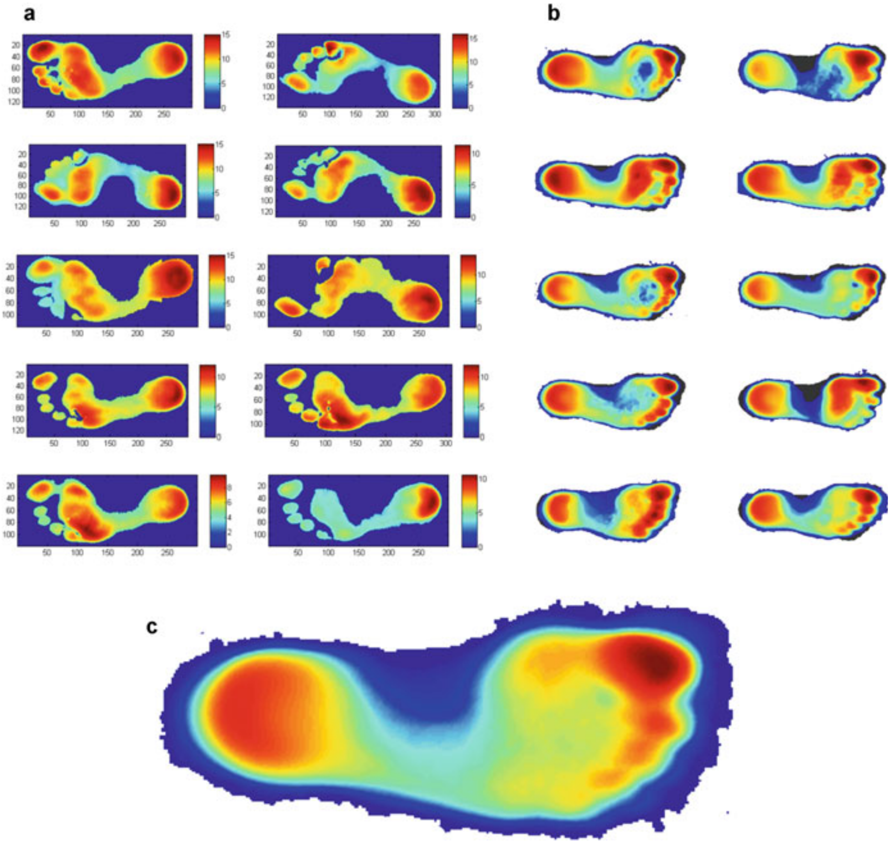

Fig. 3.5 An example of within-subject registration using ten prints from the modern, Western human dataset; (**a**) the ten prints are preprocessed as explained in Fig. 3.4. An initial registration is then performed that individually (i.e. one at a time) aligns the last nine prints with the first print in the dataset (not depicted above); (**b**) subsequently a second registration is performed in which all ten prints are individually (i.e. one at a time) aligned with their mean image; (**c**) the mean image itself. For the modern Western human and Namibian prints, this was carried out using automated algorithms

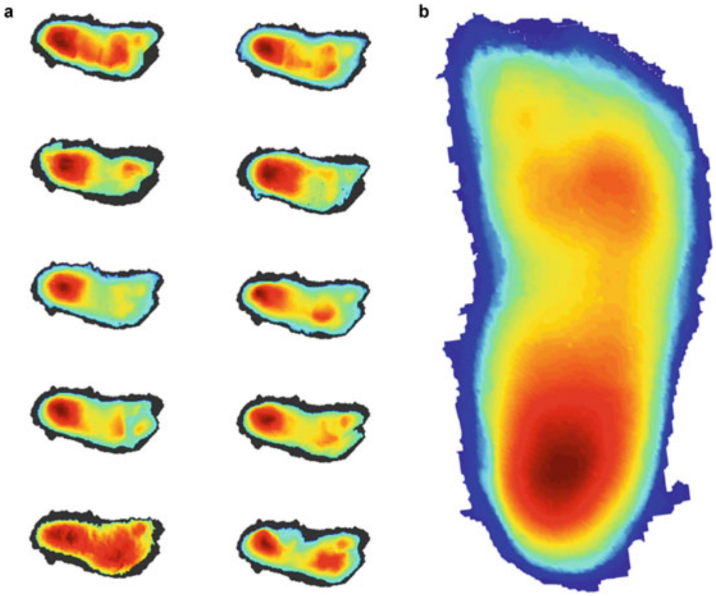

Fig. 3.6 Depiction of the same registration process shown in Fig. 3.5 for the Laetoli prints, in which registration was carried out manually (operator rotation and scaling of images) rather than using automated algorithms. The same manual registration was necessary on the Ileret prints

and Harrison 2011). In this analysis, at a macroscale we compared print populations from three natural environments, two from silt-rich flood/overbank deposits (Walvis Bay, Namibia and Ileret) (Crompton et al. 2012; Morse et al. 2013) and one from volcanic ash deposited via air-fall at Laetoli (Leakey and Harris 1987), with a sample of modern prints collected from fine sand in the laboratory. At the microscale, variation also exists within each depositional environment, dependent on local variations in grain size, moisture content, vertical stratigraphy and, significantly (especially the case at Laetoli), the degree of turbation by animal trampling (Morse et al. 2013). Substrate affects are particularly obvious in the Ileret prints, whereby withdrawal of the heel from soft, wet substrates causes side wall suction, naturally decreasing the macro-shape, specifically the width of the print (Craig 1997; Bennett et al. 2009; Morse et al. 2013). The enhanced longitudinal asymmetry – deeper forefoot (MTH1-3) than the heel – is also a feature of a softer substrate and is a visible feature in the mean Ileret print.

Technically, the substrate first holds the weight of the individual during the first phase of stance, only to fail further during the second phase associated with higher plantar pressures during toe off. The lack of clarity of toe impressions is a feature of deeper prints where foot withdrawal often modifies the impressions left by phalanges (Crompton et al. 2012). This is particularly evident at Ileret where toe drag is clear, associated with higher forces required to pull the toes out of deeper substrate. The medial longitudinal arch is also modified in softer substrates by the proximal movement of sediment under rotation of the ball of the foot, potentially producing a tendency towards a flatter arch in deeper prints.

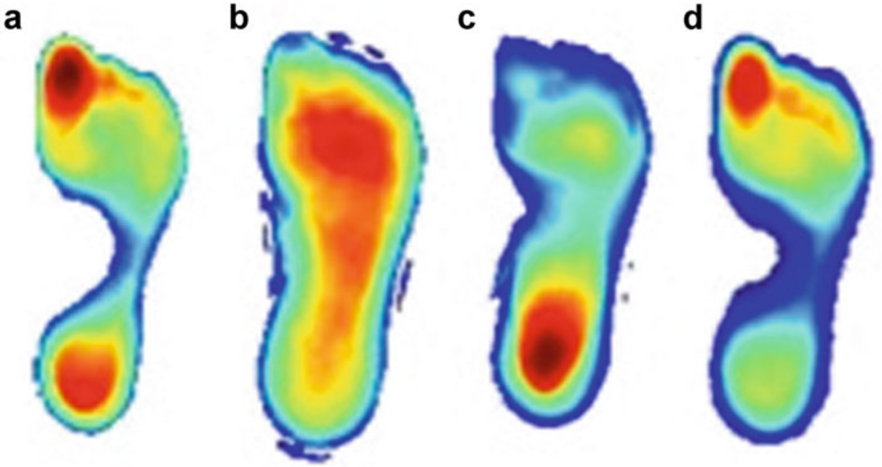

Fig. 3.7 Non-linear registration of (**a**) modern human; (**b**) Ileret; (**c**) Laetoli; (**d**) Holocene human means registered to the Namibian mean

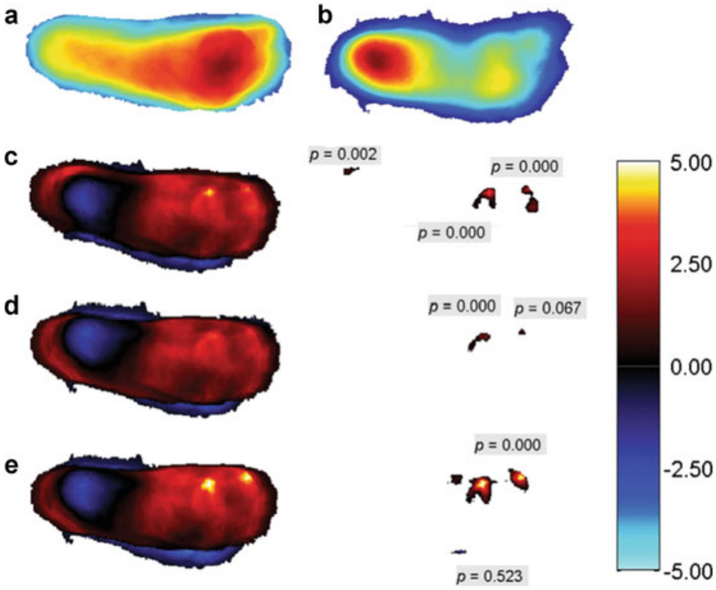

Fig. 3.8 Stage after registration to the reference mean, here Namibia, when individual prints are re-registered to the non-linear mean templates and the means regenerated

However, the methodology used in this analysis helps mitigate these influences. Principally, we are able to compare whole footprint populations on the basis of measures of central tendency rather than by comparing individual prints, which may show strong individual substrate influences (Leakey and Harris 1987; Bennett et al. 2016; Morse et al. 2013). For cross-site comparisons it subsequently becomes important that the range of sedimentological properties exhibit overlap (i.e. in terms of their geomechanical strength), thereby isolating biological (anatomy and gait) similarities and differences that impact on footprint form. It is important to note that these sedimentological conditions may not directly or obviously translate into sediment characteristics that are easily measurable in the geological record, such as average grain size, sorting or composition. Broadly similar geomechanical properties (e.g. bearing capacity, Poisson ratio, etc.) may be produced by different combinations of physical sediment characteristics (Craig 1997). There is no doubt that further experimental work is needed to explore the influence of sedimentology on footprint form (and the range of variables that define a sediment's rheology). However, we suggest that in the absence of this experimental work, and a detailed mechanistic understanding, it is perhaps most appropriate to ensure comparisons are made on prints of overlapping depths since depth does appear to correlate with substrate strength (Bates et al. 2013; Morse et al. 2013).

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Chapter 4
Reproduce to Understand: Experimental Approach Based on Footprints in Cussac Cave (Southwestern France)

Lysianna Ledoux, Gilles Berillon, Nathalie Fourment, and Jacques Jaubert

Abstract The morphology of a track depends on many factors that must be considered when interpreting it. An experimental approach is often required to understand the influence of each of these factors, both at the time of the track formation and after its formation. These aspects, which are fairly well documented for tracks found in open-air settings, are much more limited for those found in karst settings. Although caves are stable environments enabling the preservation of archaeological remains, many taphonomical processes can alter the grounds and the walls. Based on the observations made on footprints found in Cussac Cave (Dordogne region of southwestern France), this study focuses on one of these natural phenomena and tests the impact of flooding episodes and the resulting clay deposits on the track's morphology and topography. Our experiments show that although the general morphology of footprints and some details such as digits are preserved, their topography is altered by successive flooding episodes and clay deposits. The loss of definition of the footprints due to flooding episodes can also lead to misinterpretation. This work sheds new light on the Cussac footprints, while the further development of such experiments will allow us to improve our results and apply them to other settings and sites.

Keywords Taphonomy · Footprint · Cave · Palaeolithic · Experimentation

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Introduction

Tracks are among the most fragile and underestimated of archaeological remains, yet they provide a valuable source of information on site frequentation. They are the direct representation of a particular event in an individual's life, the marker and proof of human or non-human passage through a place. They offer an essential insight into the biology, locomotion, behaviour or activities of trackmakers. In the absence of other remains, tracks may even be the only elements enabling an exploration of the frequentation of a site.

Over the last few decades, and recently, palaeoichnological studies have been regularly conducted in open-air settings and have benefited from the development of new recording and analysis techniques (Mietto et al. 2003; Berge et al. 2006; Webb et al. 2006; Aramayo 2009; Bennett et al. 2009; Raichlen et al. 2010; Felstead et al. 2014; Ashton et al. 2014; Burns 2014; Bennett et al. 2016; Masao et al. 2016; Panerello et al. 2017; Wiseman and De Groote 2018; Altamura et al. 2018; McLaren et al. 2018; Smith et al. 2019; Moreno et al. 2019). In cave settings, they reached their peak between the 1970s and the early 2000s but were less developed (Duday and Garcia 1985, 1986; Garcia 1986). Human and non-human tracks have been documented and studied in the caves of Niaux (Clottes and Simonnet 1972; Pales 1976; Garcia et al. 1990), Pech Merle (Duday and Garcia 1983), Foissac (Garcia and Duday 1983), Aldène (Ambert et al. 2000; Ambert et al. 2001) and Chauvet Pont d'Arc (Garcia 2001, 2005). Recently, interest in ichnology in the karst setting has re-emerged among prehistorians, who have resumed the study of tracks in several ornated caves such as the Tuc d'Audoubert (Bégouën et al. 2009; Pastoors et al. 2015; see Pastoors et al. Chap. 13), Pech Merle (Pastoors et al. 2017), Aldène (Pastoors et al. 2015; see Galant et al. Chap. 15), Cussac (Ledoux et al. 2017; Ledoux 2019), Fontanet (Pastoors et al. 2015; Ledoux 2019), Bàsura (Citton et al. 2017; Romano et al. 2019; see Avanzini et al. Chap. 14) and Ojo Guareña (Ortega Martinez et al. 2014; see Ortega et al. Chap. 17).

Given the variety of factors that are likely to have impacted the morphology of hominin tracks (from the biology of the trackmakers to the nature of the substrate and taphonomic agents), experimental approaches have been developed, especially over the last decade, inspired by the work done on non-hominin tracks (Sollas 1879; Brand 1996; Gatesy 2003; Milàn and Bromley 2007).

The first studies were those conducted by Léon Pales, who observed variations in the footprints of the same trackmaker according to the sediment and the foot dynamic (Pales 1976). These works related to karst were pioneering and have no equivalent in this type of setting. Subsequent experiments focused on the footprints of early hominins in open-air settings and were developed within comparative and functional perspectives. Since the year 2000, an increasing number of experimental works have been conducted in response to the development of new tools (pressure pad for the recording of plantar pressure and 3D surface recording techniques such photogrammetry or optical laser scanning). The properties of the formation sediment are also central (Pataky et al. 2008a; Pataky and Goulermas 2008; Pataky et al.

2008b; D'Août et al. 2010; Crompton et al. 2012; Bennett et al. 2013; Morse et al. 2013; Hatala et al. 2013; Bennett and Morse 2014; Hatala et al. 2018; Zimmer et al. 2018). However, the potential impact of taphonomical agents remains poorly investigated and has been examined in open-air settings (Marty et al. 2009; D'Août et al. 2010; Bennett and Morse 2014; Roach et al. 2016; Panerello et al. 2017; Hatala et al. 2018; Wiseman and De Groote 2018).

Although varied in their objectives and contexts, these studies demonstrate that our interpretations of tracks require a better understanding of both the formation and the conservation setting. Each track is unique, and the objective of the ichnological study is to understand the factors behind this uniqueness. Despite increasing interest in the study of tracks in caves (Ortega Martinez et al. 2014; Pastoors et al. 2015; Pastoors et al. 2017; Citton et al. 2017; Ledoux 2019; Romano et al. 2019), ichnology in Palaeolithic caves is still little known and the formation and conservation context of these caves poorly studied. Here we present our first results drawn from experiments focusing on the impact of flooding on human footprints. This natural phenomenon has been observed in Cussac Cave (Ledoux 2019) and is recurrent in the cave setting.

The Karst Setting

Formation

As with the open-air setting, the morphology of a track produced in cave depends on the sediment and the trackmaker. Tracks are the result of the compression of sediment in response to a constraint exerted by a trackmaker; the original morphology of tracks therefore depends on both the trackmaker (locomotion, biology, behaviour, etc.) and the formation sediment (physical and mechanical properties, topography, etc.). Over time, this original morphology will be influenced by various taphonomic phenomena (erosion, bioturbation, filling, etc.). The interpretation of tracks must therefore be based first and foremost on a knowledge and understanding of their setting.

However, a third parameter can influence this morphology: the geomorphology of the karst. The movements and behaviour of trackmakers will then be highly dependent on the topography of the ground and the morphology of the walls, the height of the ceilings and the width of the network. Consequently, the resulting tracks will have a particular morphology whose interpretation will also depend on how well the trackmaker's perception of the cave is understood.

While tracks found in open-air settings generally belong to trackways, those found in caves are much more varied. Testimonies of intentional or non-intentional actions, these tracks are characterized by complete (foot, hand, knee, etc.) or partial (fingers, toes, heels, etc.) body segments. Often associated with wall traces (torch, colour or clay marks), they are the result of a variety of behaviours that are influenced either by the geometry of the cavity or by the activities that took place inside them (Bégouën et al. 2009; Pastoors and Weniger 2011; Arias et al. 2011; Ledoux et al. 2017; Medina-Alcaide et al. 2018; Romano et al. 2019).

The surface soils of a cave may have different characteristics depending on the area (various clastic sediment deposits with different sedimentary properties, calcite deposits, etc.). It may therefore be difficult to attribute several tracks to a single trackmaker if they are not produced in the same area, especially where isolated tracks are concerned.

Preservation Context

The stability of caves makes them ideal environments for the preservation of the most fragile archaeological remains, as is very well reflected in rock art. However, despite their exceptional conservative properties, caves may be subjected to taphonomical processes during their lifetime. These phenomena are varied and are generally classified into two categories (Fig. 4.1):

- Natural phenomena including sediment fillings (various sedimentary deposits), flooding, calcite deposits, erosion, desiccation, etc.
- Non-natural phenomena including trampling, track superimpositions, excavation, etc.

The same track may have been altered by one or more of these taphonomic processes. Therefore, the karst setting must be understood before the tracks can be interpreted.

Cussac Cave

Contextual Setting

Discovered in 2000 by the speleologist Marc Delluc, Cussac Cave is located south of Périgord in Dordogne (southwestern France). It opens onto a Campanian limestone cliff on the right bank of the Belingou, a tributary of the Dordogne River. It extends along some 1.6 km in a single sub-horizontal gallery divided into two parts: the Downstream Branch and the Upstream Branch (Fig. 4.2). This particularly well-preserved cave is characterized by parietal engravings and human remains deposited in bear hibernation nests, both associated with varied traces of human and non-human activity (Aujoulat et al. 2001, 2002, 2013; Fourment et al. 2012; Jaubert et al. 2012; Henry-Gambier et al. 2013; Jaubert 2015; Ledoux et al. 2017). All archaeological remains (art, charcoal, human bones) are attributed to human occupation in the Middle Gravettian period (20–28 ka calBP) (Jaubert et al. 2017). Since 2008, a multidisciplinary team has been studying the cave in order to gain a global understanding of the site. During the first few years of research, a pathway was

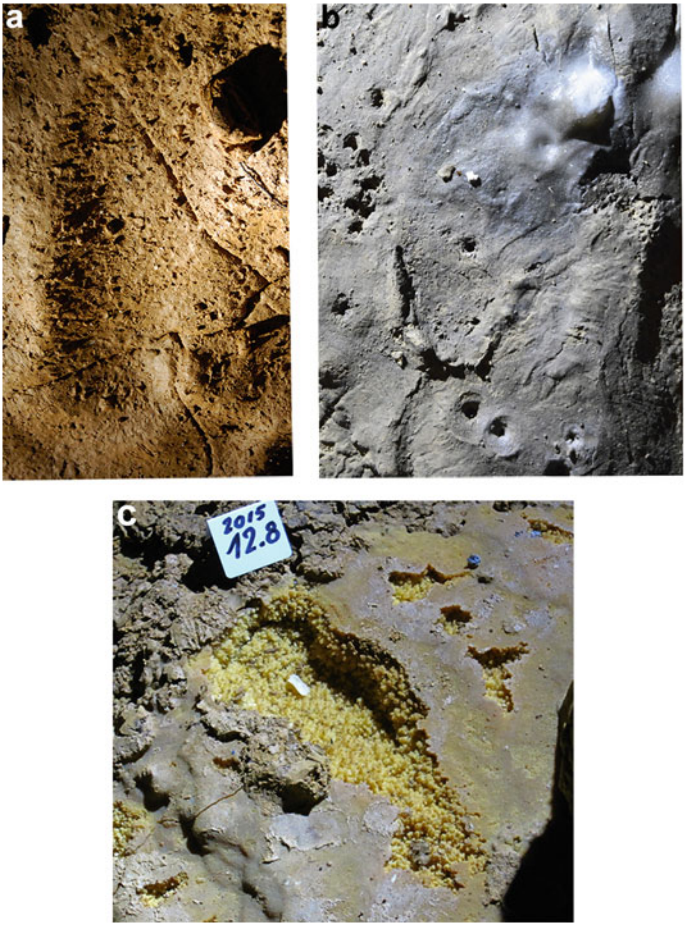


Fig. 4.1 Examples of taphonomical processes occurring in karst settings; (**a**) human footprint covered by clay deposits in Cussac Cave (Dordogne, France); (**b**) human footprint covered by concretion in Fontanet Cave (Ariège, France) (Ledoux et al. 2017); (**c**) bear manus track transformed into rimstone in Bruniquel Cave (Tarn-et-Garonne, France)

marked throughout the cave, following the one first taken by the discoverer. The aim of maintaining this single pathway is to ensure optimum preservation of the cave floors and walls.

Tracks at Cussac and Taphonomy

Although the cave is very well preserved, the current floors are not exactly the same as they were in the Palaeolithic. Consequently, few tracks have been clearly

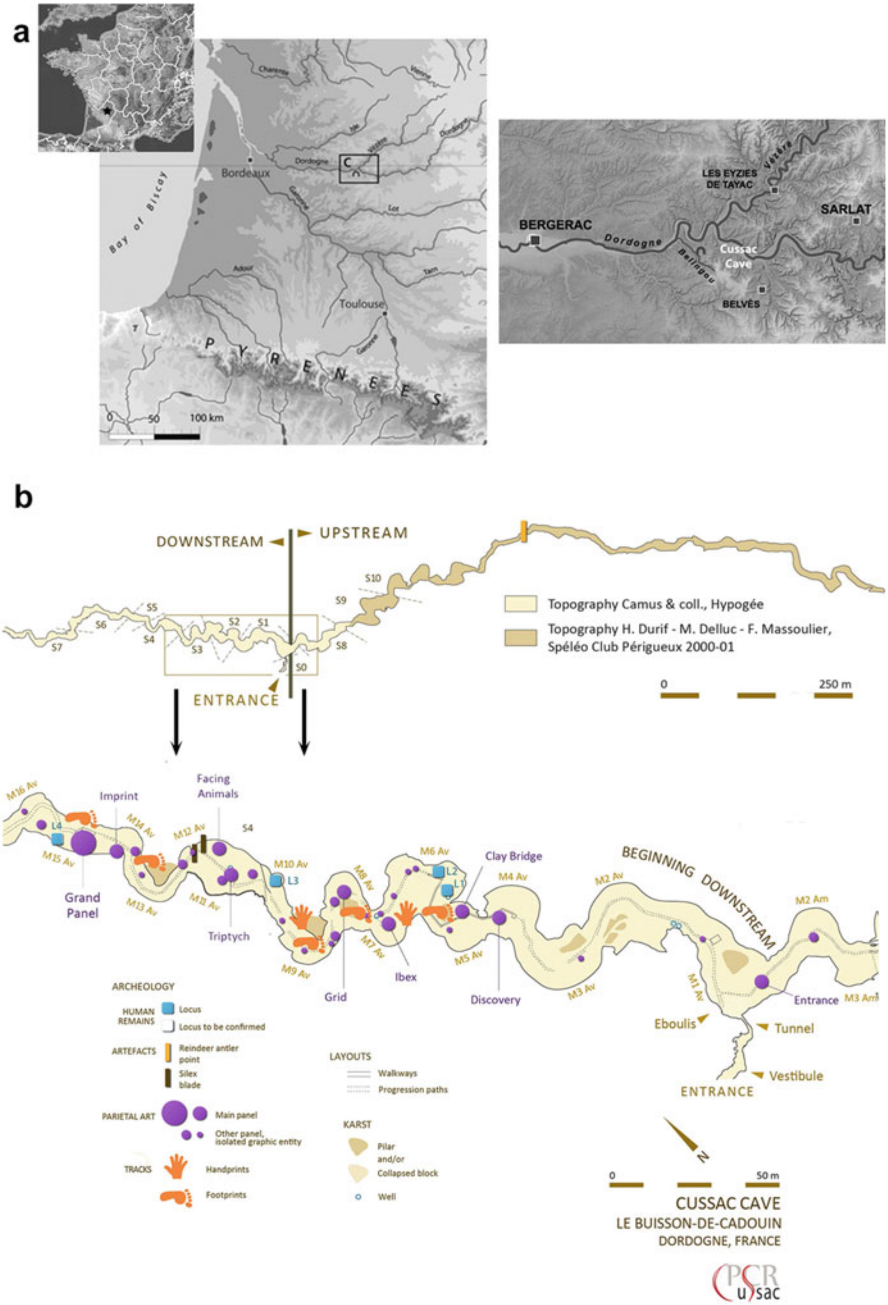


Fig. 4.2 (**a**) Geographic location of Cussac Cave; (**b**) general topography of Cussac Cave and close up of the part of the cave under study

identified as human tracks. Several factors may explain this poor preservation of the Palaeolithic cave floors (Ledoux et al. 2017; Ledoux 2019):

- Geological factors: after human occupation, the cave underwent various sedimentary events which significantly damaged the floors (sedimentary deposits, erosion, flooding, desiccation cracks, etc.).
- The omnipresence of bears in the cave. Bear tracks and human tracks are superimposed in several areas.
- The restricted accessibility of some areas due to the conservation policy.
- The current pathway which is, in some areas, probably the same as the Palaeolithic pathway.

As a consequence of these various taphonomical processes, most of the complete footprints are isolated and often altered (Fig. 4.2). Below we present the experiment carried out on the basis of one of these taphonomical phenomena, frequently observed in caves: the overflow of the subterranean river. In some areas of Cussac Cave, several flooding episodes occurred after human frequentation, covering tracks with clay (Fig. 4.1a). Through a controlled experiment, we intend to test the impact of clay deposits on the morphology and topography of footprints after flooding episodes. Assuming that water and sediment affect the contours and the general surface of the footprints, our purpose is therefore to follow the evolution of a footprint from immediately after its formation to its covering by clay deposits.

Materiel and Methods

Experimental Protocol

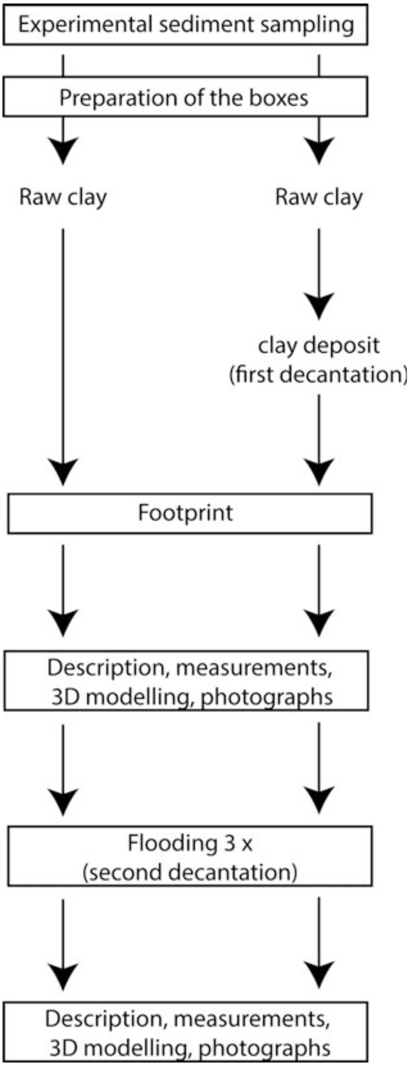
Experimental footprints were made in a cohesive, firm and moist sediment that we selected for its high clay content, similar to that of Cussac. It allowed for the impression of an entire foot. This sediment was sampled from a cave in the Dordogne region of southwestern France without any archaeological remains (Table 4.1).

From this sediment, two types of formation surface were used: one of raw clay with a moisture content of about 50% and one of raw clay covered with a second level of clay that had settled after flooding (called the first decantation) (Fig. 4.3) and

Table 4.1 Grain size analyses of the sediment sampled in Cussac Cave and in the experimental cave

Samples	Fine sand (%) (500–63 μ)	Coarse silt (%) (63–16 μ)	Fine silt (%) (16–7 μ)	Clay (%) (<7 μ)
Cussac	2.56	18.99	22.59	55.85
Experimental cave	2.8	10.78	30.42	56

Fig. 4.3 Experimental steps



with a moisture content varying between 60% and 70% (Fig. 4.3). Before creating the second substrate, we tested the impact of different sediment loads (60 g/l, 80 g/l and 100 g/l) from the first decantation on the morphology of the tracks.

Experimental footprints were made by two people: a female individual with a height of 1.69 m, weighing 55 kg and with a foot length of 24 cm, and a male individual with a height of 1.80 m, weighing 75 kg and with a foot length of 24 cm. The footprints were made in boxes of identical dimensions: 50×40×25 cm.

The second step consisted in covering the footprints with water (1.5 l) that contained a defined sediment load (called the second decantation). Based on the scenario that the cave suffered several low-power floods, the first substrates of three sediment loads were arbitrarily selected and tested (20 g/l, 40 g/l and 60 g/l) to see whether there were any noticeable differences after the last flooding episode. As the second substrate was less cohesive and less stable, it was more difficult to control for its properties. We therefore chose to keep the three sediment loads in order to understand more broadly the variability of the footprints in this type of sediment.

A maximum of three flooding episodes were carried out for each footprint.

Finally, out of a total of 19 footprints, 8 were selected for the comparative analysis. The remaining 11 are the tracks made when our experimental protocol was established.

During the decantation process, the footprints were kept in a relatively stable environment (21°C and 50–85% humidity according to the weather conditions outside). The aim was to avoid excessively rapid drying and potential desiccation cracks.

Descriptions, Metrics and 3D Models

After each step, the footprints were described in detail, distinguishing two aspects: the general morphology, which concerns the shape and the outline of the footprint, and its topography, related to its elevation and the state of its surface. In addition, seven measurements considered as most indicative of the print morphology were recorded: length 1 (distance between the most distal point of the hallux and the most inferior point of the pternion), length 2 (distance between the most distal point of the second toe and the most inferior point of the pternion), length 3 (distance between the most distal point of the forefoot and the most inferior point of the pternion), digits width (distance between the most medial point of the hallux and the most lateral point of the last toe), distal width (distance between the most medial point and the most lateral point of the forefoot), middle width (distance between the most medial point and the most lateral point of the longitudinal arch) and proximal width (distance between the most medial point and the most lateral point of the heel). They were photographed using a Nikon D7100 with a 60 mm focal length lens. Then each footprint was 3D digitized using an Artec EVA 3D light scanner 2013 (Artec Group, Luxembourg). This scanner uses the structured light triangulation technique to reconstruct a 3D model of the footprint. The accuracy achieved by this scanner is 0.5 mm at a working distance of 40 cm to 1 m, and the 3D resolution goes up to 0.1 mm. The scanner takes up to 16 frames per second and transfers them to the Artec Studio software (Modabber et al. 2016) which aligns the frames in real time.

Post-processing was performed on the Artec Studio 9 software, which recreated a colour texturized 3D mesh.

The 3D models of the footprints at different moments of the experiment were visualized and compared with CloudCompare (2.8.1.). We used part of the standard protocol proposed by Falkingham et al. (2018) to record, present and archive our 3D data. The true colour image, depth map and contour map (range of 0.5 mm) were therefore created for each footprint.

For the comparative analysis, clouds of each footprint were aligned using the CloudCompare Align tool. The multiscale Model to Model Cloud Comparison algorithm (M3C2) (Lague et al. 2013) was then used. It computes the local distance directly between two point clouds along the normal surface direction. For each distance measurement, it calculates a confidence interval based on the point cloud roughness and coregistration error. This computation serves to evaluate morphological 3D changes in surface orientation. These changes are expressed in colourized texture from the reference point cloud.

Results

Formation Sediment and Flooding Sediment Load

Formation Sediment

The tests carried out in order to verify the impact of different sediment loads (60 g/l, 80 g/l and 100 g/l) from the first decantation on the morphology of the tracks do not show any obvious differences between the footprints made on these three sediment loads. Since the general morphology and topography did not seem to vary, we used the average load of 60 g/l for subsequent experiments (Fig. 4.4a).

Flooding Sediment Load

No obvious differences were identified between the three sediment loads (20 g/l, 40 g/l and 60 g/l) tested on the footprints made in the first substrate, particularly as regard the loads of 40 g/l and 60 g/l. The average load of 60% was therefore used for subsequent experiments (Fig. 4.4b).

General Morphology

The original experimental footprints are well defined and complete, regardless of the formation sediment and the trackmaker. The distal and proximal parts are the deeper ones. Although the middle part is shallower, the medial longitudinal arch is generally well defined. Digit prints are also easily distinguishable throughout our sample (Figs. 4.5a, b, c, 4.6a, b, c).

Experimental flooding affects the footprints' morphology in several ways. The medial part of the footprint is the first to disappear after flooding episodes, irrespective of the formation sediment and the sediment load. After the third

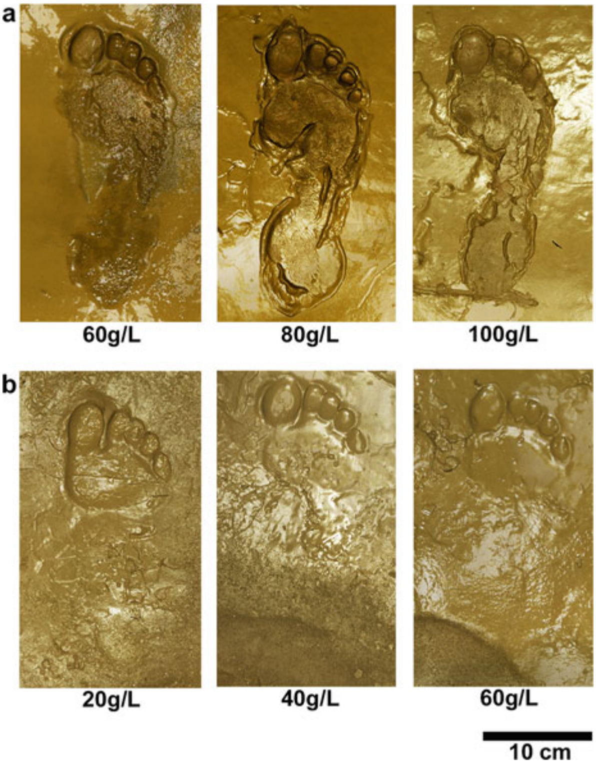


Fig. 4.4 (**a**) Footprints made on the second surface, no obvious difference according to the sediment load used; (**b**) footprints made in raw clay and covered with clay deposit after three flooding episodes, no obvious difference according to the sediment load used

flooding, this part is no longer visible on any print. The proximal part of the footprint is the second part to disappear after flooding episodes. After the last flooding, this part remains on two prints only. The distal part is the one that persists the longest throughout the flooding episodes. Five footprints retain their distal part after the last flooding. Within this part, the forefoot tends to be less visible more frequently than the digits. The hallux is the most persistent of the digits (Figs. 4.5d, e, f, 4.6d, e, f).

Generally, the flooding causes a loss of definition of the contours of the prints, which could have distorted the way they were perceived when measurements were taken. However, the many flooding episodes only modify the dimensions of the remaining areas by a few millimetres. For some footprints, the measurements of certain areas were sometimes over- or underestimated (Table 4.2). The footprint made by individual 2 in the second surface, flooded with water loaded with 80 g/l of sediment, is very representative, with a length that varies by almost 4 cm between the original experimental footprint and the remaining part of it after the first flooding (Table 4.2).

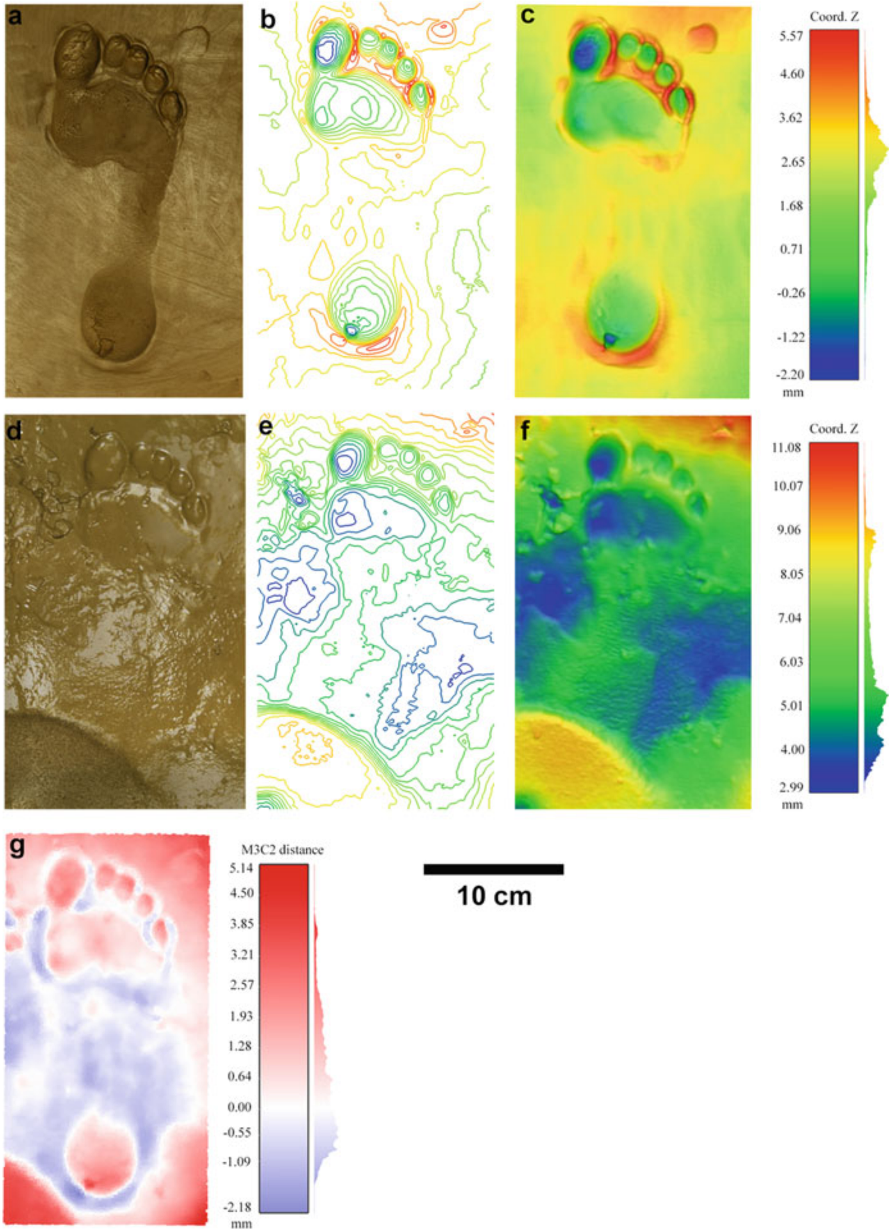


Fig. 4.5 Footprint made in the first surface by individual 1 and flooded with water containing a sediment load of 60 g/l; (**a**) first step, true colour image; (**b**) first step, contour map; (**c**) first step, depth map; (**d**) third flooding, true colour image; (**e**) third flooding, contour map; (**f**) third flooding, depth map; (**g**) M3C2 distance between the first step (original footprint) and the last step (after the third flooding)

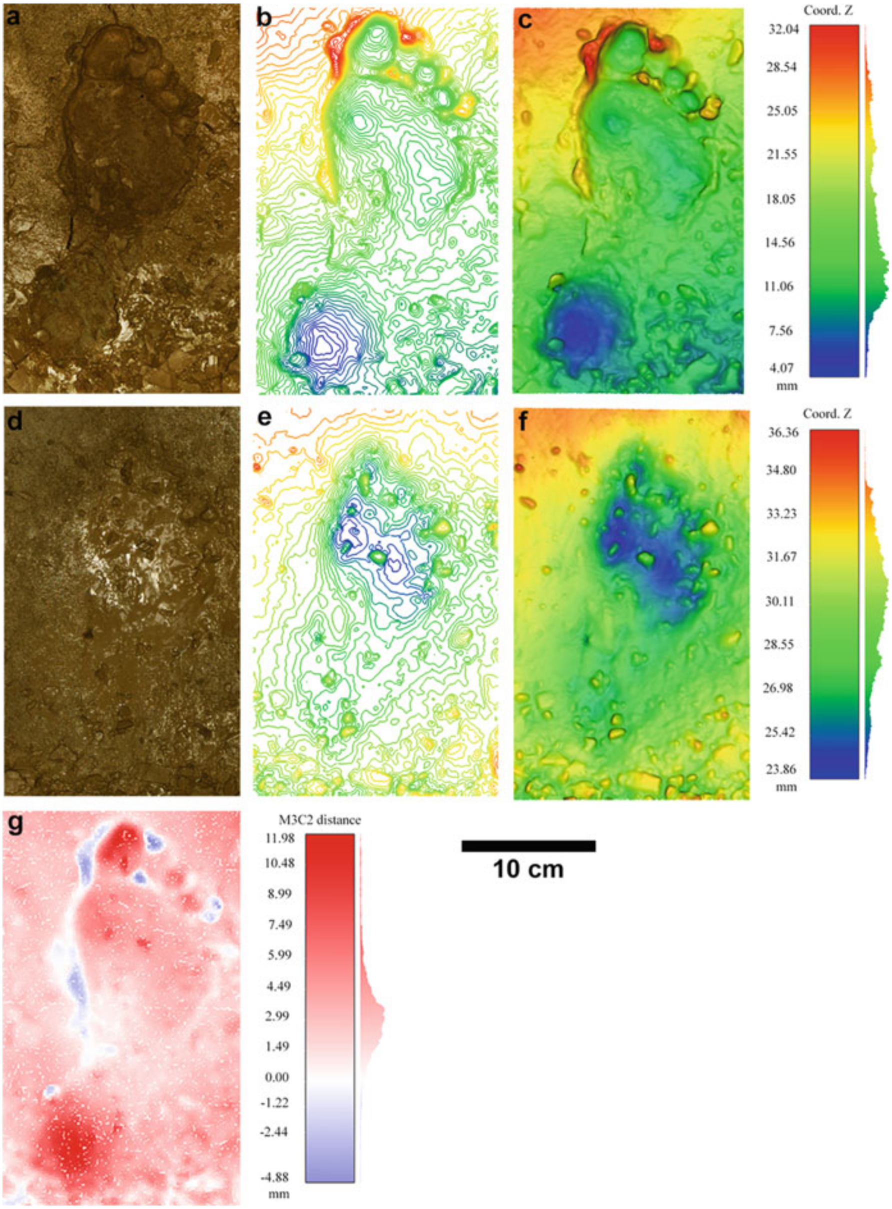


Fig. 4.6 Footprint made in the second surface by individual 2 and flooded with water containing a sediment load of 60 g/l; (**a**) first step, true colour image; (**b**) first step, contour map; (**c**) first step, depth map; (**d**) third flooding, true colour image; (**e**) third flooding, contour map; (**f**) third flooding, depth map; (**g**) M3C2 distance between the first step (original footprint) and the last step (after the third flooding)

Table 4.2 Biometry of the experimental footprints (cm)

Surface	SL	I	Step	FL 1	FL 2	FL 3	FW distal	FW middle	FW proximal	FW digits
First surface	60 g/l	1	1	23.8	23	19.9	8.5	3.2	5.3	9.5
			2	23.3	22.4	19.4	8.3		5.3	9.6
			3	23	22.3	19.8	8.5		5.5	9.5
			4				8.5			9.5
		2	1	24.7	24.3	20.8	10		4.7	9.5
			2				9.7			9.5
			3				9			8.5
Second surface	40 g/l	1	1	23.7	23.5	20.4	8.5	4.2	5.3	9.0
			2	23.4	22.4	20.7	8	4.5	5.2	9.3
			3				7			9
			4				7			8.4
		2	1	25.2	23.3	21	11.2	3.3	6.4	9.7
			2	25.5	24.4	20.7	10.7		5.3	10.6
			3				7			9
			4				7			8.4
	60 g/l	1	1	24	23.7	20.4	10.2	6.2	6.2	10.5
			2	24.4					4.5	
		2	1	24	23.4	20	10.9	3.5	6	10.3
			2	23	22.5	19.2	10.4		4.5	10.2
			3				10.6			10.2
			4				9.2			9
	80 g/l	1	1	23.6	22.9	20	8.9	5.1	5.7	9.6
			2	23.5	22	19.4	8.2	5	5.6	9.6
			3	23.1	22	20.1	8.1	4.6	6.5	9.4
		2	1	24.9	24	21.4	10.9	5.2	5.7	10.5
			2	21.4	20.7	20	10.5	5.3	4.9	10.4

FL foot length, *FW* foot width, *I* individual, *SL* sediment load

Topography

Original Experimental Footprints

The original experimental footprints made in the second surface are deeper than those made in the raw clay.

For the footprints made in raw clay, raised rims are observed around the margins of the digits, between the digits and the forefoot and sometime in the proximal part of the heel (Fig. 4.5a, b, c).

For the footprints made in the second surface, prominent raised rims associated with sediment displacement around their margins are more common (Fig. 4.6a, b, c).

These pronounced raised rims and the lack of cohesion of this substrate sometimes led to the detachment of sediment plates (Fig. 4.6a, b, c).

Footprint Evolution

Following flooding, the topography of the footprints was affected. The M3C2 algorithm allowed us to compare the surface changes of a single track between two steps. This analysis reveals that footprints are filled up by clay deposits whose thickness depends on the prints and the surface area of the prints (Figs. 4.5g and 4.6g).

For the footprints made in the first surface, the deposits that formed on the surface never exceed 10 mm after the last flooding (Fig. 4.5g).

For the footprints made in the second surface, the infilling is more complex (Fig. 4.6g). In addition to clay deposits, footprints are often filled up by detached sediment plates; infillings can then reach 20 mm.

In both surfaces, the majority of the areas affected by the infillings are most often the deepest, such as the forefoot, the digits and the heel. The relief of the margins of the prints tends to decrease. Raised rims were flattened out and sediment plates eroded (Figs. 4.5g and 4.6g).

All footprints lose definition after flooding episodes, and their margins are less easily identifiable. In general, impressions made in the second surface appear to be more markedly altered than those made in the raw clay (Fig. 4.6d, e, f, g).

Discussion

Our experiments demonstrate that low-power floods do not modify the general morphology of the prints, regardless of the formation sediment and the sediment load used. However, as highlighted by the M3C2 algorithm, their topography is altered by the clay deposits and a reduction in the relief of their margins. Some detached plates resulting from the erosion of raised rims may also fill up the footprints, particularly those made in the second surface. This detachment and displacement of sediment is likely caused by the lack of cohesion of the substrate due to its high moisture content: the higher the moisture content of the sediment, the less cohesive it is. It may also be due to the lack of cohesion between the two levels of the second surface. These characteristics make the surface more fragile, and the track may be modified during flooding. Therefore, flooding episodes contribute to the loss of track definition, and the forefoot and digits are generally the most persistent areas.

These experiments also highlight that the use of biometric data on footprints to infer biological characteristics such as sex, age, stature or body mass remains an uncertain exercise. The lack of track definition and the taphonomical processes can lead to measurement errors of several centimetres. These results are consistent with previous taphonomic studies carried out on tracks found in open-air settings (Wiseman and De Groote 2018; Zimmer et al. 2018). Based on the Holocene site of Formby Point (North West England) for the former and the Pleistocene site Engare Sero (Tanzania) for the latter, they perfectly illustrate and quantify the erosional processes that occur immediately after track exposure. Both conclude that erosion-related changes to tracks influence biological inferences. Previous studies have also demonstrated the uniqueness of tracks and the crucial role of the substrate in which they were formed (Pales 1976; Marty et al. 2009; Morse et al. 2013; Bennett and Morse 2014). Furthermore, it is known that a single trackmaker could produce a range of footprints with various morphologies according to the sediment on which they were formed (Morse et al. 2013; Bennett and Morse 2014). It has also been demonstrated that footprints are almost systematically larger than the feet that made them (Pales 1976; Hatala et al. 2018). Additionally, most inferences are based on modern reference populations. Regarding fossil tracks, there is no guarantee that the reference population used is representative of past variability (Bennett and Morse 2014). Although inferences made on tracks should be used with caution, they provide some insights for interpretation purposes. Experiments are therefore a useful tool to approximate the original shape of a track as closely as possible and/or to understand its alterations (Bennett and Morse 2014; Falkingham et al. 2018).

This work, based on observations made on the footprints found in Cussac Cave, provides some insights into the taphonomical effects of flooding events on the morphology and topography of footprints. Experiments based on taphonomical phenomena are still limited and mainly concern tracks found in open-air settings (Marty et al. 2009; Scott et al. 2010; Morse et al. 2013; Bennett and Morse 2014; Roach et al. 2016; Wiseman and De Groote 2018). The major difference between tracks found in open-air settings and those found in caves is probably the speed of taphonomical processes affecting them. Studies of tracks found in open-air settings have shown that a multitude of taphonomical processes (weather condition, bioturbation, properties of the sediment, etc.) preceded the burial and the diagenesis of the tracks. Consequently, their morphology was rapidly altered (Marty et al. 2009; Scott et al. 2010; Bennett et al. 2013; Wiseman and De Groote 2018; Zimmer et al. 2018). Additionally, their exposure led to degradations (Wiseman and De Groote 2018; Zimmer et al. 2018). Conversely, caves are stable environments allowing a high degree of track preservation. While tracks found in caves may be altered, it is assumed that they are disturbed less than those found in open-air settings. However, our work has demonstrated that although the damage to the footprint does not substantially alter its general morphology, its loss of definition or the destruction of certain parts can lead to unreliable interpretation.

Our analysis was based on 3D data. These techniques have become crucial in the study of ornated caves and are now replacing casts and other recording methods. They are most often used for conservation purposes and to encourage ex situ studies. They are also essential as they provide a precise picture of human and animal use of caves (Ortega Martinez et al. 2014; Pastoors et al. 2017; Citton et al. 2017; Ledoux 2019; Romano et al. 2019). Here we used the M3C2 algorithm (Lague et al. 2013) in order to quantify the surface changes to single footprints between each step. The same algorithm was used to quantify the ongoing erosion of the Engare Sero tracks (Zimmer et al. 2018). So far, most of the tools developed in ichnological studies have been based on the biomechanics of hominin locomotion. Consequently, these studies are more focused on the nature of the formation substrate and its interaction with the foot (Crompton et al. 2012; Morse et al. 2013; Hatala et al. 2018). While some tools such as pedobarographic statistical parametric mapping (pSPM), based on the comparison of pressure at the substrate-foot interface and footprint depth (Pataky et al. 2008a; Crompton et al. 2012; Morse et al. 2013) or biplanar X-rays studying the 3D dynamics at the foot-substrate interface, have focused on the formation of tracks to infer foot anatomy or biomechanics data (Hatala et al. 2018), the M3C2 algorithm focused on the evolution of these tracks over time. The application of such methods is then useful to complement qualitative observations and can help to understand certain taphonomical processes such as erosion or sedimentation.

While the experiment presented here provides promising data on the impact of clay deposits on the morphometry of a footprint, our sample was limited, and we only explored and controlled a few parameters. Additionally, these parameters do not necessarily extend to all caves and all tracks. The future integration of a larger sample of tracks produced by a larger number of trackmakers, in a variety of sediments combined with varied sediment loads contained in the flooding water, will undoubtedly further substantiate our results. This would also allow researchers to create reference tracks for each possible setting that could be used to study the tracks of different sites. Many phenomena and their influence on the morphology and biometry of tracks found in karst settings have yet to be documented: these experiments are the first step in the development of more experimental work. The creation of artificial flooding on the very limited surface of the box does not accurately reflect the reality of the overflow of a subterranean river. It would therefore be appropriate to carry out experiments directly in karst settings. One of the advantages of laboratory experiments is that they make it possible to recreate taphonomical phenomena in a very short time. However, the more complex the phenomenon, the more difficult it will be to control. Although this requires much more time, it would therefore be better to follow the evolution of tracks in real conditions and also taking the geometry of the cave into consideration.

Our results demonstrate that flooding and subsequent clay deposits in some areas of Cussac contributed to the lack of visibility of tracks. However, they do not explain the lack of details in Cussac's tracks. Only one complete footprint could be interpreted as undoubtedly human in the submerged areas (Fig. 4.1a). Although its outline is clearly visible with all the foot areas represented (forefoot, longitudinal arch and heel), no detail is apparent. These experiments show that clay deposits did not radically modify the morphology of the footprints and allowed the preservation of certain details such as digits, regardless of the formation sediment and the sediment load used. Additionally, the existence of low-power floods has been proven at Cussac. Apart from the clay deposits and some desiccation cracks, the floor does not seem to have suffered any other alteration. In our experiments, what seems to have had the most significant impact is the lack of cohesion of the second surface due to its high moisture content and its level of clay resulting from settling, causing the raising and displacement of sediment plates on the surface during water infiltration. However, this phenomenon did not occur at Cussac. The next step will therefore be to understand this lack of detail. Is it due to flooding or another taphonomical phenomenon? In addition to flooding, the areas involved were intensively trampled by bears, so discrimination between the two species is a challenge. By continuing our experiments, we hope to improve the determination of the prints present in these problematic areas.

Conclusion

As very few experimental works have been carried out in caves, this study will emerge as original in this type of setting. It brings new data on the taphonomy of tracks when they are subjected to flooding. Although flooding does not modify the general morphology of the tracks, their topography is altered by successive episodes and clay deposits. However, the loss of track definition and the taphonomical processes can lead to unreliable interpretation and measurement errors of several centimetres. Inferences on fossil tracks should therefore be made with caution. Our experiments were based on taphonomical phenomena observed in Cussac Cave. Although we do not yet have all the means to reliably interpret the tracks of Cussac, a larger sample involving more parameters and in situ experiments will undoubtedly allow us to refine our results and apply them to other caves.

Tracks are a significant testimony of the frequentation of caves by Palaeolithic people and their ability to adapt to an unsuitable or even dangerous environment. It is therefore essential to understand their history if we want to reconstruct past human behaviour and activities in caves and in Palaeolithic societies.

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Chapter 5
Experimental Re-creation of the Depositional Context in Which Late Pleistocene Tracks Were Found on the Pacific Coast of Canada

Duncan McLaren, Quentin Mackie, and Daryl Fedje

Abstract To better understand the depositional context of Late Pleistocene human tracks found at archaeology site EjTa-4 on Calvert Island, on the Pacific Coast of Canada, we present here the results of an experiment designed to recreate the conditions by which these tracks were formed, preserved and then revealed through excavation. Based on radiocarbon ages on small twigs and the analysis of sediments and microfossils, the interpretation of the site formation processes relate that the tracks were impressed into a clayey soil substrate just above the high tide line between 13,317 and 12,633 calBP. The features were subsequently encapsulated by black sand, which washed over the tracks from the nearby intertidal zone during a storm event. To test this interpretation, we enlisted the aid of high school student volunteers to recreate the conditions by which the tracks were formed. A clayey substrate was prepared in a laboratory setting at the University of Victoria and a few plant macrofossils were placed on top it. This was followed by having the students create tracks in the clay, which were then covered with a layer of sand. Upon excavation of these experimental tracks, we found that they had a very similar character to those found in the field, including the pressing of macrofossils into the clay by the weight of the track maker. These results support the interpretation and chronological assessment of the depositional events that occurred during late Pleistocene times at archaeology site EjTa-4.

Keywords Footprint · Experimentation · Open air · Monitoring

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Introduction

This paper follows up on archaeological findings of human tracks dating to the Late Pleistocene occupation of the Pacific coast of Canada (McLaren et al. 2018) (Fig. 5.1). These tracks were found in soft sediments beneath intertidal beach deposits on Calvert Island, British Columbia. A total of 29 tracks were identified and isolated during the excavation of a 4 × 2 m area at archaeological site EjTa-4 (Meay Channel I). Lodgepole pine twigs found on the track surface and pressed into the base of the footprint (referred to here as the true track) provide us with radiocarbon age estimates of 13,317–12,633 calBP (see Marty et al. 2009; Bennett and Morse 2014 for definition of track terms).

Archaeological site EjTa-4 is located on the western shore of Meay Channel, an inner and protected waterway situated between Calvert and Hecate Islands. Calvert Island features as a location in events related in the oral histories of the Heiltsuk (Olson 1955) and Wuikinuxv First Nations (Walkus et al. 1982). Some of the recorded oral histories from the region relate events, such as large-scale glaciation, that have not occurred since Late Pleistocene times (Gauvreau and McLaren 2016).

Ancient human track sites have not been widely reported in North America north of Mexico. There are some exceptions. For example, a recent publication describes a Late Pleistocene trackway in New Mexico which has associated human and giant ground sloth footprints dating between 15,500- and 10,000-year-old (Bustos et al. 2018). Willey et al. (2009) provide a summary of Holocene human footprints reported from North America, with a more recent discovery reported from Swan

Fig. 5.1 Location of archaeological site EjTa-4 on the Pacific coast of Canada

Point Alaska dated to 1840 calBP (Smith et al. 2019). Overall, however, human tracks appear to be an extremely rare site type across the continent.

Nearshore Late Pleistocene archaeological research on west coast of Canada requires a good knowledge of local relative sea level history (Clague et al. 1982; Fedje and Mathewes 2005; Fedje et al. 2018; Shugar et al. 2014). Due primarily to the dynamic interplay of isostatic and eustatic factors, sea level on Calvert Island was 2–3 m lower than today between 14,000 and 11,000 years ago (McLaren et al. 2014). The tracks at this site were discovered during subsurface testing below beach deposits. This subsurface testing was specifically targeting this lower shoreline and time period. However, we were not expecting to find human tracks.

Of the 29 individual tracks found, 18 were complete enough to take measurements of length and width (McLaren et al. 2018). These measurements fall into three broad categories of size (15.5 × 7; 20 × 9; and 25.5 × 11.5 cm), suggesting that a minimum of three individuals of different foot sizes left the tracks. The majority of tracks were found to be oriented towards the northwest or landward and away from the ocean. A few rough grained stone tools were found in the same stratigraphic layer.

The track surface is a light brown clayey paleosol that was located above the high tide line at the time of deposition (referred to as Stratum X). It is overlain by black pebbly sand which was washed up from the beach filling the tracks (Stratum IX). Based on our analyses of these strata, we interpret that the formation of these features involved a minimum of three people leaving footprints in a clayey area above the high tide line between 13,317 and 12,633 calBP. Later, by at least 12,640–12,576 calBP, a change in sea level, storm surge or tsunami event resulted in the dumping of sand and pea gravel onto the track surface thereby filling and capping the features. Overlying all of this are sandy gravels with late Holocene artefacts and bone (Strata VII through II), capped at the top by active sands just below the beach surface (Stratum I).

The contrasting colours between the track surface and the over track deposits enabled us to identify the true tracks. As our field crew excavated down through the black sand deposits into the more clayey deposits below, sediment displacement rims were the first indicators found (Fig. 5.2). Through careful and delicate excavation, the sediment rims were isolated revealing the tracks. In some cases, toe marks were clearly visible. Photographs were taken of each of the individual tracks, and contrast enhancement software was used to further reveal the features for publication (Fig. 5.3). Multiple photos of all the tracks found are included in the supplemental data that is associated with the original publication (McLaren et al. 2018).

Beyond providing information on the inhabitants that made these tracks, the findings are of significance as they have bearing on the Late Pleistocene occupation of North America. This is one of the earliest human occupational records on the Pacific coast of Canada and provides evidence of the early postglacial use of this part of the coast. Those who left the footprints at EjTa-4 could only have reached Calvert Island by means of watercraft. These inhabitants most likely had an economy that was heavily focussed on the marine environment, as did later populations in the region (Duffield 2017).

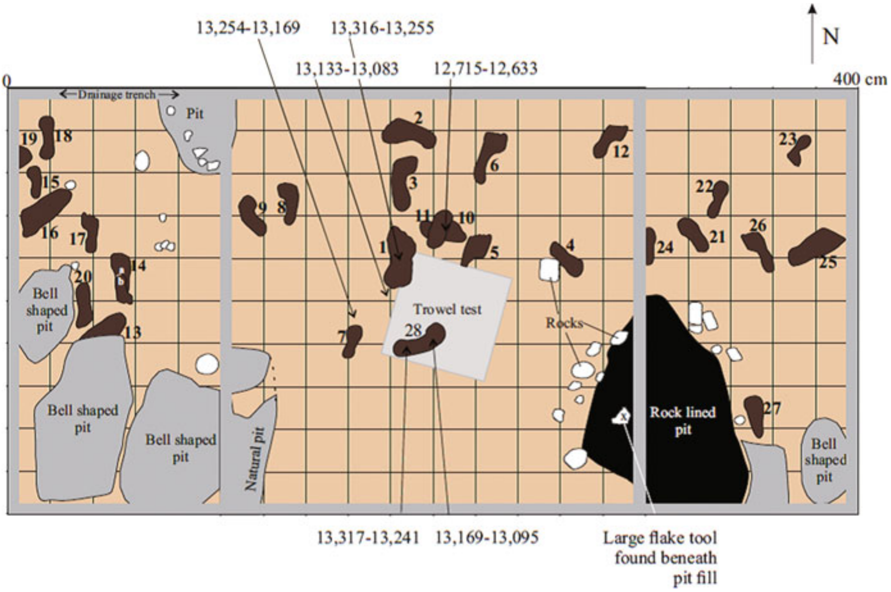


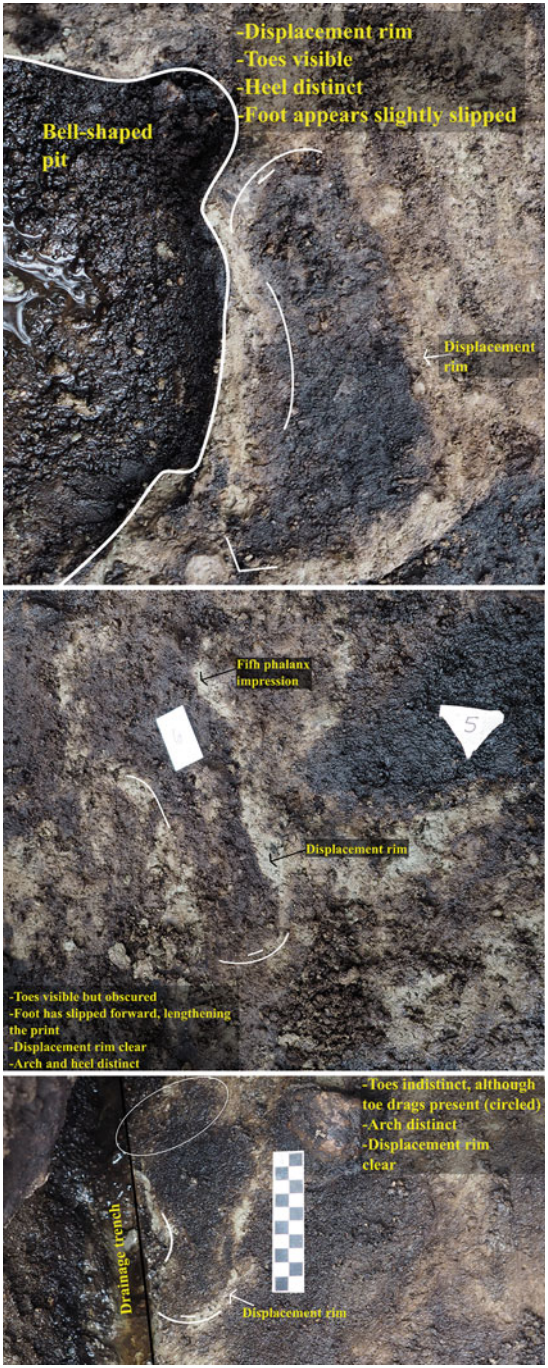
Fig. 5.2 Plan view of 4 × 2 m excavation unit and the locations and orientation of tracks and radiocarbon dates

As a part of the ongoing research associated with the discovery of these tracks, we undertook a lab-based experiment to see if we could recreate the sedimentary conditions in which the tracks were created and then buried. As a part of this process, the experimental footprints were excavated to compare our field findings with those in the lab. This primary goal of the exercise was to help understand if our site formation process interpretation was supported by experimental approach.

As a part of informing the public about aspects of our research, we have been working with school groups from local communities including Bella Bella, Oweekeno Village, Bella Coola as well as in and around Victoria, British Columbia. The experiments discussed here were conducted as part of the Let's Talk Science Program undertaken with high school students at the University of Victoria.

Experimental track re-creations have been used by a number of researchers to help understand the processes by which ancient tracks were created from different perspective. For example, Ruiz and Torices (2013) used experiments to help determine speed estimations for human trackways. Marty et al. (2009) created tracks in a number of different contexts to help determine differences in morphology and taphonomy.

Fig. 5.3 Examples of images taken of tracks that were excavated



Methods

The experimental re-creation of the tracks from EjTa-4 was conducted during educational outreach sessions at the University of Victoria led by Duncan McLaren and Quentin Mackie. The experiment was run a total of four times with the help of high school students whose feet were used to make the footprints and University student volunteers who helped with setting up and monitoring the experiments (Fig. 5.4).

A clay matrix was specially prepared for this experiment. This clay included some fine potter's sand (less than 5%) to give it some stiffness. The clay was pounded until consistent and then was placed in plastic totes to help keep it wet. Small twigs and leaf fragments were then placed on top of the clay substrate. High school students were then asked to volunteer to step into the clay to make a track. The following task involved adding dark grey coarse sand to cover the track and clay surface completely. The top of the sand was tapped gently to pack it down. The subsequent excavation of these features was undertaken by trowel and spoon.

Fig. 5.4 Experimental tracks created in clay during workshop on footprints at the University of Victoria

Results

The experiment was run a total of four times with four different high school student groups. Before covering the tracks with sand, we noted that the experimental clay matrices held the track impression well, being supported and shaped with the aid of the elasticity of the clay matrix. Sediment displacement rims were clearly visible, but were not necessarily created around the entire track. The feet of all of students were covered in the clay matrices after having completed making the track suggesting that at least some of the true track surface stuck to the bottom and sides of the foot.

Toe prints were visible in all cases, and some had sediment displacement rims between the individual toes. Sediment displacement rims were most prominent between the first and second toes. In one case, toe drag marks were left, and in another the heel had notably slipped towards the anterior.

With the addition of a layer of sand, the experimental tracks were rendered buried. The subsequent excavation of these tracks revealed that the sediment displacement rims were the first part of each track encountered (Fig. 5.5). Through further excavation, the remains of the true track could be revealed, providing a feature that could be measured. The twigs and leaves that had been left on top of the clay prior to impressing the track were impressed into the true track and in all instances needed to be removed from the clayey substrate below. All plant macrofossils recovered were covered in the clay.

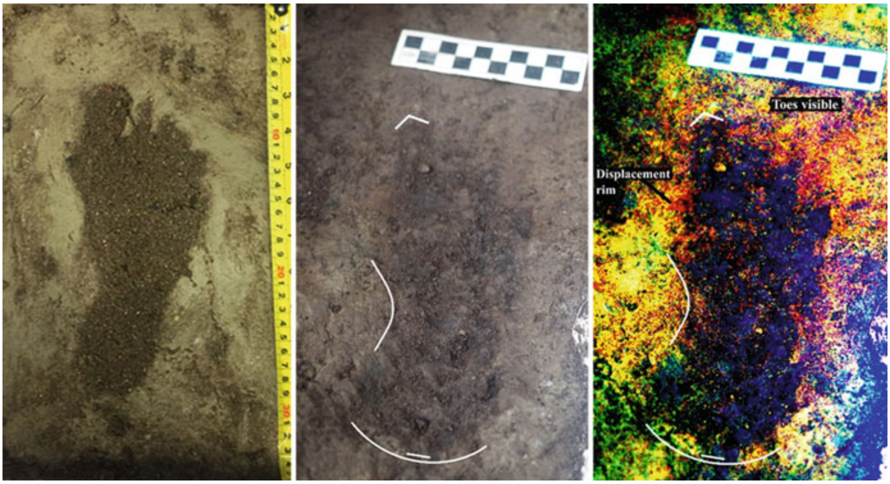


Fig. 5.5 Experiment track after excavation (*left*) compared with ancient track after excavation (*centre*) and image contrast adjustment (*right*)

Discussion and Conclusions

The results of this experimental re-creation help inform us about the site formation processes of the tracks at archaeological site EjTa-4. The clayey matrix in which the experimental tracks were created was found to be an excellent substrate to create and hold the impressions that were made. This appears to have been somewhat dependent on the amount of moisture. By extension, with too much moisture, the tracks would have been soupy and would have quickly disappeared, and with too little moisture, a track impression would not have been as clearly made. From this we have learned that the conditions at EjTa-4 would have been fairly damp, but not too wet to create conditions whereby the tracks found were initially made. This is consistent with our interpretation of the original depositional context being immediately supratidal.

During the excavation of the tracks at EjTa-4, we found that the presence and identification of the sediment displacement rims was key to the initial identification of the tracks found. In the experimental footprints, sediment displacement rims featured prominently in the tracks that were created and were prominent enough to be the first attribute encountered during excavation.

In the experimental re-creations, toe impressions were clearly visible. These remained fairly distinct even after being covered with sand and then excavated. Similarly, toe impressions were found during excavations at EjTa-4 suggesting similarities in site formation process. Details such as these toe marks are important as they reveal that we are dealing with true track impressions as opposed to undertrack deposits which lack this type of detail (Marty et al. 2009).

Of particular importance to the chronological interpretation of the tracks at EjTa-4 are the twigs that were found pressed into the true track surface. On the basis of the stratigraphic position of these twigs and the associated radiocarbon dates, we were able to assess that they were created between 13,317 and 12,633 calBP. The replication of this situation in the lab with the experimental true track surfaces having plant macrofossils pressed into them lends credence to our interpretation of the track formation process and chronology.

Based on our findings, we think that it is most likely that the tracks at EjTa-4 were buried relatively quickly after they had been created. We are not certain how long the track impressions would have lasted had they not been filled with sand. With an increase of the amount of time that the tracks were exposed it is likely that they would have washed to mush in a rain event, dried and desiccated beyond recognition during a dry period, or eventually would have become over trampled by other humans or animals. However, as the tracks were pressed into clay, it is possible that they would have retained their shape longer than tracks pressed into sand. As with most ancient track sites, it seems to be a fortuitous set of circumstances that resulted in the preservation of the features at all.

Overall, the experiment re-creation of tracks lends support to our interpretation of the site formation processes at EjTa-4. A minimum of three people left tracks just above the high tide line 13,000 years ago. These tracks were then covered by sand deposited in a high sea level event and remained capped since this time. While most track sites are revealed to archaeologists through erosion, those discovered at EjTa-4 were found through careful excavation. A key to the successful excavation of these tracks was the identification of sediment displacement rims which alerted the excavators to the likelihood that a full track lay beneath.

Acknowledgements The high school participants in the Let's Talk Science workshops where the experimental tracks were made are thanked. Katie Brynjolfson and Isabelle Rutherford, University of Victoria undergraduate volunteers, are thanked for their help in helping with the experiment reported on here. Stephanie Calce helped to organize the Let's Talk Science event for the Anthropology Department at the University of Victoria. George Mackie is thanked for preparing and pounding the clay and advice on sand and moisture content.

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Chapter 6
Reading Spoor

Epistemic Aspects of Indigenous Knowledge and its Implications for the Archaeology of Prehistoric Human Tracks

Tilman Lenssen-Erz and Andreas Pastoors

Abstract The spoor of animals and humans alike contain rich information about an individual and about a momentary activity this individual performed. If the – arguably hard-wired – human ability to read spoor and tracks is sufficiently trained, a footprint allows to glean from it various physical, kinetic, medical, social and psychologic data about an individual, as has been observed among various populations across the globe. The Ju|'hoansi San from northern Namibia still today practice traditional hunting so that tracking is a skill that is required and trained on a daily base. For a good tracker, the information she or he gets from spoor is equally rich on animal and human footprints, and it is not necessary that the tracker has been exposed before to the individual whose spoor she/he reads. In order to allow an assessment of how tenable are the interpretations by contemporary hunter-gatherers of prehistoric human footprints, this chapter elucidates methodological aspects of tracking and situates this ability in an epistemological framework.

Keywords Hunter-gatherers · Tracking · Induction · Deduction · Abduction · Hypothetico-deductive reasoning · Tacit knowledge

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Introduction

Human footprints are most prominent among the long-time under-researched features of the context of cave art. In order to compensate for this neglect, a special research programme has focused on the merging of indigenous knowledge and Western archaeological science for the benefit of both sides. With the expert assistance of indigenous San hunters from the Namibian Kalahari, the Tracking in Caves project endeavoured to better understand aspects of the Upper Palaeolithic human behaviour, traces of which are preserved in footprints in painted caves in southern France. The three professional indigenous trackers, Thui Thao, /Ui Kxunta and Tsamgao Ciqae (e.g. Pastoors et al. 2015. Lenssen-Erz et al. 2018), were invited to Europe and conducted in-depth research in the caves Niaux, Pech Merle, Fontanet, Tuc d'Audoubert and Aldène (Fig. 6.1 – see Pastoors et al. Chap. 13).

The extent of preservation of footprints from the Pleistocene depends on advantageous taphonomic circumstances and on careful treatment of the caves after modern rediscovery. Accordingly Pech Merle has less than 20 footprints, but the other caves each have at least several dozens and some several hundred. In Aldène they were left behind by visitors during the Mesolithic, Niaux is insufficiently dated, all others are of Upper Palaeolithic origin.

The documentation of the interpretations of the indigenous ichnologists is indispensable if they should be analysed archaeologically, but it is no less important to cross-check the results obtained with the results of the studies of Western sciences. The circumstance that the results of indigenous ichnologists are difficult to evaluate does not imply that they are worthless assumptions. They have to be verified or falsified with quantitative analyses and integrated into the discussion of prehistoric human footprints.

Even though the art of tracking has already been described comprehensively (Liebenberg 1990), there is a certain neglect of it in the current discourse of archaeology on prehistoric human tracks. In order to allow due appreciation of the

Fig. 6.1 The San ichnologists Thui Thao, Tsamgao Ciqae and /Ui Kxunta during their spoor investigations in the cave of Tuc d'Audoubert

methodological foundations of indigenous ichnologies, this chapter focuses on the art of tracking and its implications for the archaeology of prehistoric human tracks.

The Art of Tracking

With his ground-breaking book The Art of Tracking, the Origin of Science, Louis Liebenberg (1990) opened up new perspectives on the profoundness and epistemological complexity of the indigenous knowledge of tracking. Having immersed into the tracking culture of southern African San hunters, he understood that tracking is an intricate edifice of thought that stands a comparison to established sciences in Western cultures:

> In the narrowest sense of the word ‘spoor’ simply means ‘footprint’, but in tracking it has a much wider meaning, including all signs found on the ground or indicated by disturbed vegetation. Tracking also involves signs such as scent, urine and faeces, saliva, pellets, feeding signs, vocal and other auditory signs, visual signs, incidental signs, circumstantial signs, blood spoor, skeletal signs, paths, homes and shelters. Spoors are not confined to living creatures. Leaves and twigs rolling in the wind, long grass sweeping the ground or dislodged stones rolling down a steep slope leave their distinctive spoor. Markings left by implements, weapons or objects may indicate the activities of the persons who used them, and vehicles also leave tracks. [. . .]
>
> Spoor includes a wide range of signs, from obvious footprints, which provide detailed information on the identity and activities of an animal, to very subtle signs which may indicate no more than that some disturbance has occurred. [. . .] Signs of spoor may vary considerably with terrain, weather conditions, season, time of day and age. (Liebenberg 1990: 111–113)

Summing up the fields of knowledge that need to be mastered for successful tracking shows that reading spoor goes far beyond pattern recognition (cf. Gagnol 2013: 175). Tracking requires detailed zoological knowledge (behaviour, seasonal changes, reproduction, feeding habits, etc.) of the prey but also of animals in context including small mammals, reptiles, insects, etc. They may provide additional information if, e.g. a nocturnal animal walks through the spoor of a tracked animal, thus indicating how old a seemingly fresh track may be. Also all topics of ecological knowledge are part of the tracking skills with deep insights into biosphere and geosphere as well as pedology regarding the influence of different soil qualities on the ageing of spoor. The same applies for meteorological knowledge and weather observations that have to be memorized, e.g. in knowing which were the prevailing wind directions in the past 24 h. On top of this, each tracker needs to have exact knowledge of the place/area regarding vegetation, water points, game trails, salt licks, etc., all of which may be points of orientation for movements of animals. But also in his or her own interest, a tracker needs to have an absolute sense orientation (e.g. Brenzinger 2008), first to find the way home and second to being able to communicate spots in the landscape to others (e.g. the place where the carcass of a hunted animal is lying).

Also the potential of tracking to identify individuals is explained by Liebenberg:

> While species can be identified by characteristic features, there also exist individual variations within a species. These variations make it possible for an experienced tracker to determine the sex as well as an approximate estimation of the animal's age, size and mass. A tracker may also be able to identify a specific individual animal by its spoor. [. . .]
>
> The age of an animal may be indicated by the size of the feet. The hoofs of young antelope will also have sharper edges, while old individuals may have blunted hoofs with chipped edges. With animals with padded feet, younger individuals may have more rounded pads. Some animals have specific breeding periods. If it is known at what time of year an animal is born, a reasonably accurate estimate of its age can be made. [. . .]
>
> Apart from features characteristic to the species, there also exist random variations within the species which may vary from individual to individual.
>
> The exact shape of every individual is unique so that it is, in principle, possible to identify an individual animal. In practise this requires considerable experience, and is usually only possible with large animals. With elephant and rhinoceros it is easy to identify an individual by the random pattern of cracks underneath the feet.
>
> The shape of feet may also be altered by environmental factors. In hard terrain, hoofs of ungulates may be blunted by excessive wear, or in soft, sandy terrain, they may grow elongated hoofs due to lack of natural wear. (Liebenberg 1990: 122–124)

All which is said here on animal tracks is analogically found in human spoor (e.g. Biesele and Barclay 2001; Lowe 2002; Gagnol 2013; see Gagnol Chap. 19) since once the subtle reading is trained, it makes no difference to which type of trace the skill is applied. Therefore trackers are able to interpret many other signs of animals, e.g. where and how they were lying on the ground or if there were two animals fighting and rolling over the ground skilled trackers will be able to reconstruct complex sequences of movements and interaction. It also means that trackers are able to follow the tracks of an individual – be that person, game or herd animal – under changing soil conditions and even if mixed with imprints of other individuals of the same species.

Apart from these fields of knowing that are implied in tracking, it was also Liebenberg who pointed out that reading spoor means methodologically building hypotheses based on empirical evidence and that these hypotheses are constantly tested against ever new data (observations, perception; Liebenberg 1990: 153–157).

Methodological Aspects of Tracking

As Liebenberg has described in detail tracking, i.e. reading tracks is a special skill that is a precondition for human hunting and therefore may be considered the beginning of science (Liebenberg 1990). As such, it is related to ichnology, the science of tracks and traces, which originally was mainly occupied with fossil tracks (such as of dinosaurs), but since the discovery of the earliest hominid footprints in Laetoli (Tanzania) has also turned to humans (Lockley 1999). In current research of prehistoric human footprints, Western science reveals essentially two approaches: first, footprint outline and landmark-based geometric-morphometric analyses (e.g. Bennett et al. 2009, 2016) and, second, pixel-based quantitative analysis of the whole foot pressure (e.g. Crompton et al. 2011).

In pre-industrial societies of hunter-gatherers and herders, mastery of track reading is an existential necessity. It is being learned from early childhood onwards, requiring lifelong learning and constant practice. The reference to personal experiences and personal exposure to the object of description is at the same time a reference to the fact that tacit knowledge (Polanyi 1966) is required in tracking to a considerable extent comprising knowledge and cognitive possibilities that cannot be made explicit but rather are specifically available to each individual through an embodiment of experience.

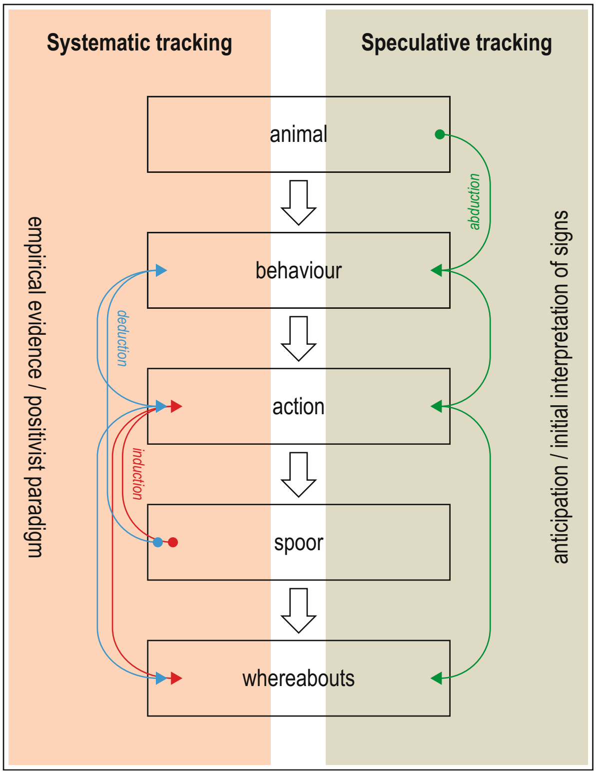
Presently indigenous ichnology has a much finer resolution of tracks than modern morphometric methods since trackers are normally able to determine from a footprint the sex and the approximate age class of a person, where the latter is not a factor of body height but based on overall foot proportions and traces of ageing.

Indigenous ichnology is not based in rationality, logic or causalities that differ drastically from Western views, as may be the case with traditional ecological knowledge (TEK) (Berkes 2008: 8). Nevertheless, taking a series of scientific measurements (e.g. Pales 1976; Webb 2007; Kinahan 2013; Ashton et al. 2014) is an unsatisfactory substitute and cannot produce understanding, as opposed to reading the ground for tracks (Chamberlin 2002). Expert tracking produces a narrative that is based on in-depth knowledge of the entire ecosystem and its agents, acquired through experience (Liebenberg 1990; Blurton Jones and Konner 1976; Lowe 2002). The capabilities of hunter-gatherers in reading tracks are legendary throughout various types of literature (e.g. Marshall Thomas 1988; Liebenberg 1990; Biesele and Barclay 2001; Lowe 2002), and no knowledgeable author leaves a doubt regarding the reliability of the trackers' skills. And also among traditional herders, equally deep analysis of tracks is found (Gagnol 2013). But despite the presence of prehistoric tracks on all continents (Lockley et al. 2008; Pasda 2013), only very little, rather anecdotal use has been made of indigenous tracking knowledge in archaeological contexts (Webb et al. 2006; Franklin and Habgood 2009).

As regards scientific scepticism about the reliability of spoor analyses by indigenous ichnologists, there have been empirical tests under controlled conditions with very high rates of accurateness of 98% (Stander et al. 1997) or 74% inter-rater reliability (Wong et al. 2011). The first study tested a group of San trackers of which Thao was part and the task was to determine for animal spoor the species, sex and age class of the animal and how old the spoor was. The second study aimed at determining whether spoor reading by Inuit hunters would be reliable enough for collecting census data on polar bears – which indeed was confirmed by the study. Furthermore, the two main ichnologists of the present study (Kxunta and Thao) have both passed the CyberTracker tracking certification (http://www.cybertracker.org/downloads/tracking/CyberTracker-Tracker-Certification-2018.pdf) with accuracy results of >90% (pers. comm. Liebenberg 2018).

If the method of tracking is analysed epistemologically, it is linked to Western scientific thought by the intellectual procedures of inductive, deductive and abductive reasoning (after C. S. Pierce 1955, cf. Liebenberg 1990; Eco and Seboek 1988) as three options to build hypotheses in the interpretation of observations (Fig. 6.2). Abduction, for that matter, can be described as a process that:

Fig. 6.2 Representation of the tracking process after Liebenberg (1990) with three types of reasoning and two principal paradigms of finding out the whereabouts of an animal or person



> begins with observations and then proceeds in a back-and-forth process of developing hypotheses and comparing the observations with information known and filed in memory. [. . .] Abductive reasoning then assembles the observations and attributes a variety of characteristics or conditions to a subject until a match is made and an hypothesis or conclusion can be stated. (Moriarty 1996: 181)

In following a spoor, the three methods of deriving conclusions, according to Liebenberg, are realized in an inductive-deductive practice which he labels systematic tracking, and a hypothetico-deductive (or abductive) one, termed speculative tracking (Fig. 6.2; Liebenberg 1990: 106–108). The former method rests quite narrowly with the observations the trackers make on the spoor they follow, thus forcing them to walk the same way as the pursued animal walked. The latter method makes an educated guess about what a pursued animal is going to do next on the basis of information gathered from the spoor up to a given moment and on general knowledge of the animal's behaviour. Thus the trackers may leave the spoor and take a shortcut to the place where the spoor is expected to be retrieved again. Gagnol, building on his own tracking research among Saharo-Sahelian camel herders, also found that successful tracking is importantly based on abductive method and what Liebenberg calls speculative tracking resounds in what Gagnol terms stratégie hodologique (Gagnol 2013: 172; Gagnol et al. 2018: 21; hodology = study of pathways; see Gagnol Chap. 19). The essence of both methods lies in the principle of liberating the search process of tracking from the dependence of visible spoor but instead making educated assumptions about what the subject may have chosen to do. In Gagnol's words:

> One imagines the general path, the assumed goal of the animal or person and the means or stratagems he or she will apply to achieve it (therefore one has to adopt his or her point of view, putting oneself in the perspective of the other). (Gagnol 2013: 173; translation from French TLE[1])

In view of such intellectual processes, deriving conclusions from observations Liebenberg emphasizes their complexity which is no less than that of modern scientists, e.g. in physics or mathematics (Liebenberg 1990: 45–46). Accordingly, upon thorough study of the character of tracking, authors have no doubt of the status of tracking as analogous to science or as its forerunner (Liebenberg 1990; Jones and Konner 1976; Chamberlin 2002). Ciqae, Kxunta and Thao assert that the decisions of trackers who hunt together and their interpretation of spoor are both based on constant exchange of opinion as well as on shared expert statements amongst the trackers (see also Liebenberg 1990; Blurton Jones and Konner 1976; Biesele and Barclay 2001). Therefore tracking can be accepted as a serious methodology in an epistemological sense, and trackers are justifiably labelled ichnologists since their professional practice largely is the interpretation of positivist data through reason and logic, based upon clearly determinable, repeatable methods. Further corroboration for this epistemological assessment of tracking is provided in the fact that for the differentiation of, e.g. male and female footprints, trackers assess the same markers and proportions on a foot as in orthopaedics or forensics (e.g. Robbins 1985; Reel et al. 2010) (Fig. 6.3).

At this juncture it must not go unmentioned that in hunter-gatherer societies, skills in tracking are not the exclusive knowledge of adult male hunters, and as mentioned before these skills are not restricted to animal tracks but also include human spoor (cf. Marshall Thomas 1988: 26; Biesele and Barclay 2001: 79; Lowe 2002: 18, 68; see Gagnol Chap. 19 and Gagnol 2013 for tracking skills of herders).

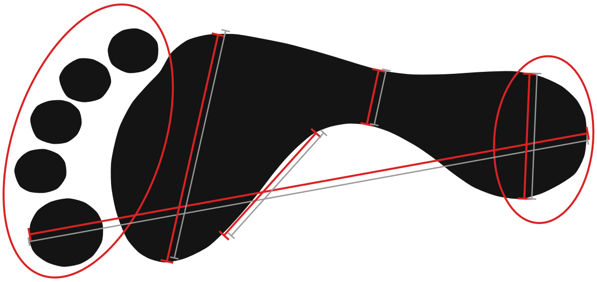


Fig. 6.3 Ways of taking data from a footprint: *grey* lines are usually measured in orthopaedics and forensics; the *red* line represent the measures San ichnologists assess. The *circles* circumscribe areas that are assessed in their totality, in particular for age estimations

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[1] In original text: "On imagine le parcours général, le but supposé de l'animal ou de la personne et les moyens ou stratagèmes qu'il ou elle mettra en œuvre pour y parvenir (il fout donc adopter son point de vue, se placer dans la perspective d'autrui)."

And as is the case with all human abilities, not every hunter or every herder in a given group is equally good in that skill (Liebenberg 1990; Gagnol 2013). There are always some trackers who through talent, persistence and ambition reach levels of mastery so that they can read spoor which would leave other members of their groups helpless.

Gagnol (2013; see Gagnol Chap. 19) in his research among Touareg (Niger) and Toubou (Chad) camel herders regarding their capability of reading spoor confirms all findings that have been reported by other authors on hunter-gatherers – even though he seems to be totally unaware of this literature. For these herders it is normal to have extraordinarily fine resolution of reading tracks regarding human spoor and regarding their domestic animals like camel, horse, cattle, donkeys, goats and sheep (Gagnol 2013: 171). Gagnol also points out that this expertise goes together with a rich vocabulary for the description of spoor details and of ways of walking (Gagnol 2013: 170). For a camel herder, it is important to know all his animals by their spoor, even if they may mix with another herd (which does not happen infrequently), and if they get astray, the herder will occasionally track it for several days (Gagnol 2013: 170).

As regards human spoor, Gagnol asserts that every individual of a community can be identified by her or his footprint, and also strangers are recognized due to their unknown imprints. Such identification is not only based on morphological features but also on details of the habitual gait of a person – and wearing sandals is not an impediment for such identification (Gagnol 2013: 171). In following thieves the best trackers are even able to track the culprit if he changes his shoes several times during his escape (one of the strategies of camel thieves to complicate pursuit; Gagnol 2013: 179; see Gagnol Chap. 19). Information imprinted through a human footprint is so rich that even social status or ethnic affiliation can be gleaned from spoor (Gagnol 2013: 176; see Gagnol Chap. 19).

The described capability of extracting information from footprints was the basis for analyses of human footprints in the Palaeolithic caves. The results of the indigenous ichnologists compiled in the course of the various studies are as detailed and precise as the tracking by masters would promise, and they go beyond the results produced by Western science. This fact is perceived and reacted to in different ways by the public. If exposed to the results, one part of the public shows scientific curiosity, wishing to learn more about the capabilities of indigenous ichnologists and to verify or falsify the results through their own investigations. Others, however, show great scepticism to the extent of rejection. Such rejection does not seem appropriate without empirical falsifications, because indigenous ichnologists have verified skills in reading tracks. Strictly speaking, their methodological approach is not so alien to Western scientific approaches. Even though Erwin Panofsky's iconographic interpretation method refers to images, there are parallels between reading tracks and interpreting images. According to Panofsky, in the case of a natural subject as the object of interpretation, a pre-iconographic description of the motifs takes first place (Panofsky 1962). Practical experience (familiarity with objects and phenomena) is an absolute prerequisite for a successful description, from which a positive correlation between experience and descriptive accuracy can be derived. In the event that the spectrum of personal experience is not sufficient, this spectrum must be extended by consulting publications or experts. Practical experience, in turn, helps to determine which publication or professional is to be consulted (Panofsky 1962: 9). This practical experience results not least from personal experiences in the world in which we live and which:

> provides the ground for all cognition and for all scientific purpose. (Husserl 1939: 38)

The concept of the lifeworld that is evoked here describes the realm of reality in which every human being inevitably participates (Schütz and Luckmann 1975). This concept asserts that there is a world of common, everyday experiences and interpretations on which all more theoretical knowledge is dependent (Schütz and Luckmann 1975: 23). A basic characteristic of the everyday lifeworld is its intersubjectivity, by which it forms a social world in which practically all members of a social body take part with roughly the same interpretations of daily phenomena (Schütz and Luckmann 1975: 33). The everyday lifeworld, seen as the most common and widest accepted kind of reality, comprises physical objects, nature and the everyday social world (Schütz and Luckmann 1975: 41).

Accordingly we contend that many processes and phenomena in the empirical world out there are understandable irrespective of the cultural imprinting an observer has. Based on this lifeworld concept, we regard phenomena like spoor as providing information on an implicit and an explicit level, the understanding of which is informed by tacit and by explicit knowledge (after Polanyi, e.g. 1966). While the implicit information is entirely embedded in the respective culture, or, as tacit knowledge, even within an individual (and therefore largely inaccessible to us, Polanyi 1966, see also Schütz and Luckmann 1975: 99–102), the explicit information is based in intersubjective experiences in the empirical world. Reading animal tracks cannot be separated from the actual behaviour of that species which the animals perform irrespective of any cultural representation and symbolization of this behaviour. Observing animal behaviour and the tracks it produces is a general human experience and is based on positivist, empirical data while the sense that is interpreted into such experience is subjective and culture-bound (Schütz and Luckmann 1975: 101). As has been pointed out before, everything that can be said on animal spoor also pertains to human footprints.

Implications for the Archaeology of Prehistoric Human Tracks

In archaeology, already at the beginning of the twentieth century, certain perplexity and a lack of experience with regard to the reading of tracks in the interpretations of prehistoric footprints in caves by Western scientists became apparent (e.g. Bégouën 1928; Lemozi 1929). Thus, not the recognition of a specific sequence of footprints gave reason to interpretations as ritual dance (de Contenson 1949) but the transfer of the generally perceived ritual status of the surrounding cave to the footprints. At this point of archaeological analysis, lacking the capability to read tracks was masked by the professional practice of interpreting cultural-historical processes. Even today not only the lack of practical experience in reading tracks proves to be problematic but also the existence of methodological limits of modern analytical procedures. This is particularly evident in the difficulty of making the sequence of steps of one and the same person morphometrically visible, even though it is obviously from one person (Bennett and Morse 2014).

Against the background of interpretations favouring ritual activities, the results of the indigenous ichnologists appear unspectacular. But they fill a vacuum of description with content. An accumulation of footprints on a spatially limited area seems like a chaotic mixture. This confusion dissolves when the indigenous ichnologists combine footprints into sequences of steps of single individuals. For this purpose it is indispensable that age, sex and individual characteristics of a person can be gleaned from the footprint even if this is not possible with all of the extant Pleistocene footprints. The demographic data is ultimately established by using morpho-classificatory factors, which are essentially based on the same features that Western science also uses.

Contextual information is also included in the track data acquisition: the nature of the ground, room height, inclination, gradient, curvature, possible obstacles and much more. The identified footprints are mapped and recorded in a data sheet. As mentioned above, the result of the work of the indigenous ichnologists is not an inventory of all footprints but of footprints about which they can give dependable information. In this way, the indigenous ichnologists' approach differs from that of Western science, in which each individual footprint is recorded by using specific attribute systems thus favouring description over interpretation. Ultimately, the discussions about these two approaches are comparable to the dichotomy in archaeology between two well established methods of object analysis: the static attribute analysis and the dynamic analysis of the chaîne opératoire. Each footprint is the result of a unique interplay of bones, muscles and various other external factors and represents therefore a non-repeatable event. But footprints, or human tracks in general, are not alone with this situation in archaeological research. Every archaeological object is the result of certain constellations of internal and external factors that cannot be reproduced accurately. Archaeological research has responded to this dilemma by developing dynamic methods of investigation, including the chaîne opératoire.

Another dynamic method is the indigenous knowledge of tracking; therefore its application is not a matter of romanticism, and it is not aimed at providing an exotic view of tracks from another world-view. Rather, it provides alternative interpretations of data, using the same empirical base that is accessible to any method (Liebenberg 1990; Lockley 1999; Lowe 2002). To the present knowledge, there is no other method for a deep understanding of spoor as remains of dynamic actions that is equally successfully applicable to tracks in all kinds of substrate and in all stages of taphonomic degradation. Western science responds to this situation by applying experimental archaeology in order to develop a dynamic method (e.g. see Ledoux et al. Chap. 4).

In fact, the interpretations of human footprints by Ciqae, Thao and Kxunta achieve levels of precision described by Liebenberg and Gagnol. This prompts questions as to which aspects of the footprint are significant for such detailed information. Liebenberg compiles different aspects of the spoors, which serve as a base for the determination of age and sex, size, depth, way of movement, body structure and association with other footprints, all of which is supported by Gagnol's observations. Ciqae, Thao and Kxunta corroborate that a male foot looks stronger and wider than a female foot, indicating that, of course, an intuitive assessment of proportions is the foundation of sex determination besides gait and step length. According to Liebenberg (1990), wear, foot tension and again size are significant for age determination, which paraphrases the criteria mentioned and judged by the trackers. Furthermore, Liebenberg noted that the exact shape of every individual is unique, and, therefore, it is possible to identify individual animals and also humans (the same is maintained for Australian aboriginal people by Lowe 2002 and for Saharan nomads by Gagnol 2013). This, too, is substantiated by Ciqae, Thao and Kxunta, who assert that, in particular, the shape of the toes and the way a foot is set on the ground help them to identify their family, neighbours and friends by their footprints. Also, age determination of a known or unknown person, so Ciqae, Thao and Kxunta affirm, is largely based on judgments of the features of heels and toes, plus a person's way of walking, since steps become shorter as a person grows old (see also Gagnol 2013 for corroboration). Through this fine-grained differentiation, they are able to distinguish different age classes among adults, even though mature feet do not continue to grow. According to these trackers, the heels become harder and more cracked the older a person gets, and also the toes become harder. Through this, so the indigenous ichnologists maintain, the soil is being thrown up by the toes in a different way by an old person than by a younger adult. Gagnol (2013: 171–172) describes analogous changes from young adults to mature adults among the animals of the Toubou and Tuareg.

In a critical appreciation of the implementation of indigenous ichnology in archaeology, it has to be conceded that there may be some influential factors that could generate possible biases. After all the original context of the spoor that the indigenous ichnologists were asked to read stems from a period, environmental conditions and population that were all entirely alien to the tracker's previous experiences. When addressing this problem with the ichnologists, they maintained that people are people and reading the tracks of complete strangers is not uncommon for them. Nevertheless, the following questions are some of those that may arise:

- Which data are collected?
- How do participants communicate?
- Can technical terms be translated?
- Do means of control apply (verification/falsification)?
- Are there repeatable results?
- Is there a second opinion?
- How indigenous is indigenous knowledge?

First, it has to be emphasized that there is a general counter balance to these biases by the practice of the San trackers which, again, shows that their approach to data (tracks in this case) has much in common with a Western view of scientific investigations (this list is based upon observations and interviews during common field work):

- Empirical approach
- Meticulous exactness
- Best-practice ethics
- Constant testing of hypotheses
- Shared expert opinion
- Prepared for constant learning
- Immediate transfer and implementation of new experiences

Secondly and more specifically, data acquisition always takes place with intense communication among the indigenous ichnologists and with the archaeologists. In particular the internal exchange between the indigenous ichnologists is a guarantee that all results that are stated are based on the inclusion of at least a second expert opinion. Repeated visits to some spoor fields in French caves showed in a random test that interpretations of imprints were the same after 3 years so that the results indeed are repeatable – even if conceding that the same persons interpreted the spoor on both occasions. It is also important to emphasize that the data that are collected for the Tracking in Caves project are the same as those which interest a tracker also outside the research scheme: what are the characteristics of that person who left a spoor and do I know her or him, where did she/he go, and what was her/his state of mind and maybe her/his intentions (cf. Gagnol et al. 2018: 20). Therefore the questions arising from the research are fully understandable to trackers, while they do not mind the ultimate consequences of their spoor identifications. Notwithstanding this initial focus on every footprint in isolation, the analyses in the caves never produced contradictory actions or behaviour. For example, in cases of footprint superimpositions, the younger spoor would always be the one leading out of the cave.

The indigenous ichnologists admit, however, that normally they would only be interested in fresh spoor because tracking is a behaviour that generates information for immediate action which is futile regarding old spoor.

With regard to due scientific doubt about the initial results of spoor reading, there is no independent, more reliable scientific method available, and every new interpretation by other trackers of once interpreted spoor would constitute just another opinion but not a verification or falsification.

Whether the analyses of the San trackers depend on specific terminology in Jul'hoansi language for which there may be no equivalent in English is still a desideratum of research, but first investigations in other San languages clearly point into this direction (e.g. Sands et al. 2017).

Finally the question of how indigenous the indigenous knowledge really is has no relevance for the research questions. The reading of Pleistocene human footprints aims at getting the maximum possible information from footprints, no matter in which way the interpreting experts acquired their knowledge. But it is only in the context of a life in rural areas where free roaming animals have outstanding economic significance where tracking is required and trained to such an extent that the most skilled individuals attain world class knowledge.

The Wider Potential of Tracking

The extraordinary abilities of indigenous ichnologists can also be applied in other fields of archaeological research. Particularly the ancient rock art of prehistoric hunter-gatherers may become a promising study object since in many regions around the globe, there are traditions of prehistoric art where animal tracks are an integral part of the rock art motif spectrum (Lenssen-Erz et al. forthcoming for an overview; Fig. 6.4). Considering that these depictions were produced by artists with the mindset of hunter-gatherers, it is obvious that reading and interpreting them is best attempted by hunter-gatherers themselves. Two pioneering field studies in Namibia indeed showed that in hundreds of engravings of animal spoor, indigenous ichnologists were not only able to identify in almost all cases the exact animal species (Nankela 2017) but also to determine sex and age class of an animal as well as which of the four legs was depicted (Lenssen-Erz et al. forthcoming). The latter study established three main findings: first the prehistoric hunter artists did not think in generic categories by producing an exemplary track of, e.g. giraffe as is found in field guide books for spoor identification. Rather for each depiction a hunter artist would conceive of a specific animal, e.g. a young male, and of this animal it would be a particular leg that was represented by the engraved spoor.

Secondly the spectrum of species represented by spoor is much richer than the spectrum of animals being depicted as figures, with a fair number of rather small animals. Also the frequency of predators, especially various species of felines, is much higher. Apparently the spoors of animals cover a different field of symbolization than the depictions of animal silhouettes.

Fig. 6.4 San ichnologists Ciqae, Kxunta and Thao reading spoor in prehistoric engravings in central Namibia's Doro !nawas region

And thirdly it emerged that instead of producing a random distribution of all possible features across all species that form part of the art canon, each species shows a clear bias towards a sex, an age class and a particular leg that is preferably depicted. The patterns that emerge cannot yet be interpreted because they produce alliances that are not self-explicatory: for example, the features of being predominantly female is shared by leopard and guinea fowl, while zebra and duiker are predominantly male; walking direction of almost all animals is up the wall, but duiker and springbok predominantly walk down the wall. Whether such associations have a common cognitive or symbolic base cannot be determined yet.

However, there are several reasons why it is necessary for a tracker to being able to determine sex, age and which of the four legs of an animal are indicated by a spoor. In the first place, a hunter must be able to identify an individual animal within a herd in order to be sure which animal he is tracking and hunting. Secondly the hunter must be able to identify each leg of an animal separately, on the one hand to understand the individual gait of every animal and on the other hand to see on which leg it may be lame, e.g. through the impact of the arrow he launched. Thirdly, if coming upon the spoor of a herd or pack of animals, it is important to quickly get an overview of how many animals are in this herd or pack – not only for hunting but also for security reasons: it requires different levels of alertness and caution if one comes upon the fresh spoor of lion whether these were left behind by two lions walking up and down in a place or whether these spoor stem from a pack of nine lions (pers. comm. O. Vogels 2019).

There is another field of indigenous knowledge that is connected to tracking which may be applicable in archaeology, notably rock art research. Indigenous ichnologists are capable to reconstruct from tracks the behavioural body postures of animals, be that game or domesticated animals, and therefore they are also well trained ethologists. Various rock art traditions, be they created by hunter-gatherers or herders, depict animals of significance for that culture in rich variations of body postures and gregarious configurations. Since archaeologists lack the training of reading spoor as much as the training of reading behaviour, their interpretation of animal behaviour depicted in rock art can only be rather superficial (e.g. Thackeray 1983; Lenssen-Erz 1994; Hollmann 2005). Involving the ethological knowledge of hunter-gatherers or pastoralists respectively to the specific art traditions made by their forerunners will certainly open new fields of meaning to these art corpora.

Conclusion

While giving tracking as indigenous knowledge a centre-stage position, this chapter does not aim at providing a critical review of the concept of indigenous knowledge since there is a broad literature on this subject (for an overview Odora Hoppers 2002). Indigenous knowledge shares at least a semantic field if it is not identical with terms such as traditional knowledge, local knowledge, civic science, traditional ecological knowledge, community archaeology, etc. Flaws of the indigenous knowledge concept are sometimes discussed due to its association with notions such as nativism, essentialism, ethnicity of knowledge, ahistorical knowledge, (romantic) notion of being static and bound, belief vs. analysis, tradition vs. modernity or knowledge as a result of power relations. While being aware of this discourse, we need not make a contribution to it. We do not imply that the indigenous knowledge we work with necessarily has to be a pristine knowledge, but instead we involve San ichnology because it is the highest standard we can get today and it promises to get the maximum possible information that can be retrieved from an imprint for which there are not yet any equally yielding machine-based analytical devices.

Further research is necessary to determine the smallest analytical steps of the methodology applied by Ciqae, Thao and Kxunta to each single imprint. We do have some indications about the procedure of extracting data from a footprint, manifested in the sections of a foot that are part of the rating process and which are also used in orthopaedics or forensics (Fig. 6.3). But this can only be the start and in order to collect first data on this topic, the entire determination process in each cave was recorded as audio protocols. The transcription and translation of the discourses of the trackers will serve as an important resource in the future for the deeper understanding of indigenous ichnology.

In the course of the two field studies 2013 and 2018, especially the last, there were no inconsistencies or contradictions in the interpretation of the approximately 1000 prehistoric human footprints examined. This expresses the professionalism and quality of the work of the indigenous ichnologists.

Currently preparations are under way to analyse most of the footprints examined by indigenous ichnologists, using quantitative methods in order to verify or falsify their results in the form of a cross-test with new methods. It will be a central task to combine Western science with indigenous ichnology and to discuss the results of both approaches. A main problem is certainly the difficulty of evaluating the results obtained by the indigenous ichnologists. But their integration into the interpretation of prehistoric footprints is still in its infancy. Following the principle of Aristotle, where the whole is more than the sum of its parts, indigenous ichnologists include the behaviour of the trackmaker in their interpretations from the beginning. For Western scientists, footprints are individual morphological features that are quantified as such, disconnected from the other footprints. The question of the behaviour of the trackmaker is handled separately and comes at the end of the statistical analyses. This methodical contrast offers great potential and promises benefits for both sides.

For the future, these experiences mean that by applying indigenous knowledge, selected source genres of archaeology can be explored in greater depth than would be the case with conventional methods alone. While the case described here was about the knowledge of hunter-gatherers, it is to be expected that the addition of, for example, pastoral nomads in other fields of research and for other epochs will also lead to new and deeper insights.

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Part II
Case Studies from Around the Globe

Chapter 7
Perspectives on Pliocene and Pleistocene Pedal Patterns and Protection

Implications for Footprints

Erik Trinkaus, Tea Jashashvili, and Biren A. Patel

Abstract As a framework for interpreting Pliocene and Pleistocene hominin footprints, the functional implications of australopith and *Homo* pedal remains are reviewed. Despite minor variations in pedal proportions and articular morphology, all of these remains exhibit tarsometatarsal skeletons fully commensurate with an efficient (human) striding bipedal gait. The Middle and Late Pleistocene *Homo* pedal phalanges exhibit robust and distally flattened metatarsal 1 heads, hallux valgus, relatively short lateral digits with largely straight proximal phalanges with dorsally oriented metatarsal facets, all similar to those of recent humans. The Pliocene and Early Pleistocene halluces lack hallux valgus and have bulbous metatarsal 1 heads. The australopith pedal remains have lateral proximal phalanges that are relatively long and dorsally curved and have more proximally oriented metatarsal facets. In addition, pre-Upper Paleolithic *Homo* lateral phalanges have robust diaphysis implying the habitual absence of protective footwear, whereas the Upper Paleolithic ones are variably gracile, especially at higher latitudes, indicating more consistent use of footwear. These paleontological considerations provide a framework for interpreting the distal portions of earlier hominin footprints (especially with respect to hallucal orientation and digital length) and suggest that many of the Late Pleistocene footprints may be unrecognized given the use of footwear.

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Introduction

The human lineage has evolved a pedal anatomy that facilitates an efficient striding bipedal gait. As the interface between the body and the substrate during gait, it is also the portion of the anatomy which is primarily responsible for the form and variation in footprints. Given that hominins have had a basically bipedal pelvic and leg anatomy since at least the early members of *Australopithecus* (Ward 2013), it is likely that variation in footprints would reflect a complex combination of pedal anatomy and the behaviours imposed on the foot. This short review is therefore intended to provide an overview of Pliocene and Pleistocene human pedal anatomy and variation, with respect to their implications for assessing footprints from the past. Particular focus is placed on the pedal digits, given the stability of the human tarsometatarsal skeleton once it became basically humanlike (or bipedal) in the earlier Pliocene (DeSilva et al. 2019).

The paleontological record for human foot evolution consists of isolated remains and a dozen partial pedal skeletons for the earliest phases, several of uncertain taxonomic affiliation. Middle Pleistocene associated feet derive from Dinaledi and Atapuerca-SH, there are half a dozen largely complete Middle Paleolithic pedal skeletons and then a relative abundance of them in the Upper Paleolithic. Only in the Middle and Upper Paleolithic, plus one *Australopithecus* specimen, are the pedal remains from associated skeletons. Therefore, for the Pliocene and Early Pleistocene, overall pedal anatomy is based on composites, often from diverse sites, whereas the later periods permit assessments from single individuals (DeSilva et al. 2019; Fig. 7.1). Isolated remains nonetheless fill out the record. The pedal remains from Aramis, Burtele and Liang Bua are not considered here, given their divergent configurations and their lack of association with footprints.

Individual points are not referenced in the discussion. For overall assessments, some of the key or more complete specimens and key aspects of the discussion, see Latimer et al. (1982), Susman (1983), Trinkaus (1983, 2005), Lordkipanidze et al. (2007), Zipfel et al. (2011), Ward (2013), Trinkaus et al. (2014, 2017), Harcourt-Smith et al. (2015), Trinkaus and Patel (2016), Pablos et al. (2017), Fernández et al. (2018), McNutt et al. (2018) and DeSilva et al. (2019). For the earlier phases, DeSilva et al. (2019) provide an extensive review; for the later phases, see especially Trinkaus (1983), Trinkaus et al. (2014, 2017) and Pablos et al. (2017).

The Tarsometatarsal Skeletons

The tarsometatarsal (TMT) skeletons of all of these hominins indicate pedal structures that are similar to those of habitually unshod recent humans. They have compact and mediolaterally compressed posterior tarsals, with the calcaneal

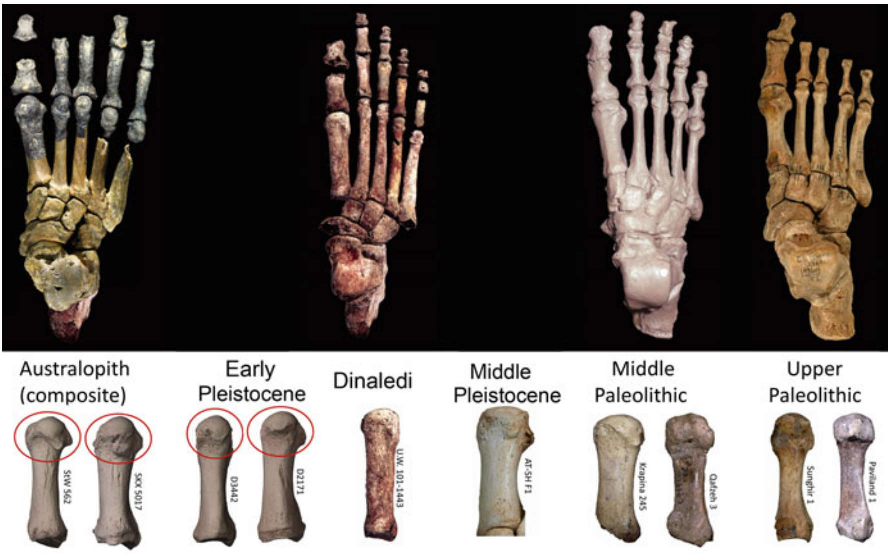


Fig. 7.1 Dorsal views of articulated pedal skeletons (*above*) and dorsal or plantar views of first metatarsals (*below*). The articulated pedal skeletons include an australopith composite (OH-8, A.L. 333-115, StW 617), Dinaledi Foot 1, Kiik-Koba 1 and Sunghir 1. The more bubous heads of the Sterkfontein, Swartkrans and Dmanisi MT-1 s are circled

tuberosity largely in line with the talar trochlea. They have low talar neck angles. The australopiths have large naviculocuboid facets, possibly reflecting modestly greater midtarsal mobility, but they are reduced to absent in *Homo* tarsals. All of them have fully adducted hallucal metatarsals despite some variation in angulation when the skeletal elements are articulated. The adduction is reflected in tarsometatarsal 1 articular orientations and the occasional metatarsal (MT) 1-2 facets; the mediolaterally curved and distally convex TMT-1 facets of some remains enhanced joint stability and were not abduction. They had fully formed longitudinal and transverse pedal arches, indicated by MT torsion (especially for rays 3 and 4) and oblique and horizontally oriented TMT articulations (especially for rays 3–5). In combination with the pedal arches, the metatarsophalangeal (MTP) articulations have mediolaterally oriented axes of rotation; for the MT-1, this resulted in perpendicular proximal and distal articular axes of rotation, permitting effective dorsiflexion at heel-off.

In this context, there was a variation in the degree of MT-1 medial divergence, overall pedal proportions, the relative sizes of articulations and other details of articular facets. It remains unclear to what extent these variations reflect body size (especially between australopiths and *Homo*), body proportions (especially ecogeographically in Middle and Late Pleistocene *Homo*), musculoskeletal hypertrophy and the effects of the presence/absence of habitual footwear use. None of these variations would have affected the basic kinesiology of the foot during a striding gait, beyond the considerable individual variation evident among recent humans.

The Hallux

In the context of adducted halluces, there are contrasts between earlier and later hominins in two aspects, the shape of the MTP articulation and the presence/degree of distal phalangeal lateral deviation (hallux valgus). Both have functional implications.

The MT-1 heads of most Middle and Late Pleistocene MT-1s are indistinguishable from those of recent humans in being relatively large and modestly distally convex, with varying degrees of distal angulation caused by different degrees of dorsal extension of the intersesamoid crest (Fig. 7.1). The articulation is evidently adapted for transmitting elevated axial joint reaction forces with only modest degrees of abduction-adduction and dorsiflexion-plantarflexion. The Dinaledi MT-1s are similar to the other later Pleistocene ones in shape, but they have relatively smaller articulations. In contrast, the australopith and initial Pleistocene *Homo* MT-1s exhibit mediolaterally and dorsoplantarly bulbous heads (Fig. 7.1). Although fully compatible with predominantly axial joint reaction forces, their marked convexities imply increased mobility of the MTP-1 joint and/or increased joint stability relative to mediolateral forces on the distal hallux.

As a result of normal toeing-out during walking, most recent humans exhibit a lateral deviation of the distal hallucal phalanx (DP-1), or hallux valgus. All of the known Late Pleistocene and the Middle Pleistocene Atapuerca-SH DP-1s exhibit a similar lateral deviation (Fig. 7.2). In contrast, the few known DP-1s from australopiths, Early Pleistocene *Homo* and the Middle Pleistocene Dinaledi sample exhibit minimal lateral deviation of the DP-1. This is particularly evident in the complete OH-10 phalanx. Given that DP-1 lateral deviation is produced by differential medial versus lateral metaphyseal growth during development, from habitual forces on the hallux, the absence of this angulation in the earlier DP-1s implies little to no toeing-out among these hominins. Yet, at least OH-10 and the Dinaledi DP-1 exhibit axial torsion, which implies a humanlike toe-off.

The Lateral Metatarsophalangeal Articulations

During heel-off and the propulsive phase of a human stance, the ball of the foot and the toes are on the substrate, the pedal arch is raised and consequently the MTP articulations are substantially dorsiflexed. This distinctively human pedal posture has resulted, most prominently in recent humans, in a dorsal extension (or doming) of the metatarsal heads. The dorsal doming of the lateral metatarsal heads is present in all of the Middle and Late Pleistocene humans (including the Dinaledi remains). Additionally, the few Early Pleistocene *Homo* specimens appear to follow the recent human pattern. However, since this feature is variably present in the australopith MTs, it is unclear to what extent the australopith MTP articulations were habitually hyperdorsiflexed, as in a fully human heel-off.

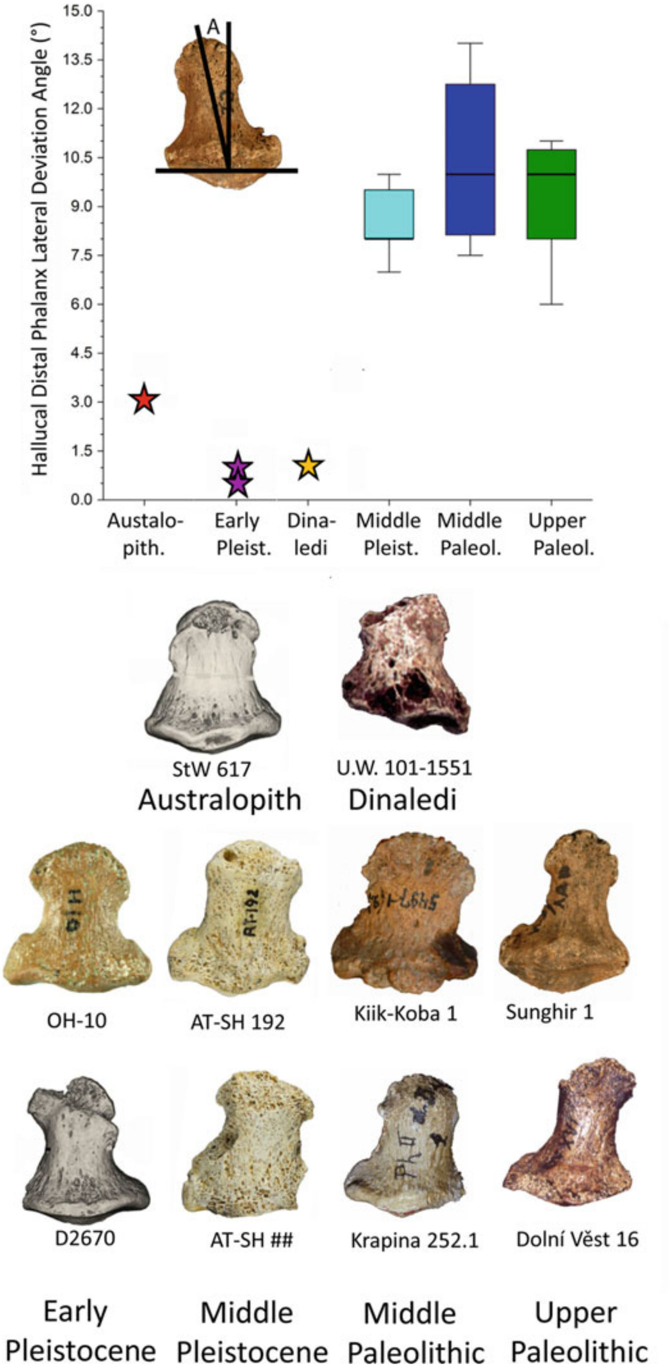


Fig. 7.2 Dorsal views of distal hallucal phalanges (*below*) and the distributions of DP-1 lateral deviation angles (*A*) (*above*)

MTP dorsiflexion at heel-off also produces a proximodorsal orientation (or canting) in recent human lateral proximal phalangeal metatarsal facets, especially of digits 2–4 (PP-2 to PP-4), such that the articular surfaces are oriented largely perpendicular to the resultant joint reaction forces. Given the more proximal position of the MT-5 head and the relative shortness of the fifth proximal phalanx (PP-5) in recent humans, this feature is less pronounced in the fifth MTP articulations.

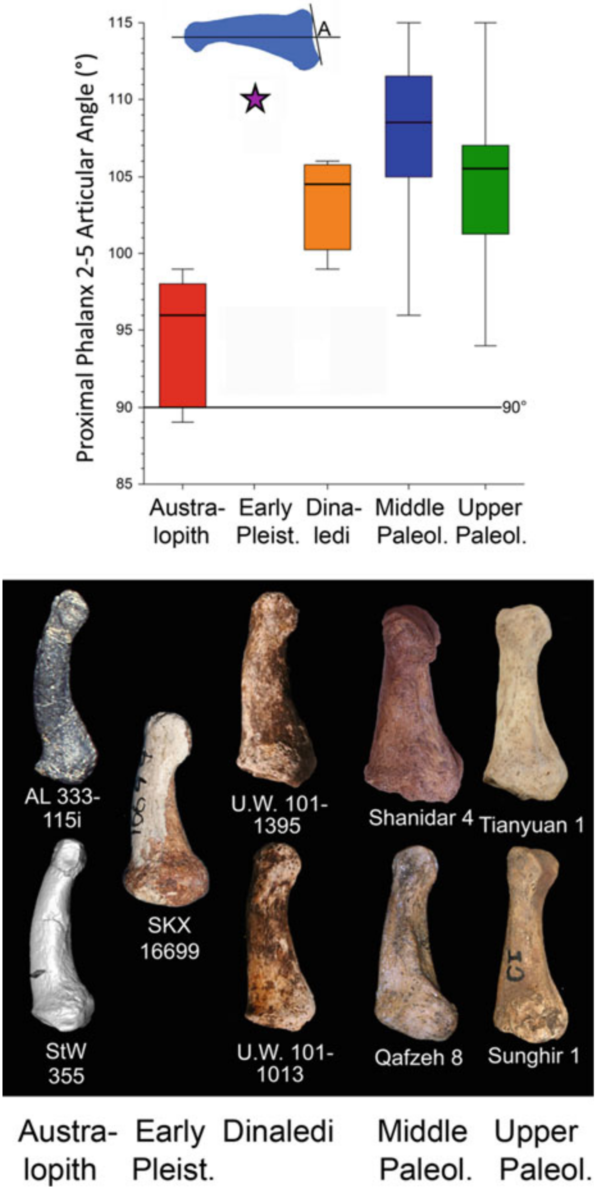
Because of the difficulty in assigning isolated PP-2s to PP-4s to digit and australopith PP-5s to digit, it is necessary to pool these phalanges for comparaisons. All of the Middle and Late Pleistocene PPs follow the recent human pattern, with the lower articular angles deriving from PP-5s (Fig. 7.3). The same applies to the Middle Pleistocene Atapuerca-SH sample. The one Early Pleistocene phalanx, likely of *Homo* (SKX-16699), is among the more recent humans. The australopiths, although they have mostly dorsally oriented facets (in contrast to the plantar orientations of ape facets), exhibit angles that are substantially below those of *Homo* PPs, overlapping only the low values of some Late Pleistocene PP-5s.

Lateral Proximal Phalanx Lengths and Shafts

The lateral proximal pedal phalanges have generally uniform articular lengths through the Late Pleistocene and including the Atapuerca-SH Middle Pleistocene sample, with sample median lengths of 23–25 mm. The SKX-16699 Early Pleistocene *Homo* phalanx and the Dinaledi ones are shorter, averaging 18–20 mm in length, given smaller body sizes. However, the australopith ones, although variable, are considerably longer, with a median length of 27–28 mm, despite their small bodies. When compared to estimated body mass from femoral head diameters (Fig. 7.4) (by individual for the Late Pleistocene and A.L. 288-1 and by each phalanx to every body mass estimate for the other samples), the Pleistocene *Homo* samples are very similar. The australopith PPs, with their generally smaller body sizes, are substantially relatively longer (even ignoring the few, probably inappropriate, high ratios). A few of the australopith ratios overlap the *Homo* ones, and two of the Dinaledi ones are also relatively high. But there is nonetheless a substantial dichotomy between the australopith and *Homo* relative phalangeal lengths.

The longer australopith proximal phalanges are associated with a suite of related diaphyseal features that contrast with those of later *Homo* (Figs. 7.3 and 7.4). The *Homo* phalanges exhibit largely dorsally straight diaphyses, ovoid-shaped midshafts and small flexor sheath ridges located on the medial and lateral midshafts (although the Dinaledi and SKX-16699 PPs have slight dorsal convexities). The australopith phalanges are distinctly curved on their dorsal margins. They have prominent flexor sheath crests that are on the medioplantar and lateroplantar diaphysis along the distal halves of the shafts. The sizes and positions of these flexor sheaths are a product of having more curved diaphysis and hence greater plantarly directed forces on the sheaths, likely arising from the stronger contraction of the long pedal digital flexor

Fig. 7.3 Lateral views of lateral proximal pedal phalanges (*below*) and distributions of proximal articular angles. The angle is relative to the mid-articular axis and is generally lower than the canting angle (which inappropriately uses the plantar surface as the plane of reference). The Middle Pleistocene Atapuerca-SH sample has angles similar to the Late Pleistocene samples (Fig. 7.4)



muscles. These specific features cause the midshafts to appear semicircular in cross-sectional shape. The phalanges are also mediolaterally expanded more distally, giving the diaphysis a proximally waisted appearance in dorsal view. However assessed, the australopith lateral proximal pedal phalanges imply some degree of prehension, albeit markedly less than the much longer ones of the great apes.

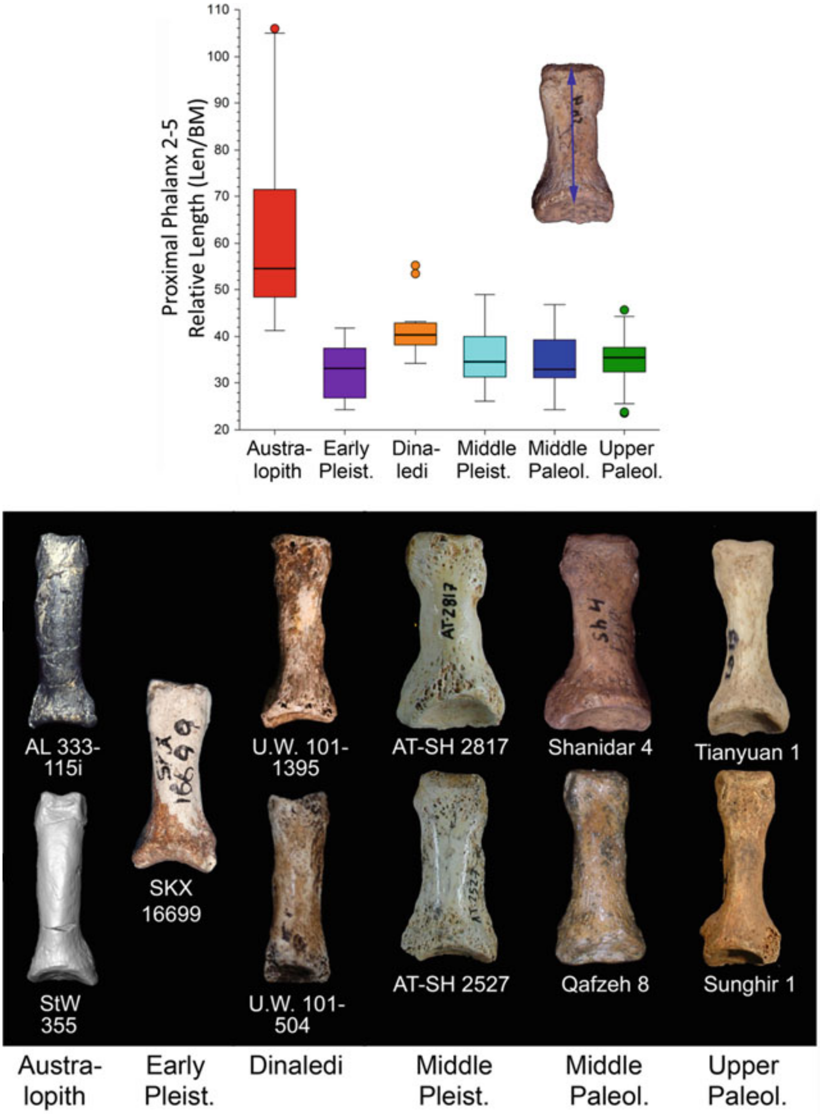


Fig. 7.4 Dorsal views of lateral proximal pedal phalanges (*below*) and articular length/estimated body mass (as a percentage) (*above*). For the Middle and Upper Paleolithic samples and A.L. 288-1, the comparisons are within individuals. For the remainder of the earlier samples, given the absence of associated phalanx lengths and body mass estimates, each phalangeal length is divided by each femoral head-based body mass estimate available for the appropriate sample. For the two Middle Pleistocene samples (Dinaledi and Atapuerca-SH), the comparisons are within site. For the StW, DNH and A.L. phalanges, the body mass estimates are from the femora attributed to *Au. africanus*, *P. robustus* and *Au. afarensis* respectively. For SKX-16699, the body mass estimates are for those attributed to early *Homo* (sensu stricto). For these reasons, and the pooling of lengths from rays 2 to 5, the box plots for the earlier samples (especially the australopiths) exhibit considerably greater variation than is indicated by the phalanges themselves

Proximal Pedal Phalanx Diaphyseal Hypertrophy

It is also possible to assess the relative degrees of hypertrophy, or robustness, of the lateral pedal phalanges, again pooling those from digits 2 to 5 and comparing those phalanges without an individually associated body mass to the range of body masses available for the appropriate sample (Fig. 7.5). To maximize sample sizes, midshaft polar moments of area are estimated from the diaphyseal diameters using ellipse formulae, and they are scaled using articular length times estimated body mass. The resultant values (Fig. 7.5) provide a large range for the australopiths, low values for the Early Pleistocene SKX-16699, higher values for the Dinaledi sample and intermediate and similar ranges for the Middle Pleistocene and Middle Paleolithic samples. Given the extensive overlap of these samples and the necessity to associate almost all of the pre-Middle Paleolithic ones by sample rather than by individual, there is probably little significance in the variations across these fossil samples.

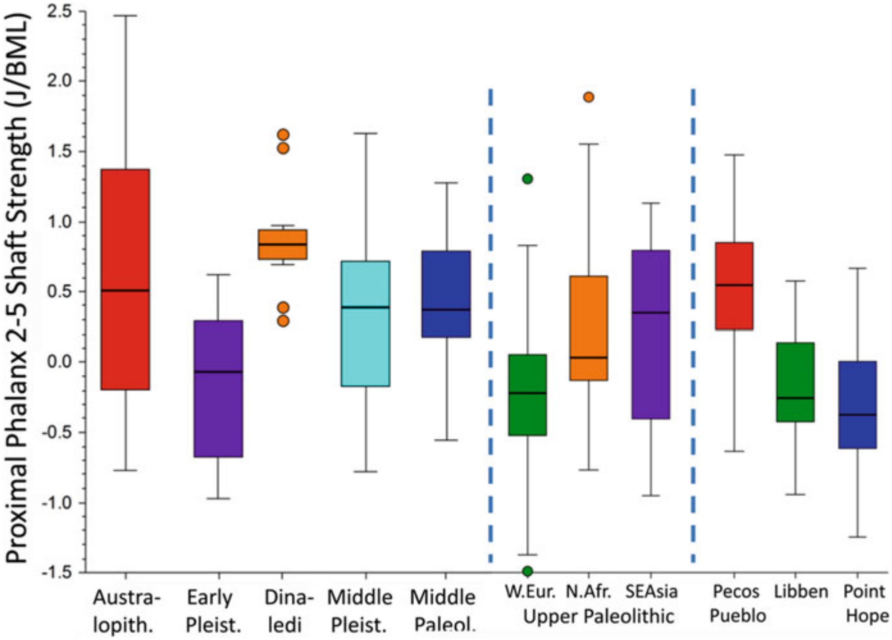


Fig. 7.5 Comparisons of midshaft relative strength across the paleontological samples and three recent Native American samples. Polar moments of area (J/Ip) are computed using standard ellipse formulae from the diaphyseal diameters, modelling the diaphysis as solid, and each is relative to the estimated body mass times phalangeal articular length (see Trinkaus and Patel 2016). As in Fig. 7.4, Late Pleistocene and recent phalanges, plus that of A.L. 288-1, are scaled by individual. The others are scaled to each of the body mass estimates for the appropriate sample. The Upper Paleolithic sample is subdivided regionally, and the recent human samples represent prehistoric Native Americans who were habitually unshod (Pecos Pueblo), shod (Point Hope) and variably shod (Libben)

In the assessment of the Upper Paleolithic phalanges, however, there is substantial interregional variation. The western Eurasian sample has relatively gracile phalanges, whereas the North African and especially the Southeast Asian one have more robust phalanges. In contrast, there is little difference across these samples in overall lower limb robustness. If these three samples are compared to ecogeographically separate Native American prehistoric samples, however, a pattern emerges. Across the Native American samples, the habitually unshod Pecos Pueblo (New Mexico) sample has robust phalanges, similar to Middle Pleistocene and Middle Paleolithic ones. The habitually shod Inuit Point Hope (Alaska) sample has relatively gracile ones, similar to the western Eurasian Upper Paleolithic sample. And the geographically intermediate Libben (northern Ohio) sample is modestly less gracile. Given that these three samples of Native Americans were similarly robust in their lower limbs, the variation in lateral pedal phalangeal hypertrophy reflects the degrees to which their lateral toes were protected by differences in the habitual use of footwear. If the framework from these Native Americans is then applied to the Upper Paleolithic samples, the inference is that the western Eurasian sample was habitually shod, the Southeast Asian one was often barefoot and the North African sample was intermediate but closer to the Southeast Asian one in the use of protective foot wear.

Implications for Pliocene and Pleistocene Footprints

The tarsometatarsal configurations of all of these Pliocene and Pleistocene pedal remains are therefore basically similar to those of recent humans, despite minor variations in size, proportions, articular details and musculoligamentous hypertrophy. They therefore imply that the primary forms of the footprints attributed to australopiths or members of the genus *Homo* should be similar. Given the high degree of variation in unshod footprint form within and across individuals among recent humans, due to normal ranges of pedal size and proportions, the variation in digital separation, degrees of toeing out during walking and variable pedal arch height, overlain by idiosyncratic variation in walking patterns, terrain and (of course) substrate characteristics, all of these hominins should have made footprints which were generally similar.

The areas of functional contrast in the pedal remains involve the digits. The australopiths and (to varying degrees) initial *Homo* digital remains indicate greater hallucal mobility and/or lateral forces on the hallux, a lack of hallux valgus (hence little toeing out), longer lateral phalanges and lateral phalanges which were less dorsiflexed in the later stages of the stance phase. The expectation would therefore be that australopith footprints, relative to those of later *Homo*, would exhibit normal human heel, arch and ball imprints, but that they would contrast in having less toeing out of the print (or more anteroposterior orientation of the footprint) and especially distally extended and deeper impressions from the lateral toes.

The one axis of variation among later Pleistocene humans is the reduction in lateral phalangeal robustness among the western Eurasian Upper Paleolithic humans and to a lesser extent among the North African ones. Especially compared to the Middle Pleistocene and the Middle Paleolithic samples, the implication is that there was a marked increase in the use of protective foot wear among these Upper Paleolithic human populations. Paleolithic footwear is not known, although at least one sample (the early Upper Paleolithic Sunghir one from northern Russia) exhibits both body decoration implying leggings/boots and extremely gracile lateral phalanges, indicating their habitual use of protective boots. Interestingly, almost all of the footprints known from Upper Paleolithic Eurasia are of unshod people, whether of children or adults. Were these people more often barefoot than their pedal phalanges and their cold temperate to glacial environments imply? Were they removing footwear to walk more securely in the karstic systems in which the footprints are primarily found? Or is there a bias in our footprint sample, such that the distinctively human barefoot ones are readily recognized, but the more amorphous ones that would be created by soft boots remain unrecorded?

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Chapter 8
Frozen in the Ashes

The 3.66-Million-Year-Old Hominin Footprints from Laetoli, Tanzania

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Abstract Fossil footprints are very useful palaeontological tools. Their features can help to identify their makers and also to infer biological as well as behavioural information. Nearly all the hominin tracks discovered so far are attributed to species of the genus *Homo*. The only exception is represented by the trackways found in the late 1970s at Laetoli, which are thought to have been made by three *Australopithecus afarensis* individuals about 3.66 million years ago. We have unearthed and described the footprints of two more individuals at Laetoli, who were moving on the same surface, in the same direction, and probably in the same timespan as the three found in the 1970s, apparently all belonging to a single herd of bipedal hominins walking from south to north. The estimated stature of one of the new individuals (about 1.65 m) exceeds those previously published for *Au. afarensis*. This evidence supports the existence of marked morphological variation within the species. Considering the bipedal footprints found at Laetoli as a whole, we can hypothesize that the tallest individual may have been the dominant male, the others smaller females and juveniles. Thus, considerable differences may have existed between sexes in these human ancestors, similar to modern gorillas.

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Forty Years of Research at Laetoli

Fossil skeletal elements can offer plenty of data on different aspects of human evolution and palaeobiology. However, the amount of information we can get about our ancestors can increase significantly through the study of fossil footprints. In fact, these ephemeral traces of life in the geological past can provide key palaeobiological insights on anatomy, locomotion biomechanics, body size, social behaviours, palaeoenvironments, and even reproductive strategies of extinct hominins (Falkingham et al. 2018). Unfortunately, due to the extremely peculiar taphonomic conditions that can lead to their preservation, fossil footprints are very rare. The hominin ichnological record is particularly poor (Bennett and Morse 2014), especially when compared to that of other vertebrate groups like dinosaurs. Nearly all the hominin tracks discovered so far are attributed to species of the genus *Homo*, with the outstanding exception of the record from Laetoli (Tanzania), dated to 3.66 million years ago (Ma).

Laetoli is one of the most important palaeoanthropological sites in the world. It is located in northern Tanzania (Fig. 8.1) at the southern margin of the Serengeti plains, within the Ngorongoro Conservation Area (NCA), in which several other world-famous palaeoanthropological localities like Olduvai Gorge, Lake Ndutu, and Nasera Rock, are found.

The Laetoli stratigraphic sequence is composed of Plio-Pleistocene volcano-sedimentary deposits divided into five main lithological units, the Laetolil Beds, Ndolanya Beds, Olgol Lavas/Naibadad Beds, Olpiro Beds, and Ngaloba Beds, from bottom to top (Hay 1987). At the base, the Laetolil Beds make up most of the sedimentary sequence, with a thickness of more than 120 m (Ditchfield and Harrison 2011). They probably formed from tephra erupted from the extinct Sadiman volcano, located about 20 km to the east of Laetoli (Hay 1987; Mollel et al. 2011), although this hypothesis is questioned by some authors (Zaitsev et al. 2011, 2015). The Laetolil Beds are divided into two units, namely, the Lower and Upper Laetolil Beds (4.36–3.85 Ma and 3.85–3.63 Ma, respectively) (Hay 1987; Deino 2011). The latter consist of a series of aeolian and fall-out tuffs (Hay 1987) and are well known for their abundant palaeontological content (Harrison and Kweka 2011).

The palaeoanthropological relevance of the Laetoli area and of the Upper Laetolil Beds in particular is well known since the mid-1930s (Reck and Kohl-Larsen 1936; Kohl-Larsen 1943), but the site turned the attention of the academia and general public in the 1970s, with the discovery of the holotype and other remains of *Australopithecus afarensis* (Leakey et al. 1976; Johanson et al. 1978), as well as of the earliest bipedal hominin tracks in the world (Leakey and Hay 1979; Leakey and Harris 1987).

Mammal, bird, and insect prints and trails were identified by Mary Leakey and collaborators in 18 sites (labelled from A to R) out of 33 total palaeontological

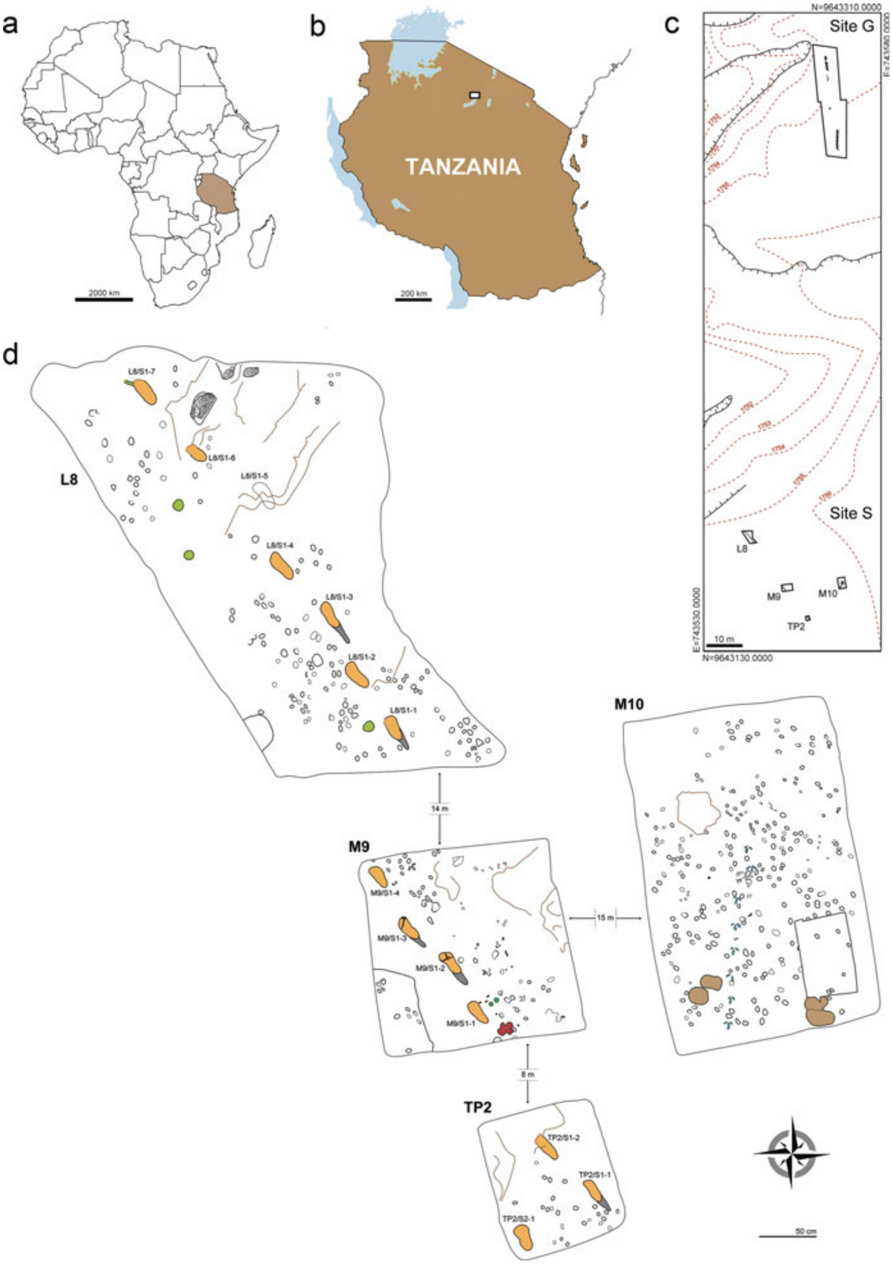

Fig. 8.1 Geographical location and site map; (**a**) location of Tanzania; (**b**) location of Laetoli in northern Tanzania; (**c**) plan view of Laetoli Locality 8 (Sites G and S); (**d**) plan view of the four test-pits excavated at Laetoli Site S. *Dashed lines* indicate uncertain contours. Hominin tracks in *orange*, equid tracks in *dark green*, rhinoceros track in *red*, giraffe tracks in *light brown*, and bird tracks in *blue*. (Modified from Masao et al. 2016)

localities in the Laetoli area (Leakey 1987; Harrison and Kweka 2011; Musiba et al. 2008). The so-called Footprint Tuff, which corresponds to the lower part of Tuff 7 in the Upper Laetolil Beds' stratigraphic sequence, hosts at least ten sublevels in which footprints are found (Hay 1987). Among these, hominin tracks were originally discovered at Site G (Locality 8). A short trackway of humanlike footprints was also unearthed at Site A (Locality 6) but was later attributed to a bear (Tuttle 2008). Site G footprints were referred to three individuals (G1, G2, G3) of different body sizes: the smaller G1 walked side by side on the left of the larger G2, while the intermediate-sized G3 superimposed its feet over those of G2 (Leakey 1981). These trackways are ascribed to *Au. afarensis* (White and Suwa 1987; Masao et al. 2016), which is the only hominin taxon found to date in the Upper Laetoli Beds (Harrison 2011).

Immediately after the first publication (Leakey and Hay 1979), the scientific and public interest in the Laetoli footprints has spread extraordinarily. Since then, they have been "mentioned in hundreds, if not thousands, of scientific works" (Jungers 2016), and a Google search for Laetoli footprints returns more than 66,000 results at the date of writing this contribution. In the first years after the discovery, the tracks were studied in several papers dealing with interactions between trackmakers (Leakey and Hay 1979; Leakey 1981), foot anatomy and locomotion (Day and Wickens 1980; White 1980; Charteris et al. 1981, 1982; Stern and Susman 1983), and depositional and palaeoenvironmental setting (Leakey and Hay 1979; Leakey 1981). In more recent years, with the development of new technologies and methods, many researchers worked on the key topic of locomotion of the Laetoli trackmakers by means of different approaches. These analyses led to conflicting views, with some authors (e.g. Raichlen et al. 2010; Crompton et al. 2012) inferring that the gait pattern of the Laetoli hominins was similar to that of modern humans, while others (e.g. Meldrum 2004; Schmid 2004; Bennett et al. 2009; Hatala et al. 2016) inferring that it was qualitatively and/or quantitatively different. However, regardless of the methods used, all the above studies are equally negatively affected by the fact that they are focused only on a limited number of G1 tracks. Although most of the G1 trackway is well preserved (unlike the overlapping footprints of G2 and G3), it belongs to the smallest of G individuals, which was very likely a juvenile (see "Laetoli Site S Footprints: Results and Implications"). Moreover, the original tracks are today buried under a protective cover (Feibel et al. 1996), and most of the studies were carried out on casts.

In light of the above, the recent discovery of new human footprints in Laetoli is of crucial importance for the knowledge of the anatomy, palaeobiology, and behaviour of Pliocene hominins.

The Discovery of Laetoli Site S

In 2014, two of us (F.T.M., E.B.I.) were commissioned to carry out a Cultural Heritage Impact Assessment (CHIA) aimed at evaluating the impact of a proposed new field museum in the area of Locality 8, that is, the palaeontological locality in which M. Leakey and co-authors discovered the first human tracks in the 1970s. According to Tanzania's Environmental Management Act (United Republic of Tanzania 2004), the CHIA is part of the Environmental and Sociological Impact Assessment (ESIA), which is a mandatory evaluation process expected to address the impact of a certain development project (e.g. infrastructure construction) on the environment, landscape, and social context (Ichumbaki and Mjema 2018). In particular, the CHIA is focused on the possible impacts on cultural heritage, both extinct (e.g. archaeological and palaeontological record) and extant (e.g. ethno-anthropological context).

Specific objectives of the CHIA were:

1. Salvaging as much of the threatened heritage as possible through surface collection and excavation
2. Preliminary analysis of the archaeological and palaeontological material rescued
3. Packing the material and presenting it to Ngorongoro Conservation Area Authority (NCAA) for curation and storage
4. Proposing mitigation measures including immediate conservation of special features encountered in the fieldwork process and proposing an appropriate monitoring schedule

The CHIA assignment was accomplished through two main fieldwork seasons. During the first season (June 21–30, 2014), the team of archaeologists, cartographers, conservators, and skilled workers aimed at obtaining an overall picture of the cultural heritage features in the area impacted by the project. In particular, the team surveyed a wide area within 500 m radius from the Site G trackways, i.e. the core area of the proposed museum project. The second season (September 13 to October 22, 2014) focused on the area of maximum impact, i.e. the surroundings of Site G. Sixty-two 2 × 2 m test-pits (each corresponding to about 2% of the total surface) were randomly positioned within a grid and carefully excavated down to the Footprint Tuff and sometimes deeper. If necessary, in case of particularly significant finds (see below), some pits were enlarged compared to the standard of 2 × 2 m.

About 150 m to the south of Site G, the team unearthed 14 hominin tracks associated with abundant tracks of other vertebrates. Footprints were found in three test-pits, respectively labelled L8, M9, and TP2 from north to south. The original square shape of L8 was modified soon after the discovery of the first bipedal tracks in order to follow the trail, thus obtaining a quite irregular shape of this test-pit (southern side, 2 m; western oblique side, 4 m). M9 was excavated some 14 m to the SSE of L8 and kept the standard size of 2 × 2 m. Following the putative alignment of the trackway, a third smaller test-pit, TP2 (1 × 1.2 m), was excavated at some 8 m to

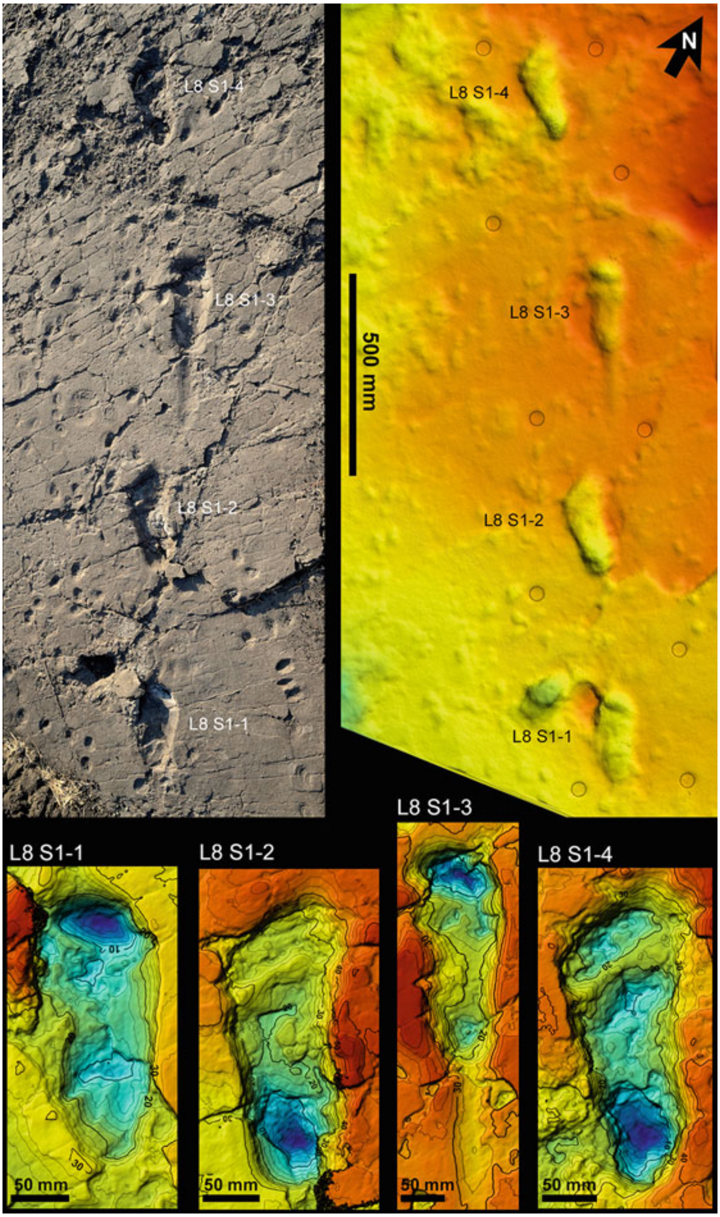

Fig. 8.2 Test-pit L8. Photo (*left*) and shaded 3D photogrammetric model (*right*) of the southern part of the printed surface, with close-ups (*bottom*) of the four footprints

the SSE of M9. Finally, test-pit M10 (2 × 3 m) was excavated about 15 m to the east of M9 to assess the occurrence of other interesting tracks (Fig. 8.1).

Once the presence of the new tracks has been ascertained and with the aim of characterizing the printed surface with a multidisciplinary approach, the Tanzanian-Italian research group was established, pivoting on a collaboration already started for years in Olduvai Gorge (e.g. Cherin et al. 2016). The new team reopened the four test-pits in September 2015. Fourteen hominin tracks in different preservation states always associated with tracks of other vertebrates were unearthed in test-pits L8, M9, and TP2 (Masao et al. 2016). All these prints are clearly referable to a single trail, with an estimated total length of 32 m and trending SSE to NNW. Following the code used for the other footprint sites in Laetoli (Leakey 1981; Leakey 1987; Harrison and Kweka 2011), the new site was identified as Site S, and the new tracks are attributed to individual S1 (footprint numbers S1-1–7 in L8, S1-1–4 in M9, and S1-1–2 in TP2) (Fig. 8.2). An additional track referable to a second individual (S2) was found in the SW corner of TP2. Conversely, only non-hominin footprints were recorded in M10 (Masao et al. 2016).

Survey of Laetoli Site S: A Case Study for Photogrammetry Application in Extreme Environments

Modern developments in computing power, rendering software, and hardware availability allowed a rapid and widespread diffusion of photogrammetry techniques in Earth Sciences and other disciplines. The majority of these techniques are based on Structure from Motion (SfM) algorithms (e.g. Luhmann et al. 2013; Mallison and Wings 2014; James et al. 2017). Among others, SfM techniques have been used in recent years to study river systems (e.g. Marteau et al. 2017), landslide dynamics and volumes (e.g. Stumpf et al. 2015), cliff morphology (e.g. Warrick et al. 2017), active fault structure and dynamics (e.g. Johnson et al. 2014), geobody architecture of depositional systems (e.g. Mancini et al. 2019), as well as ichnological contexts with human tracks (e.g. Rüther et al. 2012; Bennett et al. 2016; Bustos et al. 2018; Helm et al. 2018; Zimmer et al. 2018; Romano et al. 2019). SfM algorithms allow obtaining three-dimensional models from a series of overlapping pictures taken from different camera positions. The obtained high-resolution models can be easily shared between researchers and can be used for detailed qualitative descriptions and accurate quantitative analyses at the sub-mm-scale (Mallison and Wings 2014). However, in order to get affordable data from SfM, field data must be supported by accurate in situ topographic measurements.

The photogrammetric survey of the new footprint Site S was carried out in an extreme environmental context, characterized by unfavourable climatic conditions, need for light equipment, and little time available. Therefore, we had to set up a working procedure that, despite these problems, could lead to good results in terms of accuracy and precision and could also serve as a reference for other scientific activities in similar contexts (Menconero et al. 2019).

The Laetoli area is located over a wide plateau at about 1700 m above sea level, to the west of the volcanic complex of Sadiman (2870 m), Lemagrut (3135 m), and Oldeani (3200 m), and north to the Lake Eyasi basin. The plateau is characterized by a tabular or slightly corrugated morphology. In some areas, the landscape is more articulated due to the presence of valleys, gorges, and gullies originated by the action of wind and small streams, whose erosional energy is very intense during the dry season (May–October) and rainy season (November–May), respectively. The current vegetation cover is primarily determined by topography, soil composition, and climate (Anderson 2008) but is also influenced by natural and anthropic fires, as well as by the grazing activity of the extremely abundant wild herbivore mammals and domestic livestock (cattle, sheep, and goats) bred by local tribes with nomadic/semi-nomadic pastoral economy (Holdo et al. 2009). The vegetation mainly includes thorny thickets and dry bushland, consisting of shrubby and arboreal deciduous species of the genera *Vachellia*, *Senegalia*, and *Commiphora*, associated with several forms of grasses (e.g. *Sporoboro*, *Digitaria*, *Themeda*, *Aristida*, *Brachiaria*, *Cenchrus*) (Herlocker and Dirschl 1972; Andrews and Bamford 2008). The presence of numerous and densely distributed thorny plants can cause numerous problems during research activities. The wild animal community of the Laetoli area is still abundant and diverse, thanks to the low human demographic density, the presence of impenetrable thorny xerophilous shrublands, and the protection measures by the NCAA. Among reptiles, several snakes – such as the black mamba (*Dendroaspis polylepis*), green mamba (*D. angusticeps*), Egyptian cobra (*Naja haje*), spitting cobra (*N. nigricollis*), and puff adder (*Bitis arietans*) – can be potentially very dangerous to humans. The same goes for some large-sized mammals, like the African bush elephant (*Loxodonta africana*), spotted hyena (*Crocuta crocuta*), leopard (*Panthera pardus*), and African lion (*Panthera leo*). With regard to scientific activities, the low demographic density makes very hard to get consumer goods like food, water, and materials, which have to be bought in larger villages, such as Karatu, about 4-hour drive from Laetoli. As for the hygienic and sanitary conditions, thanks to the high average altitude and predominantly dry climate of the plateau, the whole Laetoli area is less affected by tropical pathologies that are common in the nearby low-altitude areas. However, especially in wet areas close to perennial small rivers, there are small populations of hematophagous dipterans like the mosquitos *Anophele* (vector of *Plasmodium*, responsible for malaria) and *Aedes* (carrier of various viruses responsible for serious diseases), as well as some horseflies (*Tabanidae*) and blackflies (*Simuliidae*), which can cause painful bites and severe skin irritations.

The above environmental conditions (climate, vegetation, fauna) are added to logistical complications (short time available, problems related to natural lighting, lack of electricity, long car trips along rough trails) in making extremely difficult the fieldwork in Laetoli (and similar contexts). Under these conditions, clear goals for the fieldwork are necessary. In our case, the work at Site S was aimed at obtaining 3D models of the new tracks for documentation and morphometric analysis. We chose the SfM photogrammetry technique, thanks to its technical advantages (relatively short time of data acquisition and processing, light and handy equipment, reduced costs) and excellent results in terms of resolution (Westoby et al. 2012).

Each test-pit (L8, M9, TP2, and M10) was entirely surveyed at lower resolution (Fig. 8.3), and then detailed 3D models of some inner portions (single tracks or groups of close prints) were acquired (Fig. 8.4). Targets of the control point system were immediately positioned after excavation. We placed four perimeter targets at the corner of each test-pit and four inner targets around each subarea surveyed in detail (14 in L8, 10 in M9, 14 in TP2, and 14 in M10). For the measurement of the control points, we used a measuring tape and a water level, which are lighter and easier to handle than a total station theodolite. We selected these low-tech tools also considering (1) measuring only four points for each test-pit to scale the general 3D models and (2) aligning the detailed 3D models of the single footprints to the general models using the coordinates of the inner targets. For the perimeter target measurements, we placed two rods equipped with a spherical level on successive pairs of targets, and we marked points at the same height on the rods for each pair by using the water level device. The vertical distance between these points and the targets, as well as their mutual distance, were recorded. Repeating this process for all pairs of targets, the relative plan position and the height of the control points were determined respectively by trilateration and levelling. A preliminary accuracy check was carried out by means of trilateration graphic rules in plan and with the method of successive levelling for heights. By assigning a z-coordinate to the first control point, all subsequent coordinates were derived from addition and subtraction of heights between two successive points. The check was performed by computing the sum of all height differences and by verifying that the obtained value was close to zero. Finally, the error obtained in each test-pit was distributed to every z-coordinate of the points, in order to minimize it.

Photographic acquisition was performed with a DSLR camera, sometimes fixed on a 3-m-long telescopic rod for photographic shots from the top downwards. With regard to scene lighting, since we had no possibility to control light intensity and direction, we tried to reduce shadows by shooting especially during the central hours of the day (i.e. with subvertical sun rays). However, this was not always possible due to the excavation schedule and little time available. Therefore, we had to address the problem of high-contrast shadows in post-processing.

The texture resolution control of 3D models, namely, the Ground Sampling Distance (GSD), can be performed a priori using geometric formulas. The calculation is based on the principle of similar triangles, which are found in the geometry of the shooting. The variables are the size of the sensor (Sw) and the focal length of the camera (Fl), the size in pixel of the images (Iw), and the distance (H). The triangle with the base Sw and height Fl is similar to the triangle which has the base Gw (width of the image on the ground) and height H; consequently, the two triangles have proportional respective sides (Sw: Gw = Fl: H). The GSD is the ratio between Gw and Iw multiplied by 100 (GSD = Gw/Iw × 100). Connecting the proportion with the formula of GSD, the final formula GSD = (Sw × H × 100): (Fl × Iw) is obtained. Among the variables, the one that can be easily managed is the distance H,

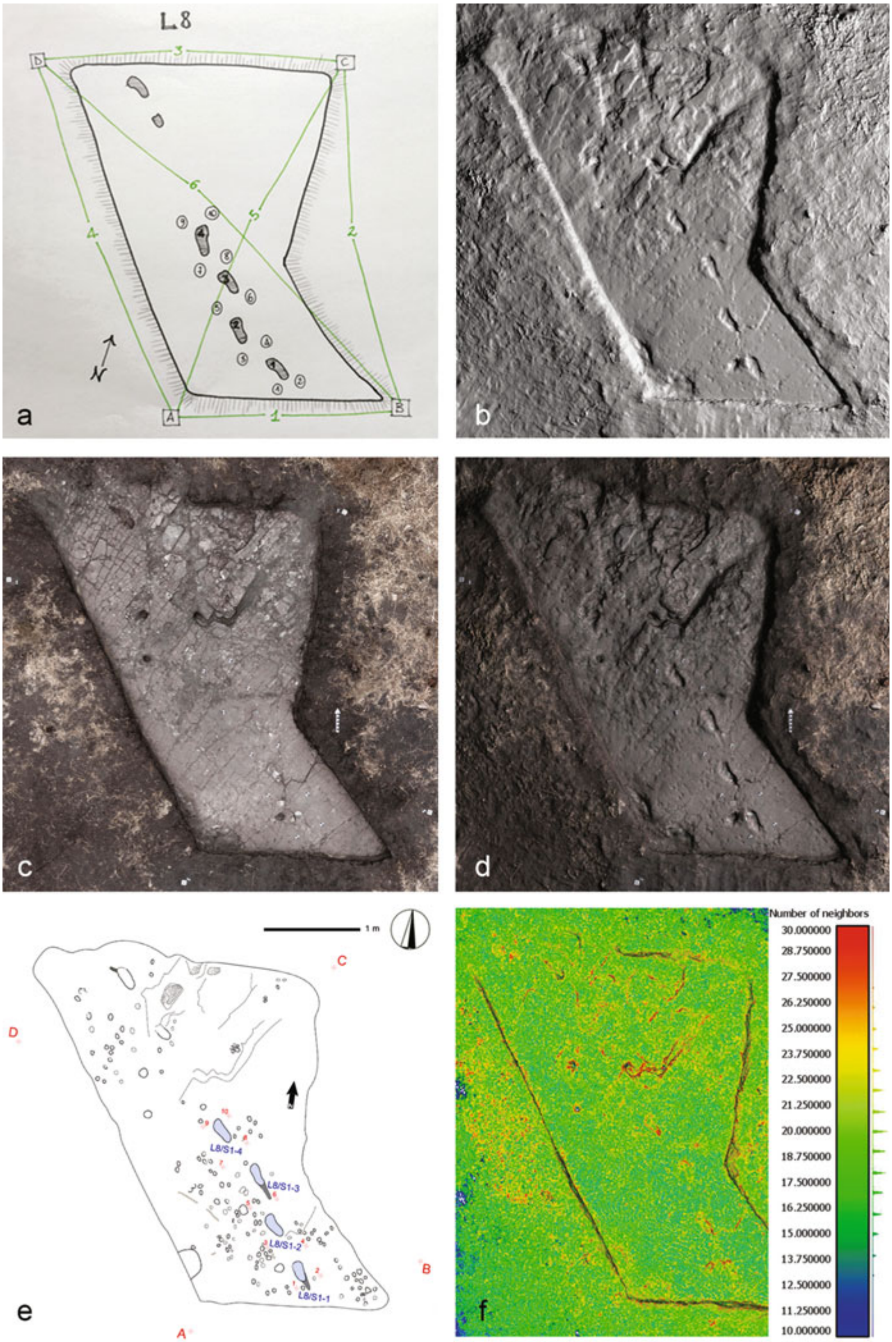

Fig. 8.3 Test-pit L8; (**a**) eidotype; (**b**) shaded model; (**c**) textured model; (**d**) textured and shaded model; (**e**) drawing; (**f**) density of the point cloud by determining the number of nearest neighbours in a sphere with 0.5 cm radius

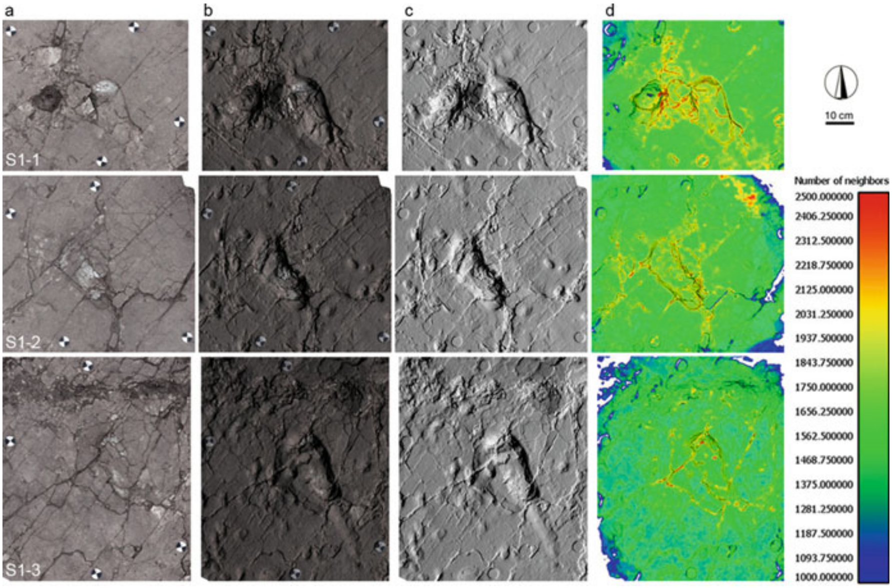

Fig. 8.4 Three footprints from test-pit L8; (**a**) textured model; (**b**) textured and shaded model; (**c**) shaded model; (**e**) density of the point cloud by determining the number of nearest neighbours in a sphere with 0.5 cm radius

since all the others depend on the photographic equipment available (Menconero et al. 2019).

It is impossible to know a priori the density of the point cloud coming from a photogrammetric process. As for the Laetoli footprints, the goal was to obtain a texture resolution less than 0.1 cm/px. This was achieved by choosing suitable shooting distance both for the whole test-pits and individual footprints. More than 2000 photos were taken in three working days, for a total of about 50 GB. Especially when working in remote areas, it is important not to economize on shots and possibly select them a posteriori.

Data processing started with checking topographic measurements in plan and height, which is preliminary to the definition of the control point coordinates. The trilateration method was used to obtain x, y coordinates of the control points in plan. For each test-pit, six measurements were taken at the same height: the length of the four sides of the perimeter and the length of the two diagonals. Redundant measurements were used to compute the errors. In addition to a preliminary graphical control by CAD software, we used an automatic calculation software to adjust a new set of x, y coordinates and heights of the control points by least squares technique. The residues of adjustments never exceeded 10 mm, which is fully acceptable considering the size of the test-pits. We used the adjusted x, y, z coordinates of the control points to scale and locate in the 3D space the SfM models. A check on point cloud density was also carried out by a software for 3D point cloud and mesh processing and analysis. The average density found in the Laetoli point clouds is around

20 points/cm^3 for the test-pits and 1500 points/cm^3 for the detailed footprints (Masao et al. 2016; Menconero et al. 2019).

The 3D models obtained by SfM were also used in the morphometric analysis of the hominin tracks. We used a contouring and modelling software that transforms x, y, z data into maps. The x, y, z-format files were imported into the software and transformed into grid files. The software uses randomly spaced x, y, z data to create regularly spaced grids composed of nodes with x, y, z coordinates. The Triangulation with Linear Interpolation gridding method was applied, because it works better with data that are evenly distributed over the grid area. This method creates network of triangles with no edge intersection starting from data points and computes new values along the edges. The grid spacing was set at 1 mm. Standard morphometric measurements (footprint length, footprint max width, footprint heel width, angle of gait, step length, and stride length) were taken from contour maps and compared with those taken manually both on the original tracks during the fieldwork and on 1:1 scale sketches of the test-pits, hand-drawn on transparent plastic sheets (Masao et al. 2016).

Laetoli Site S Footprints: Results and Implications

The detailed analysis of the new bipedal footprints at Site S started trying to frame this outstanding finding into the stratigraphic context of the Upper Laetolil Beds. A detailed sequence analysis of the excavation profiles at Site S and extended geological observations in the whole Laetoli area were performed. In particular, we tried to reconstruct the stratigraphic relationships between the footprint-bearing units of Site S and Site G, using both field observation and literature descriptions of the sequence outcropping in the original site.

The Laetoli Footprint Tuff is part of Tuff 7 together with the overlying Augite Biotite Tuff and can be divided into a lower and an upper unit. These can be respectively subdivided into 14 and 4 sublevels. Tracks are found on eight sublevels within the lower unit and two within the upper one (Leakey and Hay 1979; Hay and Leakey 1982; Hay 1987). In particular, hominin tracks at Site G are located on the top of horizon B, namely, on sublevel 14 of the Footprint Tuff lower unit (Hay and Leakey 1982; White and Suwa 1987). Though with some local differences presumably due to lateral variability, we found that the Site S sequence corresponded quite well with the original description of the Footprint Tuff stratigraphy provided by Hay (1987). In particular, we observed that the Site S tracks were printed on the top of the lower subunit of the Footprint Tuff, corresponding to the aforementioned horizon B (Masao et al. 2016). Consequently, our data indicate with reasonable confidence that the footprints of S1 and S2 lie on the same stratigraphic position as those at Site G. Considering that (1) Tuff 7 includes a sequence of several sublevels originated by distinct volcanic eruptions close in time, and that its overall deposition time is estimated in weeks (Hay and Leakey 1982; Hay 1987), (2) trackways from Site G and Site S show almost the same orientation, and (3) all trackmakers were moving approximately at the same moderate speed (see below), we hypothesized that the tracks from the two sites were left by a homogeneous group of hominins walking together on the same palaeosurface (Masao et al. 2016).

The overall morphology of the S1 tracks fits those from Site G and is particularly similar to the prints of G2, namely, the larger individual (Robbins 1987): the heel is oval shaped and is pressed deeply into the ground; the medial side of the arch is higher than the lateral one; the ball region is oriented at an angle of about 75° with respect to the longitudinal axis of the foot and is delimited anteriorly by a transversal ridge, formed when the toes gripped the wet volcanic ash and pushed it posteriorly; the adducted hallux extends more anteriorly than the other toes in all visible footprints; unfortunately, no clear distinction among the other toes is visible. The only preserved track of S2 is abnormally widened in the anterior part, probably due to a lateral slipping of the foot before the toe-off and/or to taphonomic factors related to the fragmentation of the Footprint Tuff.

Stride length was used to estimate the walking speed of the Laetoli trackmakers. Mean values of about 0.44–0.9 m/s were obtained, depending on the computing method (Alexander 1976; Dingwall et al. 2013). The average length of the S1 tracks is 261 mm (range 245–274 mm). Lower average values were measured for the three individuals at Site G: 180 mm for G1, 225 mm for G2, and 209 mm for G3 (Leakey 1981; Tuttle 1987), although a study of some G footprint casts based on digital methods (Bennett et al. 2016) suggested higher values for G1 (193 mm) and G3 (228 mm). Stature was computed first with Tuttle's (1987) approach, which is based on the ratio between foot length and stature in modern humans (foot length in *Homo sapiens* is generally about 14–16% of stature). We also estimated stature using the two methods published by Dingwall et al. (2013). The first is based on regressions of stature by footprint length in modern Daasanach people from Lake Turkana (Kenya); the second – which we considered more reliable because it is not influenced by modern human data – is based on the foot/stature ratio known for *Au. afarensis*. Similarly, we estimated the body mass of the trackmakers by means of the regression equation that relates footprint area to body mass in *H. sapiens*, as well as of the equation based on the ratio between foot length and body mass in *Au. afarensis* (Dingwall et al. 2013). All the above data were also measured/calculated for G individuals, using a 3D model of a first-generation cast of the southern portion of the Site G trackways.

Our results showed that no matter which method is employed to estimate stature and body mass, S1 and S2 were taller and had a larger body mass than the G individuals (S1, 161–168 cm/41.3–48.1 kg; S2, 142–149 cm/36.5–42.4 kg; G1, 111–116 cm/28.5–33.1 kg; G2, 139–145 cm/35.6–41.4 kg; G3, 129–135 cm/33.1–38.5 kg) (Masao et al. 2016). These results extended the dimensional range of the Laetoli trackmakers and identified S1 as a large-sized individual, probably a male. The stature of about 165 cm for S1 is remarkable and exceeds those estimated to date for any australopithecine. The stature of S1 falls within the maximum range of modern *Homo sapiens* and also fits the available *Homo erectus* sensu lato estimates based on both skeletal remains and footprints. The body mass range

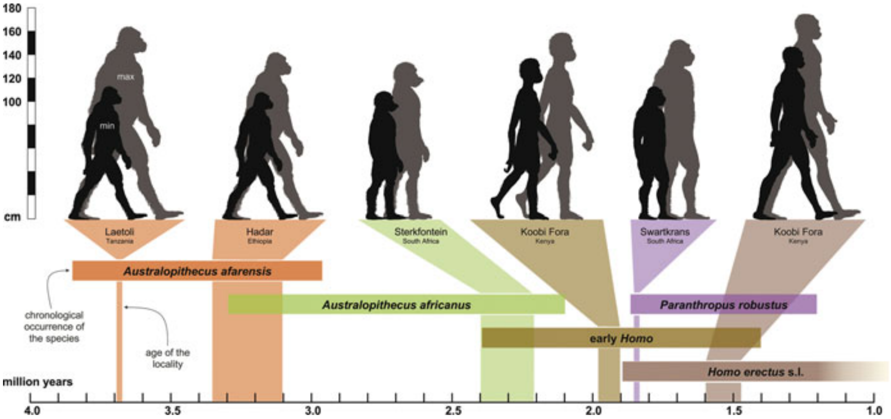

Fig. 8.5 Minimum and maximum estimated statures of selected fossil hominins by species and locality over time for the interval 4–1 million years

estimated for S1 falls within the range of male *Au. afarensis* (40.2–61.0 kg) (Grabowski et al. 2015).

Our results provided independent evidence for the occurrence of large-sized individuals among hominins as ancient as 3.66 Ma and supported a nonlinear evolutionary trend in hominin body size (Jungers et al. 2016). Moreover, ascribing the S1 tracks to a possible male allowed reconsidering the sex and age of the other Laetoli individuals. According to our body-mass estimations, G1 and G3 fall within the range of putative *Au. afarensis* females, whereas G2 and S2 span across the upper female and the lower male ranges, which are estimated at 25.5–38.1 and 40.2–61.0 kg, respectively (Grabowski et al. 2015). A possible reconstruction is that the Laetoli individuals are S1, a male; G2 and S2, females; and G1 and G3, smaller females or juvenile individuals.

Both the new composition of the group and the impressive body size difference point to a considerable sexual dimorphism in *Au. Afarensis* (Fig. 8.5), as hypothesized by many scholars on the basis of skeletal remains (e.g. Johanson and White 1979; Kimbel and White 1988; McHenry 1991; Richmond and Jungers 1995; Lockwood et al. 1996; Plavcan et al. 2005; Harmon 2006; Gordon et al. 2008). In turn, this view supports social organization and reproductive strategies closer to the polygynous gorillas (Harcourt and Stewart 2007) than to other moderately dimorphic species, like the promiscuous chimpanzees or the extant and, possibly, extinct humans (Masao et al. 2016).

Laetoli Footprints: Perspectives

The recent discovery of Laetoli Site S footprints, after about 40 years from the pioneering works by Mary Leakey and colleagues at Site G, has achieved a remarkable media coverage and has drawn the attention of the scientific community.

Raichlen and Gordon (2017) used proportional toe depth (i.e. a measure of the difference between toe depth and hindfoot depth in tracks) as a proxy to get information about the locomotor style of the Laetoli trackmakers. They confirmed that the footprints from Site S are overall very similar to those from Site G, thus supporting the hypothesis that bipedal locomotion in *Au. afarensis* was more similar to modern-human-like extended-limb pattern than to chimpanzee-like bent-knee-bent-hip pattern (Raichlen et al. 2010).

DeSilva et al. (2019) included data on the Laetoli footprints from Sites G and S in their comprehensive review of Plio-Pleistocene hominin foot evolution.

In their very interesting work, Villmoare et al. (2019) inferred data on sexual dimorphism in *H. erectus* s.l. through the analysis of fossil footprints from Ileret, Kenya (about 1.5 Ma). Their results are in perfect agreement with ours in the recognition of a gorilla-like high level of dimorphism in *Au. afarensis* from Laetoli. These data are in contrast with those obtained for the Ileret sample, in which footprints show a much lower degree of sexual dimorphism, although slightly higher than that of modern humans. According to the authors, this would suggest that by 1.5 million years ago, at least *H. erectus* s.l. had transitioned away from polygyny (Villmoare et al. 2019).

Following a completely different line of research, the original contribution by Ichumbaki et al. (2019) addressed the topic of local community's interpretations of the Laetoli hominin footprints. For the first time, the authors documented narratives of Maasai (i.e. local people living in the Laetoli area) dealing with their perceptions on what the footprints are and to whom they belong. The Maasai people connect Laetoli footprints to the tale of *Lakalanga*, a strong hero who helped them to win a battle against a neighbouring community. According to the story – which is consolidated into the local community oral tradition – *Lakalanga* was so big that wherever he walked, he left visible tracks on the ground. Thus, the discovery of the large-sized footprints at Site S has offered a further confirmation to the Maasai that the hero warrior *Lakalanga* really existed (Ichumbaki et al. 2019).

The aforementioned papers represent a synthetic selection of those in which Site S footprints have been studied/mentioned after their recent description (Masao et al. 2016). However, besides these research contributions, the discovery of Site S calls on the whole international scientific community to question itself on the challenging issue of conservation. Our fieldwork at Laetoli in 2014–2015 showed us the relevance and peculiarities of the site. Besides the good preservation of the footprints and their outstanding scientific significance, we could also verify the aggressiveness of the East African environment on the ichnological record. Through qualitative observations of the conservation status of the Footprint Tuff, we could ascertain how the disruptive action of weathering, flora, and fauna is threatening the footprints even before excavation. This is jeopardizing a unique piece of cultural heritage that is still largely unknown. Similar concerns were highlighted by several authors (Feibel et al. 1996; Getty Conservation Institute 1996; Agnew and Demas 1998) after the assessment of the state of conservation of the Site G footprints, which in the 1990s had been the subject of a project of consolidation, reburial, and protection coordinated by the Getty Conservation Institute and Tanzanian Antiquities Division (Musiba et al. 2012). Further analyses are necessary at Site S to address the crucial issue of the conservation of this invaluable palaeontological heritage. Large portions of the printed surfaces unearthed in the test-pits are already severely threatened by natural agents and could quickly disappear even if unexcavated (Masao et al. 2016). Fractures are bringing to disintegration of part of the Footprint Tuff into small cubic blocks. Roots are displacing the stratigraphic sequence and are opening preferential ways for water to penetrate the substrate and for arthropods to dig burrows in the ground. Therefore, keeping the situation as it is may not be the right way to preserve the site, because unexcavated footprints may be saved from weathering if they are excavated and properly treated. At the same time, we are aware that any excavation without a clear understanding of the physical, chemical, and biological risks to which the Footprint Tuff is exposed should not be undertaken. A modern project aimed at the excavation, conservation, and valorization of the Laetoli tracks must be preceded by a multidisciplinary study of environmental data such as local microclimate, temperature and humidity variations, rainfall, dominant wind, geological and petrographic characteristics of the substrate, interstitial water composition and flow, physical damage due to trespassing of livestock and wild animals, and local vegetation composition and its change. Future plans must include a programme of continuous monitoring of the footprints, especially with the involvement of the local community (Ichumbaki et al. 2019).

Once established a comprehensive plan of conservation and valorization of the Laetoli footprints in close collaboration with all the involved Tanzanian (e.g. Ministry of Natural Resources and Tourism, NCAA) and international (e.g. UNESCO) institutions, new systematic excavations can be carried out. This would allow unearthing the entire S1 and S2 trackways and also opening up the intriguing possibility of discovering tracks of other individuals. This new research would noticeably improve the available dataset on the foot anatomy, locomotor pattern, body size variation, social structure, and behaviour of the Laetoli australopithecines.

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Chapter 9
Steps from History

The Happisburgh Footprints and Their Connections with the Past

Nick Ashton

Abstract Human footprints were discovered at Happisburgh, UK, in 2013. This paper describes their discovery and the difficulties of recording such enigmatic remains in a coastal environment. The geological and environmental context in which they were found is given, together with the evidence of the dating of the site to either 850,000 or 950,000 years ago. The implications of how humans coped with long, cold winters of northern Europe is discussed; the evidence of a family group indicates that seasonal migration is highly unlikely, leaving the possibilities of either physiological adaptations, such as functional body hair, or the use of technologies such as shelter, clothing and fire. The second part of the paper shows the various ways in which the footprints have reached wide and diverse audiences through media reports, exhibitions and books. They show the powerful messages that footprints can generate through the ideas and emotions that they provoke and the immediacy of their connection with the deep past.

Keywords Human footprints · Lower Palaeolithic · Early Pleistocene · Britain · Europe

Introduction

Footprints tell stories. They can provide information about bipedalism, posture, gait and stature, as well as on occasion, the sex and age range of a group and activities being undertaken (e.g. Leakey and Hay 1979; Day and Wickens 1980; Charteris et al. 1981; Behrensmeyer and Laporte 1981; Bell 2007; Roberts 2008; Bennett et al. 2009; Dingwall et al. 2013). Modern-day trackers can provide new insights into past

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prints through their skills and knowledge (Pastoors et al. 2015, 2017). But footprints also connect a wider public directly to our past. They are the visible trace fossils that everyone can recognise from life today and therefore have a resonance with a wider audience than the bones and stones that contribute most of the evidence from our deep past. The Happisburgh footprints were discovered in 2013. This paper explains their discovery and the information that can be gleaned from them while reviewing how these short-lived glimpses of our distant cousins make unexpected connections with the present.

Background to Happisburgh

Happisburgh is a small village on the northeast coast of Norfolk in the UK (Fig. 9.1). The cliffs on which the village sits consist of glacial sands, silts and clays that were deposited by the Anglian Glaciation, which is correlated with Marine Isotope Stage (MIS) 12, c. 450,000 years ago (450 ka). Beneath the glacial succession lies the Cromer Forest-bed Formation (CF-bF), which is composed of estuarine, fluvial and alluvial deposits that span the Early and early Middle Pleistocene, between c. 2 and 0.5 million years ago (Ma). The CF-bF outcrops extensively around a 70 km stretch of coast between Sheringham in the north to Pakefield in the south. The deposits include several important interglacial sites famous for Early and early Middle Pleistocene fossil remains (Reid 1882; West 1980; Preece et al. 2009; Stuart and Lister 2010; Preece and Parfitt 2012).

In the last 20 years, there has been accelerated erosion of the coastal cliffs and the underlying sediment, which has led to increased exposures of the CF-bF and, for the first time, the discovery of undisputed Lower Palaeolithic artefacts within the sediments. Of particular note are Pakefield, dating to c. 700 ka (Parfitt et al. 2005), Happisburgh Site 1 (HSB1) dating to c. 500 ka (Ashton et al. 2008; Lewis et al. 2019) and Happisburgh Site 3 (HSB3), dating to c. 850 ka or possibly c. 950 ka (Parfitt et al. 2010; Ashton et al. 2014). This evidence has extended the record of human occupation of northern Europe by at least 350,000 years and has also provided important insights into the environments of the early human occupation in northern latitudes (Candy et al. 2011; Ashton and Lewis 2012).

Happisburgh Site 3

The pre-glacial Pleistocene succession at Happisburgh was first investigated by Reid (1882) and more recently by West (1980). West described the sediments exposed at the base of the cliffs and in the foreshore at a number of locations and also in a

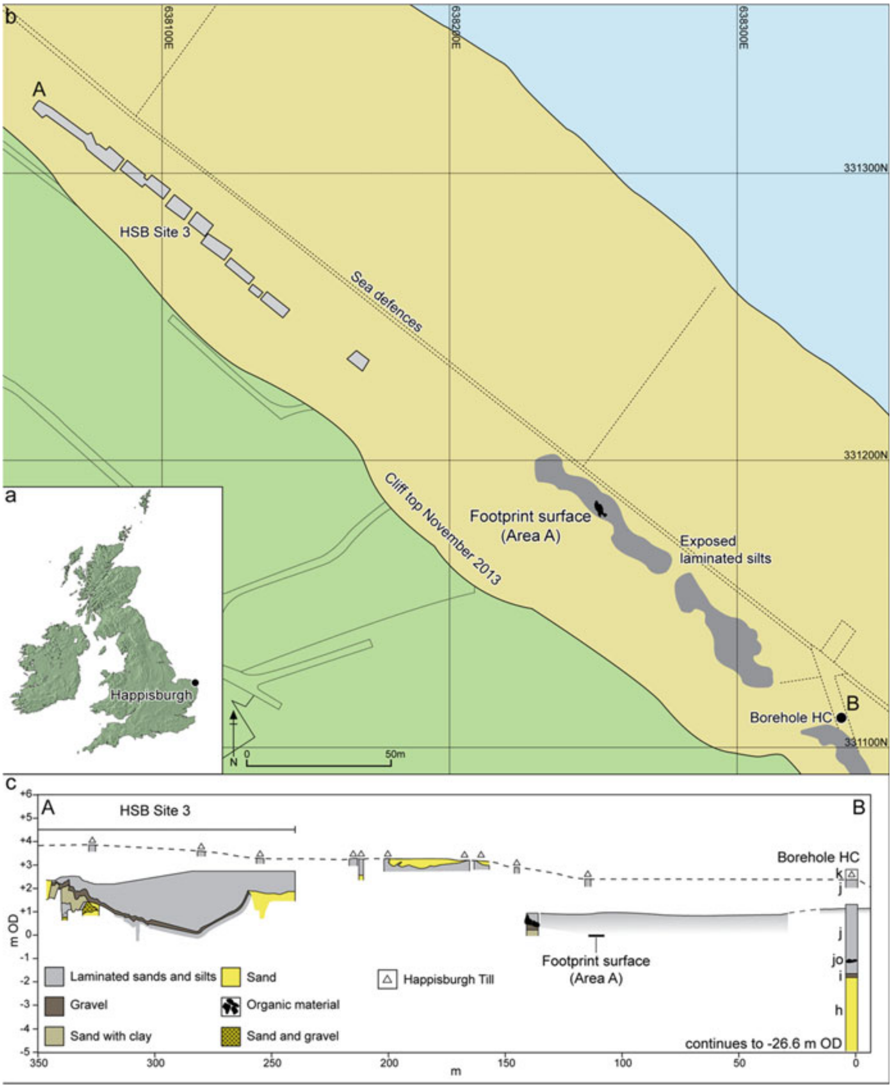

Fig. 9.1 (**a**) Map of Britain showing location of Happisburgh; (**b**) plan of Happisburgh Site 3, exposed and recorded foreshore sediments, location of footprint surface and of borehole HC; (**c**) schematic cross-section of recorded sediments from Happisburgh Site 3 through to borehole HC showing stratigraphic position of footprint surface. (Illustration C. Williams)

borehole near the former slipway on to the beach (Fig. 9.1). This borehole (HC) demonstrated a sequence of laminated silts and sands beneath the Happisburgh Till. Palynological data from the laminated silts indicated an interglacial vegetational succession, which West attributed to a late stage of the Early Pleistocene.

Happisburgh Site 3 was discovered in 2005, some 330 m to the northeast of Borehole HC, while undertaking a coastal survey of CF-bF deposits on a 3 km stretch of coast to the north of Happisburgh. Seasonal excavation until 2012 revealed a series of deposits that relate to those of West in Borehole HC (Parfitt et al. 2010). At Site 3 they consist of a series of estuarine sands and silts which infill channels. The channels have a lag gravel at their base up to 0.2 m in thickness, from which an artefact assemblage has been recovered, consisting of c. 80 flint flakes, flake tools and cores, all in remarkably fresh condition.

The sediments also contain a rich assemblage of fauna and flora (Parfitt et al. 2010). Pollen, wood and other plant remains indicate a regional vegetational succession that had changed from deciduous woodland to coniferous forest. The more localised environment can be reconstructed from study of the insect remains suggesting a floodplain that consisted of a mosaic of grassland, stands of alder, small pools and marsh. This is supported by grassland pollen recovered from a hyaena coprolite. The vertebrate remains include part of the skull of European sturgeon (*Acipenser sturio*), which today spawn in deep-water estuaries. Together with other indicators of brackish water and the interpretation of the laminated silts and sands, the evidence suggests that the site was in the upper reaches of an estuary of a large river. Other vertebrate fauna includes giant elk (*Cervalces latifrons*), red deer (*Cervus elaphus*) and an extinct form of horse (*Equus suessenbornensis*), alongside larger herbivores such as an early form of mammoth (*Mammuthus meridionalis*) and hippopotamus (*Hippopotamus amphibius*).

The shift in the vegetational succession towards coniferous forest suggests that the site dates towards the end of an interglacial with a cooler climate (Parfitt et al. 2010). This is supported by the beetle remains, which indicate that summer temperatures were similar to East Anglia today with an average of about 17 °C. But the winters were between −3 and 0 °C, whereas today the average is 4 °C. A modern-day analogue would be southern Scandinavia or Denmark, which would have made winters a challenge to survive and prompts questions about the level of technology in terms of shelter, clothing and fire (Ashton and Lewis 2012).

The age of the site is constrained by the overlying glacial sediments, which indicate that it is older than 450 ka. A reversed palaeomagnetic signal suggests that the site predates the Brunhes-Matuyama boundary at 780 ka and is Early Pleistocene in age. Refinement of the age can be determined by the mammalian fossils; *Mammuthus meridionalis* is known to have become extinct about 800 ka, and the horse, *Equus Suessenbornensis*, also became extinct about this time, both of which support the evidence from the palaeomagnetics. A maximum age can be determined from the extinct giant elk, *Cervalces latifrons*, and red deer, *Cervus elaphus*, which first evolved about a million years ago. The pollen suggests a date towards the end of an interglacial, with the two most likely stages being MIS 21 at 850 ka or MIS 25 at 950 ka (Parfitt et al. 2010).

The Footprint Surface

Fieldwork at Happisburgh continued after the excavations were completed in 2012, with funding by English Heritage (now Historic England), through a programme of geophysical and coring surveys to understand better the distribution of CF-bF sediments on the foreshore and inland and whether evidence of their survival could be found offshore through further survey and diving (Ashton et al. 2018). In early May 2013, during the survey work, an area of laminated silts was exposed c. 110 m northwest of borehole HC and c. 140 m of the excavations of Site 3 (Figs. 9.2 and 9.3; Ashton et al. 2014). The laminated sediments could be traced laterally between the three locations. Although the exact stratigraphic relationships

Fig. 9.2 View of footprint surface cliff top looking south. (Photo M. Bates)

Fig. 9.3 View of footprint surface looking north. (Photo M. Bates)

remain uncertain, they are of a similar age and, based on Site 3, date to either 850 ka or 950 ka.

In the new exposure, beach sand had been removed by the sea, and the laminated sediments were subject to wave erosion. When exposed, the bedding surfaces provide natural planes of weakness, and the washing out of sandy laminae results in the removal of layers of laminated silts and the exposure of new, undisturbed bedding surfaces. In most cases, these surfaces are flat or gently undulating and display ripple structures formed during the original deposition of the sediments. However, one horizon had very different surface characteristics where a series of hollows ranging from circular to elongate in outline were visible over an area of c. 12 m^2. The elongate hollows were generally 30–50 mm in depth, 140–250 mm in length and 60–110 mm in width. The visual similarity to Holocene footprint surfaces prompted more detailed investigation of this horizon. However, the surface was located in the intertidal zone and was prone to rapid destruction by wave action or to reburial as the beach was re-established. The situation presented particular challenges for recording and analysis of the features and prevented either lifting of the footprint surface as sediment blocks or standard casting of moulds of the surface. Initially it was hoped to laser scan the surface, but availability of equipment was a problem. However, a relatively new technique of multi-image photogrammetry was just beginning to be more widely used in archaeology, and so, with the expertise of Sarah Duffy from the University of York, a team was mobilised, and this method was used a few days after discovery.

Multi-image photogrammetry simply uses a series of digital images of an object or surface with fixed points, taken from different angles, which when combined with specialist software creates a 3D model (Fig. 9.4). The principle was fine, but the practicality was more difficult. The combination of tides, blown beach sand, weather conditions and time constraints made recording the surface extremely difficult. Prior to recording, water was used to wash away the beach sand that had been deposited during previous high tides, though it was impossible to completely clear the surface and remove all water from the hollows due to persistent rain. Field measurement of the hollows was not possible because of the time constraints, but multi-image photogrammetry proved to be an effective method for rapid recording of the surface features and allowed subsequent metric analysis of footprint shape and size, although estimates of depth were more problematic. Laser scanning was also attempted a week later, but by this time, the features had become severely eroded through successive tidal cycles, and by the end of May 2013, they had been completely removed (Ashton et al. 2014).

After recording, the first task was to determine the agency responsible for their formation. The possibility of them being recent footprints was immediately ruled out due to the hardness and compaction of the laminated sediments. Walking across similar sediments has little impact even in heavy boots. Extensive searches were made for natural erosive agencies that might be responsible, but none of the hollows were consistent with the range of processes that are normally found in an estuarine environment. After initial scepticism and careful scrutiny of the evidence, it was

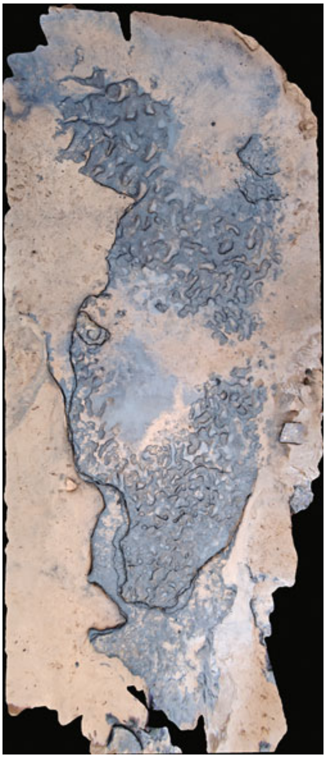

Fig. 9.4 Model of footprint surface produced from photogrammetric survey. (Modelling S. Duffy)

concluded that the hollows were indeed ancient human footprints (Ashton et al. 2014).

The surface was analysed using vertical images produced from the multi-image photogrammetry. Depth measurements were not possible as water or sand was often retained in the base of the prints. A total of 152 hollows were measured, and this revealed that the lengths, widths and width/length ratios were consistent within the expected range of juvenile and adult hominin footprints (Ashton et al. 2014). In some cases, left or right and front or back of the foot were also apparent, including two instances of toes, providing information about direction of movement. The less elongated features were also potentially hominin footprints, where impressions from just heels or the front of feet were preserved, or overprinting had obscured original features. The time elapsed from initial exposure to recording also led to some erosion of the surface, which affected the shape and clarity of the prints.

More detailed analysis by Isabelle de Groote, from Liverpool John Moores University, was limited to 12 prints where complete outlines could be clearly identified (Ashton et al. 2014). They were thought to indicate at least five individuals with foot lengths between 140 and 260 mm. Based on recent populations, stature can be estimated from foot length using a ratio of 0.15 for foot length/stature (Dingwall et al. 2013). Fossil skeletal evidence suggests that body proportions of Middle

Pleistocene hominins were similar to modern humans, and therefore this ratio can also be applied to past populations (Carretero et al. 2012; Pablos et al. 2012). The 0.15 ratio suggested a height range for the Happisburgh hominins of between 0.93 and 1.73 m, indicating the presence of adults and children. For the orientation studies, a larger dataset of 49 prints was analysed, showing a preferred south-north orientation. In 29 cases where the arch and the front/back of the foot could be identified, the direction of movement was also assessed, showing a preferred direction of movement to the south.

Unfortunately, there are no human fossils from Britain that date to this period, but the closest comparison is Gran Dolina (TD6) at Atapuerca in northern Spain where bones and teeth dating to c. 800 ka have been named as *Homo antecessor* or Pioneer Man (Carbonell et al. 2005, 2008). This attribution has recently been examined using 2D morphometrics on a range of footprints from Pliocene, Pleistocene and Holocene sites (Wiseman et al. 2020). They conclude that the dimensions of the Happisburgh footprints were most similar to the *H. erectus* footprints from Ileret in Kenya. This conforms with an attribution of the Happisburgh hominins to *H. antecessor*, thought to be a European cousin of *H. erectus*. If this attribution is correct, then estimates of stature from the fossil bones from Gran Dolina TD6 can be compared to Happisburgh. The tali recovered from TD6 show a mean stature of 1.73 m for males and 1.68 m for females (Pablos et al. 2012). This would suggest that the tallest individual at Happisburgh was an adult male with the smaller footprints being produced by either adult females or juveniles and by children. An obvious interpretation is that the Happisburgh footprints were left by a family group.

The search for further footprints at Happisburgh has been difficult. Excavation is not practical as the deposits extend for several hundred metres and are up to 2 m in depth with multiple horizons. The chance of selecting the right area and encountering a footprint surface is minimal. In fact the sea is the best excavator through the twice daily peeling off of surfaces in an impartial way. Since 2014 there have been periodic exposures of the laminated silts between Site 3 and Borehole HC, and on occasion there have been reports of possible footprints. Often by the time a visit to the site is made, the prints have either eroded away or have been buried by beach sand. In one case, a small exposure was revealed during a field visit and a record made (pers. comm. Simon Lewis). The most successful approach has been through several local collectors and trained amateurs, who equipped with GPS have been able to collect, record and report new artefacts and fossils and also alert us to any new exposures with potential prints. On-the-spot photography with multiple images is encouraged, and this will hopefully capture enough information of any future footprint surfaces before they are eroded away.

Implications of the Happisburgh Footprints

Questions remain about how the Happisburgh hominins survived the long, cold winters of northern Europe. One suggestion is that they seasonally migrated. However to make any appreciable difference to winter temperatures, they would have had to have travelled to coastal areas of southern Europe. This might have been feasible for adult hunting groups, but the evidence from Happisburgh shows the presence of children. Such a journey would have been virtually impossible as a family group. The implication from the footprints is that the humans were residents and surviving the long, cold winters.

An alternative option for survival was that the Happisburgh humans had functional body hair that gave them sufficient protection from the cold. The favoured hypothesis that hominins lost their body hair over several million years in open, equatorial areas of Africa deserves re-examination (Wheeler 1984, 1991, 1992). The argument goes that with bipedalism, there was less need for protection from the sun, leading to a reduction in body hair, other than the scalp. One of the evolutionary advantages was better thermoregulation through more efficient sweat glands, which also enabled longer day-time hunting. This may have been the case, but there is no direct proof. It may have had advantages for Africa, but there were serious shortcomings for the more seasonal climates of Europe. So perhaps humans entering Europe from Africa still had body hair, or it redeveloped as they evolved in more northerly latitudes.

The simplest answer to how the humans coped with cooler climates is that they had better control of fire and were more capable of making clothes and shelters than previously thought. Unfortunately there is no evidence for the use of these technologies at this time. Better evidence for ways of buffering against the cold start to be introduced from around 500 ka. At High Lodge in Suffolk, there are scrapers that were ideal tools for processing hides, presumably for building simple shelters or use as clothing (Ashton et al. 1992). From 400 ka at Beeches Pit, also in Suffolk, or Menez Dregan in Brittany, there are distinct hearths from fires (Gowlett et al. 2005; Preece et al. 2007; Ravon 2018). If earlier evidence is to be found, then Happisburgh with its rich organic preservation is an obvious place to look.

If the footprint evidence is correct and the humans were all-year residents, then perhaps the biggest challenge was the short growing season of northern latitudes (Ashton 2015; Hosfield 2016). This implied a greater dependence on meat and more effective scavenging or possibly hunting. If meat acquisition was a struggle, what other resources were available? The big advantage for Happisburgh was its estuary situation, providing important resources such as collectable shellfish and seaweed over the difficult winter months. Perhaps these pioneering populations were able to cope in northern Europe but only in coastal or estuary situations (Cohen et al. 2012).

Impact of the Happisburgh Footprints

The evidence that the footprints provide of a family group, wandering along the edge of an estuary, not only received academic attention as the oldest footprints outside Africa but drew wide appreciation from public audiences around the globe. Here was the story of a family group, somehow surviving the cold winters of northern Europe at almost a million years ago. The footprints were published in February 2014 to coincide with an exhibition Britain: One Million years of the Human Story at the Natural History Museum in London, where Happisburgh began the story with video footage of the footprint discovery (Ashton et al. 2014; Dinnis and Stringer 2014). A British Museum press release on February 7th, a few hours before the publication, led to widespread coverage by all UK television and radio networks, as well as many abroad, with an astonishing 250 newspaper reports around the world.

But news is short-lived, so it is more gratifying to see how the footprints have endured in other, sometimes unexpected, ways. The footprints prompted mention in several books. One of the more popular accounts has been in *The Road to Little Dribbling: More Notes from a Small Island* by Bill Bryson, who visited Happisburgh and described the footprints on his return journey around Britain (Bryson 2015). A more unusual project was undertaken by the Dutch radio broadcaster and writer, Mathijs Deen, who in *Over Oude Wegen: Een Reis door de Geschiedenis van Europa* (Down Old Roads: A Journey through Europe's History, Deen 2018) explores by car the famous ancient journeys and stories along routeways that still connect us today. The first journey that he describes was that potentially taken by *Homo antecessor* from Atapuerca in northern Spain to Happisburgh.

This year, a beautifully written book, *Time Song*, was published by Julia Blackburn (2019). It interleaves her own stories and encounters, with thoughts on Doggerland, the now vanished prehistoric landscape that lies beneath the North Sea. She reflects on the Happisburgh footprints and the people who left them behind. They feature in 2 of the 18 *Time Song* poems, with the first about their discovery:

> The weather was bad.
>   Rain falling,
>   Waves crashing.
>
>   Over the next two weeks.
>   The hollows were photographed.
>   and scanned with lasers,
>   Before they vanished,
>   Leaving no trace.
>
>   One hundred and two footprints.
>   Twelve of them complete,
>   Indicating five individuals.
>   Of different ages:
>   A little human group.
>   Moving in a southerly direction.
>   Across the mudflats.
>   Of a large tidal river,

> Between eight hundred and fifty.
> And nine hundred and fifty.
> Thousand.
> Years ago.
> Making a further jump back.
> In the history of habitation.
> In this country,
> Now called England.
> (Blackburn 2019: 62–63)

A very different topic has been covered by Antonia Malchik in her thought-provoking book, *A Walking Life: Reclaiming Our Health and Our Freedom One Step at a Time* (Malchik 2019). The book examines from an American perspective the car-centric culture in which we live and the barriers imposed by a modern world on the freedom to walk. Bipedalism, she argues, is one of the characteristics that make us human, represented in part by the footprints from Happisburgh. Walking is essential for our health, a powerful means to rehabilitation and important for societal welfare. The interactions that it brings can encourage and bind communities, in contrast to the often cocooned, loneliness of suburban, motor-driven life.

She devotes much of the final chapter, “Meandering”, to her visit to Happisburgh, describing her own journey and the significance of the discovery. One section particularly struck me, where she comments on a deep, underlying lesson from the Happisburgh footprints: the importance of meandering, rather than efficiency, for learning.

> “The footprints weren’t in a straight line,” Ashton told me when we met at his British Museum office. Not being in a straight line was a criticism other researchers had levelled at the find. But to him, the wandering nature of the footprints made complete sense. Because the Happisburgh footprints included children. This wasn’t just a temporary hunting party, a group moving through seasonally. These people were living there.
>
> The Laetoli footprints are in a straight line, and it’s easy to imagine those hominins some three or four million years ago walking across the savannah, heading … where? The Happisburgh footprints, though, give us movement and life, images of children veering off to poke in the mud, chase some small animal or crustacean, or peer at a plant, just as my children did at that age. Just as the infants in Karen Adolph’s lab do, roaming around in the most inefficient manner possible because that is how we grow and explore and learn. (Malchik 2019: 204)

Is this another human characteristic, at times forgotten from our childhood – that of curiosity?

Connections to the present were also made through a small, but powerful, exhibition at the British Museum in April 2017. Called Moving Stories, the exhibition drew together three journeys about migration. The first was the million-year-old journey told by footprints discovered at Happisburgh. A life-size image of the footprint surface was projected onto the floor, and visitors were encouraged to step into the prints of their distant relatives (Fig. 9.5). The surface was animated with water ebbing and flowing across the surface – an image that would have been apparent at the time of their creation over 850,000 years ago, as well a view that we had on their discovery. A muted soundtrack took the visitor back to Happisburgh through the sounds of gently flowing water, with the cries and calls of estuary birds

Fig. 9.5 Moving Stories exhibition at the British Museum, April 2017. The footprint surface is projected onto the floor and gently animated with flowing water. It has its own space within a shipping container, representing modern migration, with a window onto the second story of the pictorial diary, *Ali's Boat*. (Photo British Museum)

and background chatter of children and their parents. The exhibition explained that this was a metaphorical journey that had taken the family beyond the natural boundaries of the known world. But it was this and similar journeys that eventually led to adaptation to more difficult environments through better provision of basic human needs: food, clothing, shelter and fire.

The Happisburgh journey was juxtaposed against the heart-wrenching story of exile in the contemporary work, *Ali's Boat*, by Iraqi artist Sadik Kwaish Alfraji. *Ali's Boat* is a pictorial diary that tells the story of a young boy wishing to escape the horrors of present-day Iraq. It is inspired by an encounter with his 11-year-old nephew who, on Sadik's departure from Iraq to the Netherlands in 2009, gave him a drawing of a boat, with the words "I wish this boat takes me to you". The exhibition showed how in the present day many migrants still have a quest for the same basic human needs of food, warmth and shelter but with boundaries and barriers drawn by politics rather than geography.

The third journey of Moving Stories was told through the work of Édouard Glissant, a poet and philosopher from Martinique, about the slave trade diasporas from Africa. Remarkably his work offers a positive outlook, suggesting that although migrants may lose their social and cultural unity, they gain cultural diversity and multiplicity; importantly differences can unite, rather than divide and are the means to build global communities. The underlying lesson of all three journeys was that migration not only brings hardship but also opportunities and it is an inherent human trait that goes back to the deep past.

Conclusion

It is quite astonishing how a few simple footprints beneath a beach in Norfolk can invoke such wide and varied reaction and generate such profound thoughts and ideas. Many people are simply awe-inspired by their age, brief appearance and the serendipity of being spotted and recorded. For others they are a journey by pioneers, pushing the boundaries of the known world, or one to the unknown world through their enigmatic appearance and disappearance as a brief glimpse into the now drowned landscapes of the North Sea. They are both past and present. The importance of history is what it can tell us about today or tomorrow or the thoughts and emotions that it can provoke. For most, the power of Happisburgh lies in the family group and the everyday story of children playing at the water's edge. I admire the eyes, knowledge and skills of the modern tracker and envy their ability to interpret a different world. I lack their skills, but I do have my own vision of Happisburgh some 850,000 years ago.

> The tide was gently rising as the family group picked their way around the shallow pools on the mudflats of the estuary edge. They paused to watch a herd of horse grazing near the reedswamp on the far bank. A lone rhinoceros and three mammoths could be seen as silhouettes in the distance. The parents watched warily and rather enviously as a cackle of hyaenas greedily tore apart the flesh of an elk, little more than a stone's throw away. They had been beaten by their competitors to the injured animal. Today their family would survive on the plant roots and shellfish they had eaten earlier. Tomorrow there might be other opportunities before the lions, wolves and hyaenas took their share. The three children seemed oblivious to the danger, splashing about bare-foot at the water's edge. The older boy realised the risk and encouraged them on; they had to reach the safety of the deep pine forest before dusk. The sun was sinking fast and a chill breeze rippled across the water as a skein of geese took flight. The family continued on their way leaving trails of footprints in the estuary muds. (Ashton 2017: 1)

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Chapter 10

Reconsideration of the Antiquity of the Middle Palaeolithic Footprints from Theopetra Cave (Thessaly, Greece)

Nina Kyparissi-Apostolika and Sotiris K. Manolis

Abstract During the 1996 field season, four footprints were found in undisturbed deposits at the borders of squares Θ10-I10 at a depth of 3.5 m at the Theopetra Cave excavation site. The footprints lie adjacent to an ash horizon that has been dated to ca ~135 ka. Two footprints in the trail are complete and measure 150.4 mm and 138.96 mm in length. Based on modern European standards, these lengths would be consistent with young children aged between 2 and 4 years old and 90–100 cm in stature. The two complete footprints, which follow each other in the trail, appear both to have been left feet. The partial print, which immediately precedes the two complete prints in the series, also appears to have been by a left foot. This suggests that what initially seems to be a single trail is actually a composite of two or more trails of prints. This hypothesis is supported by the different characteristics of the two complete prints. One is consistent with a bare foot and clearly shows the impressions of the toes, ball, arch and heel. The other is characterized by a simpler contour and is more sharply defined and indicates that the individual was wearing some kind of foot covering. An important question is what kind of hominid made the footprints? These footprints may have been made by Neanderthals or early *Homo sapiens*, based on thermoluminescence dating results.

Keywords Footprints · Early *Homo sapiens* · Neanderthals · Middle Pleistocene · Theopetra Cave · Europe · Greece

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Introduction

Theopetra Cave (21°40′46″E, 39°40′51″N) is a unique prehistoric site in central Greece (Fig. 10.1), as several cultural periods (Middle and Upper Palaeolithic, Mesolithic and Neolithic) are represented (Kyparissi-Apostolika 1998, 1999; Facorellis et al. 2001; Karkanas 2001).

Excavations at Theopetra Cave have produced many significant anthropological findings, among which the prehistoric footprints are distinctive. During the 1996 field season, four footprints were found in undisturbed deposits in square Θ10 at a depth of 3.5 m (Fig. 10.2) (Manolis et al. 2000). The footprints lie adjacent to an ash horizon that has been dated to ca ~130 ka (new date after Valladas et al. 2007). These

Fig. 10.1 Map of Greece showing the site of Theopetra Cave

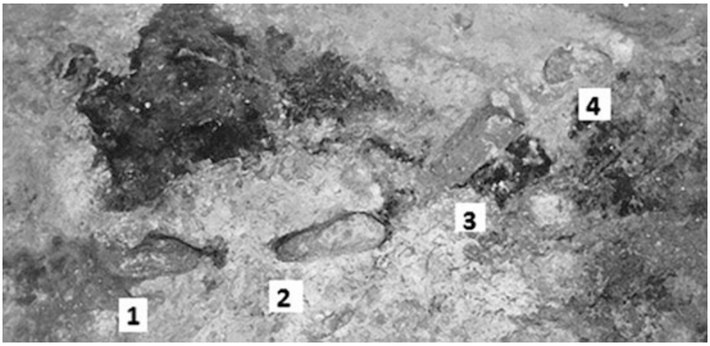

Fig. 10.2 The footprints found in the Theopetra Cave

footprints were found among others printed in an extensive ashy and burnt area of five serial trenches in axis 10 of the excavation grid (Z10, H10, Θ10, I10, K10), 16 to 20 m^2. Most of the remaining footprints rather belong to animals, but the presence of a few more human ones among them cannot be excluded (Fig. 10.2).

In palaeoanthropology it is well understood that we cannot know in detail the behaviour of upright body posture and bipedalism. Our inferences concerning the shaping of the body and the way of walking are derived from comparing data after following a logical sequence of thoughts. These are based mostly on the hypothesis of the homology of various anatomic characteristics.

The footprints are an undeniable proof of the existence of hominids and/or prehistoric humans in general, and we can draw from them very important information about locomotion and composition of the group, through comparative and experimental methods.

Such information might be (after Day 1991):

- Morphological: Because in palaeoanthropology the findings are mostly hard – fossilized bones – the discovery of footprints may give us information about the shape of the soft parts of the foot and the size and morphology of its anatomical picture. This includes the position of the metatarsal area, the heel, the toes, their prominence and the presence of an arch. The measurements allow us to estimate the size and compare it to that of other known human populations. The stature may also be estimated from world data where the length of the foot is approximately 15% of the height.
- Behavioural: By studying the footprints we can make inferences about the way of walking, whether the individual was running at the time the footprints were made, and we can also estimate the pace. Of course, this is not always possible, because it is required that the series of steps lies undisturbed, like in the case of Laetoli, Tanzania.
- Environmental: Together with the human footprints there could be others made by animals, in which case we will be able to assume if they are contemporary with

each other. Related botanical data will allow us to recreate the climatic and environmental conditions at the given time.

Historical Background

The most ancient footprints in the world are the ones discovered in Laetoli, Tanzania, and have been dated to 3.7 Ma. Therefore, when footprints are discovered, some of the questions that need to be answered can be: Who were the hominids that created them? Were they male or female and of what age? How tall were they? How much did they weigh? Some of these questions may be answered, but comparative data are required. Next, we will see which of these we have been able to answer through our research so far.

The most ancient footprints in Europe were found at Happisburgh, UK, dated to the Early Pleistocene (ca ~1–0.78 Ma) (Ashton et al. 2014). The following caves or open-air sites have been dated to the Middle Pleistocene: Roccamonfina, Italy, 325,000–385,000, open air (Avanzini et al. 2004, 2008); Terra Amata, France, 300,000–400,000, open air (de Lumley 1966, 1967); and Theopetra Cave, Greece, ca 130,000, cave (Manolis et al. 2000).

Late Pleistocene sites are caves such as the Vârtop Cave in Romania dated 62 ka (Onac et al. 2005); the Grotta del Cavallo in Italy (the first known appearance of anatomically modern humans in Europe, ~44 ka (Benazzi et al. 2011); and several caves in France such as Lascaux, Niaux, Aldene, Peche Merle, Fontanet, Ariège and Chauvet, Bàsura in Italy and Ojo Guareña in Spain (Lockley et al. 2008). All these sites except the Vârtop Cave and Grotta del Cavallo have been dated below 30,000 years and therefore are undoubtedly the trails of anatomically modern humans. The footprints of children seem to be an important component of the trail record of Palaeolithic caves. For example, Chauvet Cave in southern France revealed a trail of footprints of a young boy (8 years old and 1.5 m tall) (Harrington 1999). Niaux is of significant interest because it includes footprints that may represent children (Pales 1976). In the Réseau Clastres, three trails of children are recorded (Lockley et al. 2008). In the Bàsura Cave in Italy, (Chiapella 1952; see Chap. 14) Late Pleistocene tracks of children were found.

Materials and Methods

After the necessary cleaning process took place, the footprints were copied and photographed, and a negative cast was created. Positive casts of the footprints were also created for the necessity of research (mapping). The questions arising are of the same kind as the ones mentioned earlier. Nevertheless, a more thorough observation revealed that all four footprints were made by left feet, and this caused one more question to rise: are these solitary footprints or trails of steps crossing each other, some of which have been lost?

The suggestion that we are before a series of steps made by different individuals is considered the most possible, since the first two prints were made by a foot with some kind of covering, the third has been made by a bare foot, whereas the fourth one is not clearly distinguished, either because it has been rotated or because other footprints have been made on it.

Chronology – Dating

Ten burnt flint specimens unearthed from the lower part of the Middle Palaeolithic sequence of the cave (layers II2 and II4) were dated by thermoluminescence (TL), which gave dates ranging between ~110 and 135 ka (Valladas et al. 2007). The positions of the TL-dated samples are shown in Fig. 10.3. These results are not consistent with the earlier ^{14}C dates (Facorellis and Maniatis 1999), as they support a much later date for these layers (Facorellis et al. 2013). Facorellis and his colleagues (2013) note that the depositional sequence of Theopetra Cave is complex with frequently appearing filled channels and underground tunnels as well as labyrinthine large burrows. It is well established by sediment micromorphological analysis that

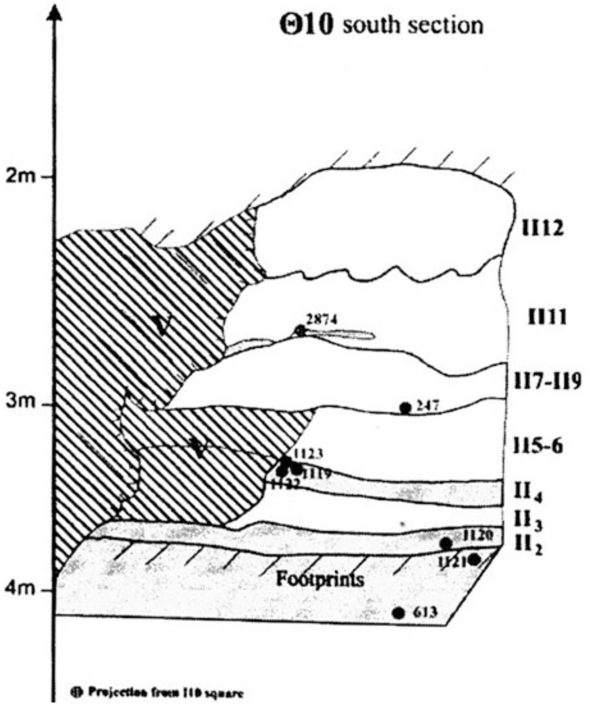

Fig. 10.3 Stratigraphic profile of the trench I10 showing the position of the samples. (After Facorellis et al. 2013)

the Pleistocene sediments underwent an intense diagenetic mechanical and chemical alteration related to the cave's hydrological conditions.

Comparison between the ^{14}C dates with the much older TL dates of 11 burnt flint specimens indicates that most of the charcoal samples have been contaminated by a progressively increasing unidentified amount of exogenous carbon, thus yielding more recent dates (Facorellis et al. 2013).

Archaeology – Lithic Artefacts

The Middle Palaeolithic (II1–8) is represented by the most clearly stratified lithic deposits. The principal characteristic of the layer II2 lithic industry is the use of the Levallois technique for production of a wide range of tool types. The assemblages from layer II4 bear technological and morphological characteristics often encountered in the terminal Middle Palaeolithic industries of the Balkans and the Near East. Their principal characteristic is the use of both Levallois unipolar and prismatic bipolar core reduction strategies. The tool inventory of Theopetra Cave contains Middle and, to a lesser extent, Upper Palaeolithic types (Panagopoulou 1999, 2000).

Description of the Footprints

A detailed examination disclosed that all four footprints were made by left feet, and it remains unresolved whether these are solitary footprints or continuous trails of steps crossing each other where some intermediate steps are missing. There are four footprints. The first footprint in the trail (No 1) lacks the posterior half of the foot and had been made by a covered foot. The second is complete (Fig. 10.4a) and was also created by a covered foot. Although the footprint is restricted due to the covering material (footwear), we can clearly observe the arch region and the support lines at the external region of the foot. The distance between these two left footprints is small (25 cm), so there is not enough space for the right footprint, which is not preserved. This led us to suppose that they belong to different individuals. The third is also complete but has been made by a bare foot (Fig. 10.4b). The big toe, the ball, the arch and the heel region are evident in the footprint. The last one is disturbed, and it is very difficult to be analysed.

Two methods of analysis have been used, which led to almost the same results, stereophotography and photogrammetry. The latter was used by M. Day for the analysis of various footprints from Laetoli (Tanzania), Niaux Cave (France), Bàsura Cave (Italy), and Uskmouth (Great Britain). Both methods include the creation of contour lines (mapping).

However, when we evaluated this method, we estimated it would be quite difficult to produce an illustration of the contours. This means that the researchers might miss important parts of the contours (in different altitudes), and so they would

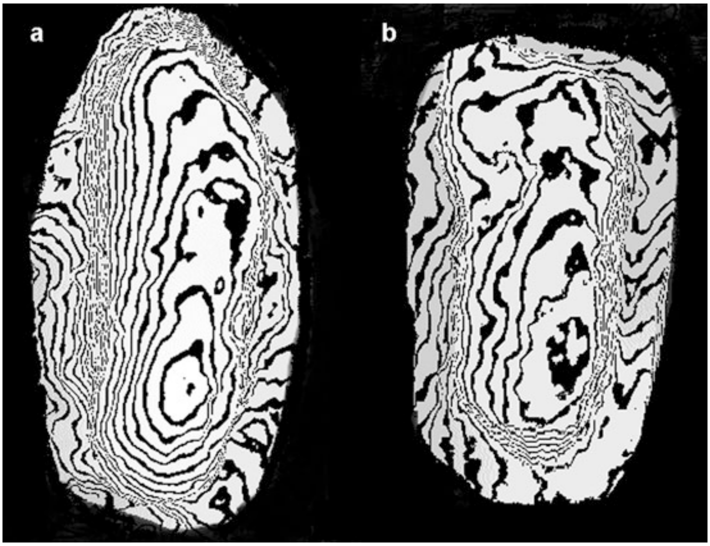

Fig. 10.4 Contours shaped by 3D laser scanning of the Theopetra footprints; (**a**) Theopetra No 2; (**b**) Theopetra No 3

have to fill them in, without being certain that the additions were correct. It was therefore decided (see Manolis et al. 2000) to illustrate the contours of the studied footprints by using a 3D laser scanner, and the results were indeed impressive. It should also be noted that this method was innovative, the software was still under development, and this was the first official application in anthropological material. Subsequent studies mainly use 3D laser scanner in the study of footprints.

The length and width of the footprints were measured as well, so that they could be compared to data from contemporary humans. The formulae for the estimation of height when sex and age are unknown (as in this case) are the following (after Grivas et al. 2008):

$$\text{Height(cm)} = 17.369 + 5.879 \times [\text{right foot length(in cm)}]$$

$$\text{Height(cm)} = 17.592 + 5.861 \times [\text{left foot length(in cm)}]$$

Another formula is the estimation of stature by the foot length as a percentage of body height. The percentage may vary from 14% to 16% according to the population measured, although the traditional figure quoted is 15% (Topinard 1877). This formula applies to both sexes and individuals of all ages. However, when calculating the size of the foot from footprints rather than contours (footwear), there is a difference of 1%, meaning that the length of the foot is 14% of the height and not 15%, with a variation of ±25.4 mm (Robbins 1985, 1986).

Results

Contour Analysis (3D Laser Scanner)

In order to proceed with our study, we needed to gather data from the contemporary Greek population. For this first stage, footprints from three subadults (one male and two females) were collected. Comparing the contours of the footprints to those of contemporary juveniles revealed that the former belong to human children.

We can easily see the typical form of the human footprint in the prints of Theopetra No 2 and 3 in comparison to the prints produced by contemporary children. This comparison was done in order to prove what seemed to be well understood: that the ancient footprints belonged to human beings.

The footprint (Fig. 10.5a) was made by a female whose left foot was covered by three thin stockings, and thus we recreated a print by a covered foot. Notice the resemblance in the pattern in both prints (Theopetra No. 2 (Fig. 10.5b) and contemporary female).

The footprint (Fig. 10.6a) was made by a male child (bare foot). Notice the similar pattern (ball, arch and the heel region) with the No 3 footprint of Theopetra (Fig. 10.6b).

All measurements confirm the first suggestion and leave us with no doubt that they are the footprints of young children (Table 10.1).

This seems highly unlikely. By comparing the length of the feet, we can make the following suggestions.

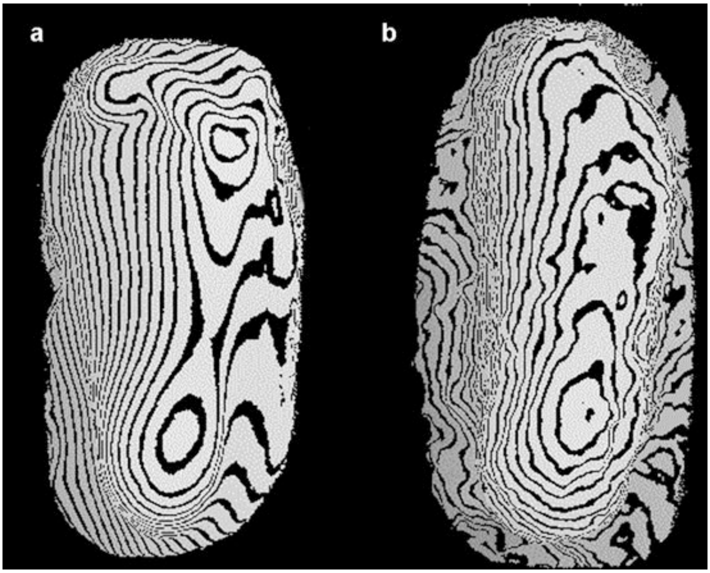

Fig. 10.5 Contour of the footprint created by covered foot of female, 3 years old (**a**), and the No 2 footprint of Theopetra Cave (**b**). Note the almost similar pattern in the heel and toe region

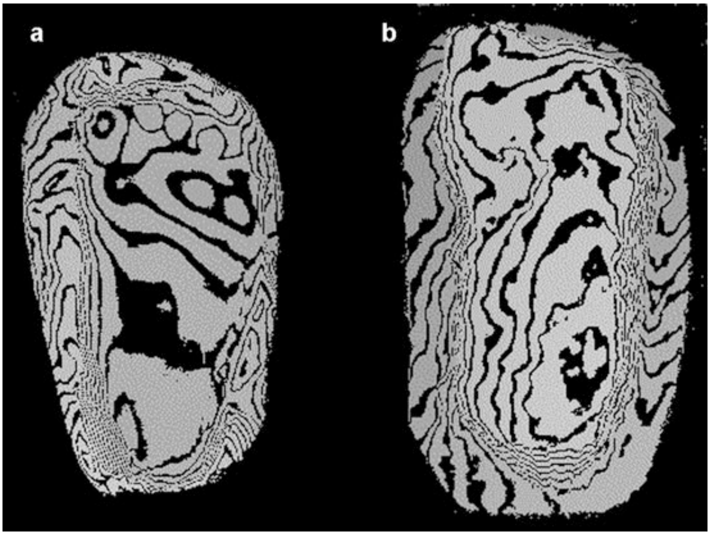

Fig. 10.6 Contour of the footprint created by the bare foot; (**a**) modern child; (**b**) No 3 footprint of Theopetra Cave. Note the similarity in the pattern of the toes, ball, arch and heel regions

Table 10.1 Measurements of the complete Theopetra footprints and the reference sample of modern Greek children (in mm)

Variables	Theopetra No 2	Theopetra No 3	Modern female (2 years old)	Modern male (3 years old)	Modern male (3 years old)
Foot length	150.86	138.11	140.2	142.9	165.0
Heel width	47.28	51.17	33.84	35.19	40.33
Ball width	54.03	62.82	58.94	55.39	62.0

Sex and Age

Footprint No. 2: If a male (young boy) made the footprint, then it should be a child of about 3 years. If, on the other hand, a female made it, it should be between 3 and 4 years of age. Note that we should be particularly careful in our final statements, because a covered foot created the print, and so measurements may not necessarily correspond to the actual dimensions. This means that the print is actually bigger than the foot that created it. Footprint No 3: this bare footprint was made by a child between 2 and 2.5 years of age, regardless of sex.

The comparison with mean values of Muller et al. (2012) reveals that most probably the two footprints (No 2 and No 3) were made by children aged 3 and 2 years, respectively. Nevertheless, an older age can't be excluded as a result of volume reduction due to diagenesis.

Stature

From the footprints available, the ones that provide us with more information are No 2 and No 3.

The stature for the individual 2 falls in the range 97.3–106.5 cm (Robbins 1985, 1986). Applying the percentage of 15% (Topinard 1877), a height of 100.6 cm was estimated. Finally, the application of the formula of Grivas and his colleagues (2008) gave a stature of 106.0 cm.

The individual that left the bare footprint No 3 probably was a child between 2 and 2.5 years of age, either male or female. The stature falls in the range 89.1–97.5 cm (Robbins 1985, 1986). Applying the percentage of 15% (Topinard 1877), a height of 89.1 cm was estimated. The application of the formula of Grivas and his colleagues (2008) gave a stature 98.5 cm.

All these calculations are assumptions, because there are several uncertainties when working with footprints.

Discussion

From the results of our study thus far, we can summarize the following:

- Footprint size and form: We have limited knowledge about the rate of growth and development of Neanderthal children. Trinkaus (1983) implies that during the first year of their life, Neanderthal children are identical to the children of anatomically modern humans, but this is based mostly on cranial remains. We should also point out that the rate of maturation in Neanderthal children has challenged many scientists, and Dean et al. (1986) proposed that the rate of development in Neanderthal children may have been faster than that in the children of early modern humans. Another recent study of Rosas et al. (2017) notes that Neanderthals' growth rate is very similar to that of *Homo sapiens*, in general, but differences have been observed in the development of the brain and spine of these two human groups. These are the main conclusions of a study which focussed on Neanderthal child approximately 8 years old, who lived in the cave of El Sidrón (Spain).
- Foot function and footwear: Neanderthals used fire; they certainly buried their dead; they seem to have self-medicated with local plants; and they undoubtedly used foot coverings. It is very crucial to know whether the Neanderthals and early humans have the same foot function. Recently Bennett and his colleagues (2016) conclude that foot function has remained almost unchanged, perhaps experiencing evolutionary homeostasis, for the last 3.66 million years. The archaeological record has limited evidence of footwear. The most ancient evidence appears to be in Theopetra Cave. The footwear probably had significant use among Middle Palaeolithic humans, who may have had various forms of foot covering, to provide insulation and protection from cold weather and rough substrate

(Trinkaus 2005). This phenomenon of footwear use must have been widespread although the archaeological findings are very rare.

- Age: Children between 2 and 4 years of age produced the footprints, bearing in mind that these children could belong to early *Homo sapiens* or Neanderthals. The analysis of the footprints gave a clear reconstruction of the facts that occurred at this time in the cave. Firstly, the cave was in use during the Middle Palaeolithic (Kyparissi-Apostolika 1999; Karkanas 2001; Valladas et al. 2007; Facorellis et al. 2013). There are traces of fire remnants on an ashy wet surface, and the footprints are very near these remnants. This could mean that the children were walking and playing in the area surrounding the hearth. We suppose that there are several trails (at least two) which were made by different individuals. The evidence that an individual who wore some kind of foot covering made the first two prints supports this. A bare foot has made the third print, whereas the fourth one is not clearly distinguished, either because it has been rotated or because other footprints have been made on it. The study of the footprints reconstructs and brings the children in our eyes**:** We can imagine these children playing in the cave and leaving their traces in the ashy wet surface around the burnt remnants.
- Neanderthal children or not? Through dating of specimens from the layer on which the footprints were found, it became obvious that at the specific time point early *Homo sapiens* and Neanderthals coexisted. The former make an appearance in Europe early, at about ~210 ka in Apidima Cave, Greece (Harvati et al. 2019). The latter resided in Europe, and their remains are found all over the continent. Evaluating all the available information, it is difficult to conclude what kind of individuals left these footprints. How do we know that they are Neanderthal children? We do not know this because the form and shape of the footprints are not consistent with the known anatomy of Neanderthals, from various other sites. Duveau et al. (2019: 19411) note, “They are relatively broader, especially in the midfoot, than the footprints made by *Homo sapiens,* which corresponds to a more robust foot and a less pronounced arch”.

The fact that the footprints of Theopetra have been made by children aged 2–4 years would lead one to hypothesize that probably the foot at this age is not fully developed. On the other hand, the cultural findings (lithic artefacts) seem to be Mousterian (the typical technological expression of Neanderthals) and have led to the conclusion that the footprints were made by Neanderthal children.

Conclusion

Both the palaeoanthropological and archaeological records suggest that foot covering was present during the Middle Palaeolithic. The only evidence that helps us in this case for establishing chronology is the lithic material found in this layer. If eventually the assessment that the tools are Mousterian (Panagopoulou 1999, 2000) is confirmed, we will positively assume that they were Neanderthal children. But even if they turn out to be the children of early *Homo sapiens*, the significance of the findings is still great, since that would prove beyond reasonable doubt the presence of anatomically modern humans in Europe at approximately ~135 ka much earlier of what was thought until now.

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Chapter 11
On the Tracks of Neandertals: The Ichnological Assemblage from Le Rozel (Normandy, France)

Jérémy Duveau, Gilles Berillon, and Christine Verna

Abstract Hominin tracks represent a unique window into moments in the life of extinct individuals. They can provide biological and locomotor data that are not accessible from skeletal remains. However, these tracks are relatively scarce in the fossil record, particularly those attributed to Neandertals. They are also most often devoid of associated archaeological material, which limits their interpretation. The Palaeolithic site of Le Rozel (Normandy, France) located in a dune complex formed during the Upper Pleistocene has yielded between 2012 and 2017 several hundred tracks (257 hominin footprints, 8 handprints as well as 6 animal tracks). This ichnological assemblage is distributed within five stratigraphic subunits dated to 80,000 years. These subunits are rich in archaeological material that attests to brief occupations by Neandertal groups and provides information about the activities that they carried out. The ichnological assemblage discovered at Le Rozel is the largest attributed to Neandertals to date and more generally the most important for hominin taxa other than *Homo sapiens*. The particularly large number of footprints can provide major information for our understanding of the Palaeolithic occupations at Le Rozel and for our knowledge of the composition of Neandertal groups.

Keywords Group composition · Morphometry · Footprint · Neandertals · Le Rozel

Introduction

Tracks, and especially footprints, are unique vestiges that provide direct information on the locomotor and biological characteristics (e.g. stature, body mass, age) of hominin groups (e.g. Bennett et al. 2009; Crompton et al. 2011; Bennett and Morse 2014). Such information can be obtained from trackways (e.g. Leakey and Hay 1979; Masao et al. 2016; Roach et al. 2016) or from isolated footprints by using

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morphometric methods (Dingwall et al. 2013; Ashton et al. 2014; Citton et al. 2017) or expert tracker readings (Pastoors et al. 2015, 2017). Ichnological assemblages require a quick sedimentary burial to be preserved in an open-air context; this differs from the cave context, where they are usually found at the surface of the soil (see Chap. 4). As it, they represent an original snapshot on the composition of groups and their behaviours during their lives (e.g. Mastrolorenzo et al. 2006; Hasiotis et al. 2007; Schmincke et al. 2010; Falkingham 2014). They differ in this respect from skeletal or lithic material whose accumulations may have occurred during various and repeated occupations over long periods (Farizy 1994; Pettitt 1997). However, the study of tracks is usually a challenging task. Indeed, if their morphology reflects the biological and locomotor characteristics of trackmakers, they are also affected by the nature of substrate and by taphonomic modifications (e.g. Allen 1997; Bennett and Morse 2014; see Chap. 2). In addition, despite several significant discoveries in recent years (e.g. Altamura et al. 2018; Bustos et al. 2018; McLaren et al. 2018; see Chap. 5), the number of sites that yielded hominin tracks is relatively low compared to sites with archaeological and palaeoanthropological material (e.g. Kim et al. 2008; Lockley et al. 2008, 2016; Bennett and Morse 2014). This rarity is even more important for the footprints attributed to Neandertals since only nine footprints found at four sites attributed to this taxon were reported to date (Fig. 11.1).

In this context, here we present the largest ichnological assemblage attributed to Neandertal discovered at the archaeological site from Le Rozel (Manche, France). We present first a synthesis of the previously known footprints attributed to Neandertals. Then the archaeological site of Le Rozel will be presented before describing

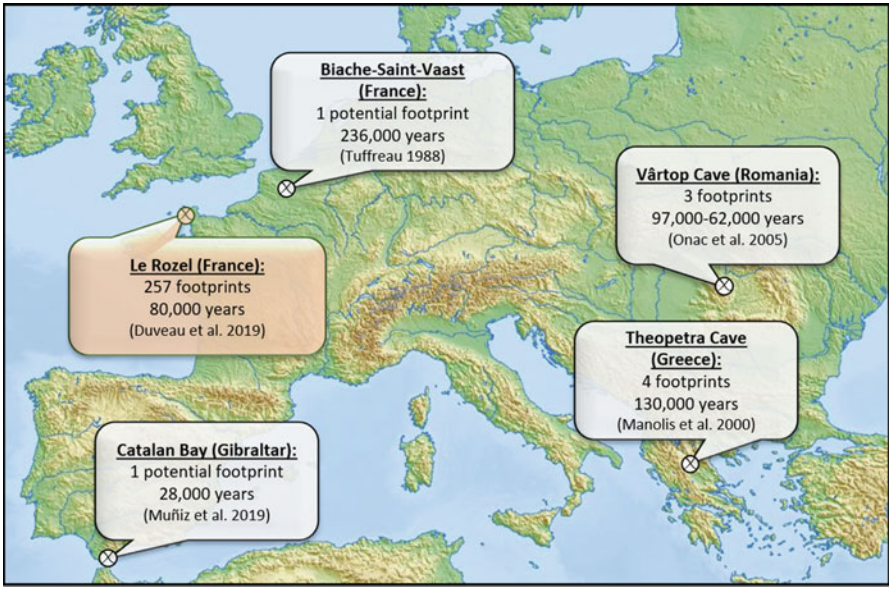

Fig. 11.1 Geographical distribution of the footprints attributed to Neandertals

the ichnological sample discovered there between 2012 and 2017. Finally, the importance of this assemblage in relation to other sites that yielded hominin footprints, and in particular those attributed to Neandertals, will be discussed before concluding on the potential of these footprints to yield direct information on the trackmaker groups that lived at Le Rozel 80,000 years ago.

The Neandertal Footprint Record

The oldest track attributed to Neandertals is also the first that has been described: it is a single footprint discovered in 1976 in a silty ground at the Middle Pleistocene site of Biache-Saint-Vaast (France) (Tuffreau 1978, 1988). It is associated with two fragmentary human skulls that bear Neandertal features as well as with archaeological material including lithic industry and 236,000-year-old faunal remains (Tuffreau 1988; Rougier 2003; Guipert et al. 2011; Bahain et al. 2015). The attribution of the track to a Neandertal individual is based on the cranial remains and on the associated archaeological material. This footprint is poorly preserved and was probably damaged by bovid trampling making its identification as a hominin footprint and its analysis difficult (Tuffreau 1988).

Four footprints were discovered in 1996 in the Greek cave of Theopetra. They were made in a clay substrate dated by thermoluminescence to 130,000 years (Manolis et al. 2000; Valladas et al. 2007; see Chap. 10). They are associated with a Mousterian industry that allows to attribute them to Neandertals (Manolis et al. 2000; Valladas et al. 2007). The four footprints were probably made by different individuals with their left feet. The second and the third footprints are relatively complete. They are 14 and 15 cm long and were made by young children whose ages and statures are estimated to 2 and 4 years and to 86 and 100 cm (Manolis et al. 2000). Furthermore, Manolis et al. (2000) suggest that the third footprint was made by a shod individual, which would represent the oldest occurrence of a shoe among hominins. Casts of the footprints were realized, and the two most complete were 3D digitized (Manolis et al. 2000).

Three footprints made in calcareous mud dated by U-Th between 97,000 and 62,000 years were discovered in the Romanian Vârtop Cave (Onac et al. 2005; see Chap. 12). No archaeological or palaeoanthropological material was associated with these tracks. The taxonomic attribution to Neandertals is based only on the chronological age, Neandertals being the only taxon known in Europe for this time period. The three footprints were made by a single individual (Onac et al. 2005; Harvati and Roksandic 2016). Two of them are partial, consisting only of either heel or forefoot impressions. The third footprint is longitudinally complete; it is 22 cm long and was made by an individual whose height was estimated to 146 cm (Viehmann 1987). It is characterized by a space described as important (1.6 cm) between the hallux and the second toe impressions (Onac et al. 2005). Its morphology would reflect the robust Neandertal anatomy (Onac et al. 2005).

More recently, a potential human footprint was discovered in the dune complex of Catalan Bay at Gibraltar. OSL dating of the aeolian unit where the footprint was made provided an age of 28,000 years (Muñiz et al. 2019). This footprint is described as poorly preserved. It is 17 cm long and was made by an individual whose height is estimated between 106 and 126 cm and who was descending a slope (Muñiz et al. 2019). No archaeological or palaeoanthropological remains are associated with this footprint. Moreover, its morphology does not allow to discard *Homo sapiens* as the possible trackmaker (Muñiz et al. 2019). Therefore, the taxonomic attribution to a Neandertal individual is only based on the discovery a few kilometres away of archaeological material that would indicate that Neandertal groups may have lived in the region until 28,000 years BP (Finlayson et al. 2006). However, the dating of this material is questioned not only as regards stratigraphic consistency (Delson and Harvati 2006) but also for methodological aspects (Wood et al. 2013). Therefore, the lack of consensus on these dates combined with the fact that the footprint would correspond to the last Neandertal occurrence raises questions about the validity of the taxonomic attribution to a Neandertal individual.

In this synthesis on footprints attributed to Neandertals, it is necessary to mention those discovered in the Romanian cave of Ciur Izbuc (Webb et al. 2014; see Chap. 12). The research undertaken at this cave yielded 400 human footprints, dated between 36,500 and 29,000 years calBP, before three quarters of them were destroyed (Webb et al. 2014). The absence of archaeological or palaeoanthropological material associated with the footprints makes their taxonomic attribution complex. Indeed, the lowest limit of the chronological interval is close to the last occurrence of Neandertals reported in central and Eastern Europe (Pinhasi et al. 2011; Devièse et al. 2017). However, skeletal remains provided evidence of the occurrence of *Homo sapiens* in Romania around the period when the footprints were made (Trinkaus et al. 2003; Soficaru et al. 2007; Higham et al. 2011). It is thus more likely that these footprints were made by *Homo sapiens* (Webb et al. 2014).

Lastly, the footprints discovered in the Italian site of Bàsura Cave were for a long time attributed to Neandertals (Pales 1954, 1960). For this attribution, L. Pales used the presence of a Mousterian industry in a nearby cave and remains of cave bears that he considered as contemporary to Neandertals. However, subsequent radiocarbon dating on charcoals discovered in the same layer as the footprints invalidated their taxonomic attribution to Neandertals, showing instead that they were made by *Homo sapiens* (Molleson et al. 1972; De Lumley and Vicino 1984).

The Archaeological Site from Le Rozel

Located on the western coast of the Cotentin (Manche, Normandy) (Fig. 11.1), Le Rozel (49°28′20.92″ N, 1°50′25.58″ W) is part of a dune formation in a creek opened in a schist cliff. This dune complex is composed of soft aeolian sand and was formed during the end of the Eemian and the beginning of the Last Glacial Period, between 115,000 and 70,000 years ago (Van Vliet-Lanoë et al. 2006). The site was discovered in the 1960s by Yves Roupin following coastal erosion that uncovered several faunal bones at the base of the dune. These initial discoveries led to a survey in 1967 and to the first excavations in 1969 directed by Frédéric Scuvée (Scuvée and Verague 1984). The monitoring of the site since the 1980s has revealed significant damages caused by erosion and led to annual excavations under the direction of D. Cliquet since 2012.

Le Rozel shows a long stratigraphic sequence (Fig. 11.2) dominated by detrital elements brought by wind dynamics (Van Vliet-Lanoë et al. 2006). This sequence is delimited at its summit by a 6- to 8-m-thick head above a palaeodune massif. The archaeological layers discovered since 2012 are located within five stratigraphic subunits of this palaeodune (D3b-1 to D3b-5) composed of fine to medium sand (Cliquet et al. 2018a, b). The OSL dating carried out within the stratigraphic sequence places these subunits around 80,000 years (Mercier et al. 2019). Furthermore, geochronological and sedimentary analyses have shown that the stratigraphic subunits were formed and covered quickly (Mercier et al. 2019) which means that each subunit represents a relatively short and likely single occupation phase. The first three subunits (D3b-1 to D3b-3) are composed of subhorizontal organic soils, brown to black in colour, and consist of degraded dune sand where lithic industries, charcoals, faunal remains and tracks were discovered (Fig. 11.3). The Palaeolithic

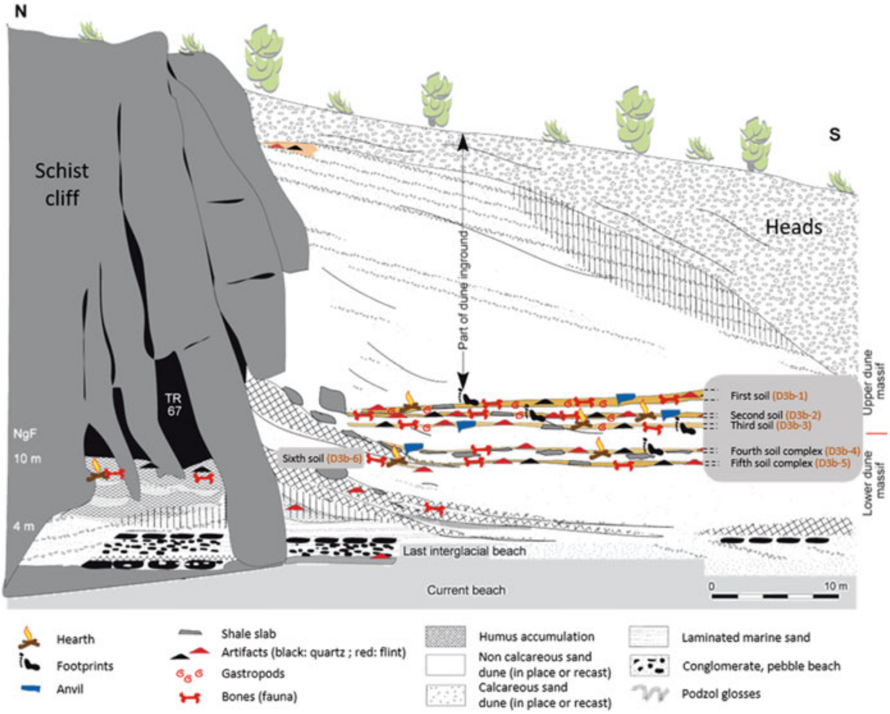

Fig. 11.2 Cross section of the dune complex from Le Rozel and locations of the Palaeolithic occupations. (Modified from Cliquet et al. 2018b)

Fig. 11.3 The archaeological site from Le Rozel; (**a**) view of the site; (**b**) Levallois flakes; (**c**) blades; (**d**) knapping spot; (**e**) hearth; (**f**) butchery area. (Photos D. Cliquet)

activities in these soils seem to be structured around hearths and, for the D3b-2 and D3b-3 subunits, knapping spots (Cliquet et al. 2018a, b). The D3b-4 and D3b-5 subunits, whose excavations are still in progress, are affected by numerous intertwined mudflows that are intersected by small schist plates. These subunits yielded lithic industries, knapping spots, hearths, faunal remains and most of the tracks (Cliquet et al. 2018a, b). Below these stratigraphic subunits are the occupation layers identified and studied by Scuvée during the 1960s (Scuvée and Verague 1984). Two layers (Scuvée E2 and Scuvée E3) were located at the base of the dune and included faunal remains and lithic industry, while a third layer (Scuvée F2) was located inside a rock shelter (TR 67) where hearths, faunal remains and lithic artefacts were discovered (Scuvée and Verague 1984; Van Vliet-Lanoë et al. 2006; Cliquet et al. 2018a, b).

The analyses carried out on the archaeological material discovered at Le Rozel show that two techno-cultural worlds were operated by the human groups 80,000 years ago (Cliquet et al. 2018a, b). This dichotomy observed between the two sets of occupations is particularly visible with the lithic industries. Indeed, although the raw materials and their relative frequency are similar between the upper and lower subunits (a majority of local flint and to a lesser extent quartz; anecdotal use of sandstone and mylonite), the characteristics of the industry differ. The industries discovered in subunits D3b-1 to D3b-3 mainly represent direct debitage flakes and Levallois flakes. The D3b-4 and D3b-5 ones correspond to a higher proportion of lamellar and laminar productions. While some blades come from the production of direct debitage flakes or Levallois flakes, a lot of them have been obtained by semi-rotating or rotating debitages (Cliquet et al. 2018a, b).

The three more recent upper subunits (D3b-1 to D3b-3) provide evidence of butchery activities (Fig. 11.3), whereas site function for the lower subunits (D3b-4, D3b-5, Scuvée E2-E3, Scuvée F2) is not yet established (Cliquet et al. 2018a, b).

Within the D3b-1 to D3b-3 subunits, the fauna consumed is largely dominated by red deer, horse and aurochs, both in terms of number of remains and minimum number of individuals (Sévêque 2017). The bones of these three species bear the characteristic stigmata of skinning, dismantling and the recovery of meat. The study of the slaughter periods of this fauna enabled to estimate that Palaeolithic occupations took place during bad weather seasons, between autumn and spring (Sévêque 2017; Cliquet et al. 2018b). Other bones belong to straight-tusked elephant, grassland rhinoceros, roe deer and rabbit whose nutritional usefulness is not confirmed. Anthracological analyses show that the hearths were mainly composed of Scots pine and yews, which could reflect a vegetal selection. Anthracological and zooarchaeological material provide a representation of the environments during the Palaeolithic occupations of the site (Stoetzel et al. 2016; Sévêque 2017; Cliquet et al. 2018a, b): they are characteristic of a temperate climate and open landscapes, including humid temperate semi-wooded meadows.

The lower subunits (D3b-4 and D3b-5) are less informative than the first three; only the large fauna, which is weakly conserved, provides results. In these layers, red deer is once again the most frequent, with horse and aurochs (Sévêque 2017; Cliquet et al. 2018a, b).

In the absence of human osteological remains, the Palaeolithic occupations at Le Rozel are attributed to Neandertals by considering the chronostratigraphic context and the characteristics of the archaeological material. On the one hand, the D3b-1 to D3b-5 subunits are dated to 80,000 years when Neandertals were the only taxon known in Europe (Benazzi et al. 2011; Nigst et al. 2014; Hublin 2015). On the other hand, the technological features of the archaeological material, especially that of the upper subunits, have already been observed on other Mousterian sites associated with Neandertal remains (Cliquet et al. 2018b). The cultural dichotomy between the upper and the lower subunits suggests the presence of different groups.

Material and Methods

The analysis of the ichnological set discovered between 2012 and 2017 at Le Rozel led to the identification of 271 tracks including 257 hominin footprints, 8 hominin handprints (Fig. 11.4) as well as 6 animal tracks (Duveau et al. 2019).

These tracks were identified by morphological criteria; they had to reflect the anatomy and the locomotor behaviour of the trackmakers. More particularly, human footprints reflect a rounded heel, a narrow midfoot, relatively short toes including a robust and adducted hallux (e.g. Aiello and Dean 1990; Klenerman and Wood 2006; Morse et al. 2010; Bennett and Morse 2014). The heel and forefoot impressions are deeper than that of the midfoot (Crompton and Pataky 2009; Morse et al. 2010; Bennett and Morse 2014). Moreover, the identification of the human footprints was reinforced by using the morphometric test developed by Morse et al. in 2010 (Duveau et al. 2019). Human handprints are recognizable by the impressions of a rounded palm, relatively wider than the heel of the foot, and the fingers are relatively long except the thumb which is smaller. This thumb has an abduction capacity unlike the human hallux (e.g. Aiello and Dean 1990; Jones and Lederman 2006). At last, the animal tracks were identified and taxonomically attributed thanks to identification criteria from the literature (e.g. Bang et al. 2001; Murie and Elbroch 2005).

Each track was photographed and described in situ. Casts were made of 64 tracks between 2013 and 2016. Seventy original tracks were directly extracted after a chemical consolidation of the substrate in 2017. The casts and extracted footprints are curated in the premises of the Direction Régionale des Affaires Culturelles (DRAC, Caen, France). 180 tracks including 170 footprints were digitized in 3D.

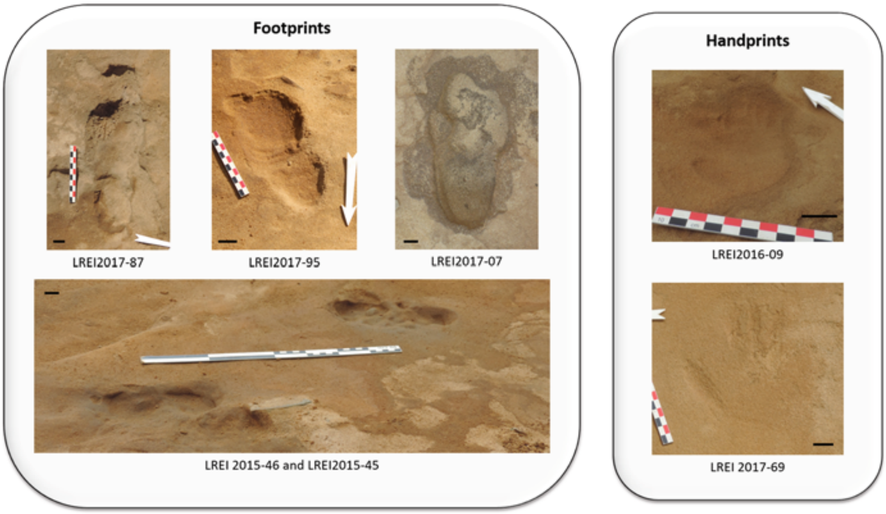

Fig. 11.4 Hominin footprints and handprints discovered at Le Rozel. (Photos D. Cliquet) (scale bar : 10 and 40 cm)

Seventy-seven footprints were digitized by using photogrammetry with the Agisoft Protocan software (v.1.4.0) and a Canon EOS 1300D camera. 137 footprints were 3D modelled by using a Noomeo OptiNum surface scan. The use of these different acquisition techniques required that we run morphometric comparisons between them prior to analysis. These comparisons did not detect any differences between the types of acquisition (Duveau et al. 2019).

Besides, each track was measured in situ. These measurements were controlled and specified on the tracks digitized in 3D by using Geomagic Studio 2013. The length was measured along the longitudinal axis. For footprints, this axis is from the most proximal point of the heel to the distal end of the second toe. Therefore, length measurement requires that the footprint is longitudinally complete and that the toe impressions can be differentiated from the rest of the print. In addition, we measured the maximum width of the forefoot, along a mediolateral axis perpendicular to the longitudinal axis. The lengths and widths of the footprints from Le Rozel were compared to those of the other footprints attributed to Neandertals using published data: two of the four footprints from Theopetra Cave (Manolis et al. 2000), the most complete footprint from Vârtop Cave (Onac et al. 2005) and the potential footprint from Catalan Bay (Muñiz et al. 2019).

Results

Preservation and Distribution of the Tracks

The 271 discovered tracks have been preserved thanks to a rapid sedimentary cover by aeolian sand. Indeed, experimental observations carried out in situ have shown that without this protection, the tracks could have been damaged, if not entirely destroyed, in a few tens of minutes. Due to the erosive action of the wind on the tracks, as well as other taphonomic agents, this ichnological assemblage probably represents only a sample of the initial assemblage left by the trackmakers ~80,000 years ago.

The tracks come from the subunits D3b-1 to D3b-5 and were discovered in the same layers as the archaeological material. Nearly 80% of the reported tracks come from the D3b-4 stratigraphic subunit, which extends over more than 90 m^2; 11% of the tracks come from the D3b-5 subunit; the rest of the tracks are similarly distributed among the three other subunits. Among the 271 tracks, 198 were made in sandy mud and 73 in dune sand. The tracks made in dune sand, which mainly come from the D3b-1 to D3b-3 subunits, are less well preserved (i.e. they reflect less anatomical details and in particular less clear toe impressions) than those made in sandy mud that come from the D3b-4 and D3b-5 subunits. This differential conservation partly explains the differences in distribution between the subunits. The depth of the tracks is highly variable, from a few millimetres to 5 cm, and may suggest varying moisture conditions when they were made.

Human Footprints

Description: Among the 257 footprints, 5 trackways composed of 2 to 3 footprints were reported (Fig. 11.4), the rest of the footprint set consisting of isolated tracks. They include 112 left prints, 115 right prints and 30 impressions of indeterminate laterality. Footprint morphology is variable which is common for footprints made in soft substrate (e.g. Allen 1997; Morse et al. 2013; Bustos et al. 2018), such as dune sand or sandy mud. The quality of the prints is variable, and some are partial. Ten prints correspond only to the heel impressions, and three reflect only the forefoot. Eighty-eight footprints are longitudinally complete since they show proximally the impressions of rounded heels and distally clear impressions of the tip of the toes. Of these longitudinally complete footprints, not all the toes are systematically printed. The hallux impression and to a lesser extent that of the second toe are the most common and the deepest toe impressions. With one exception, the hallux impression is always visible when the impressions of toes can be distinguished from the rest of the footprint. The remaining 156 footprints reflect a relatively complete foot outline but do not provide evidence, such as variation in depth, allowing to distinguish the toe impressions. It is therefore difficult to attest that they are longitudinally complete.

The best-preserved footprints reflect morphological features close to those of humans including a fully adducted hallux and a midfoot mediolaterally narrow. Moreover, the heel and forefoot impressions are the deepest areas of the footprints; the forefoot is on average deeper than the heel. The midfoot impression is shallow and has a slight outline. This depth distribution and the narrowing of the midfoot impression are consistent with an architecture of the foot in vault. These architectural characteristics are less pronounced for the smallest footprints, which suggest a flatter foot for the youngest individuals. They are also less marked compared to footprints made by *Homo sapiens* (Duveau et al. 2019), which is consistent with our knowledge of the anatomy of the Neandertal foot, which was more robust and had a less pronounced plantar arch than the *Homo sapiens* foot (Trinkaus et al. 1991; Berillon 2000).

Comparative morphometry: The 3D modelling of 169 footprints allows accurate morphometric comparisons according to the subunits (Fig. 11.5a). These comparisons were carried out on footprints sufficiently complete that were made on horizontal layers and that do not show any evidence of sliding. The footprints from the D3b-4 stratigraphic subunit, the densest in tracks, have lengths ranging from 11.4 to 28.4 cm (mean, 19.2 cm) and widths from 4.5 to 12.8 cm (mean, 8.4 cm). The exploitable footprints from the other stratigraphic subunits fall within these ranges (Fig. 11.5). The footprints from the D3b-1 subunit are shorter (12.3–18.4 cm) and narrower (mean, 5.1–8.4 cm) than the average of those from the D3b-4. The footprints from the D3b-2 and D3b-3 subunits are on average longer (respectively, 21.4 cm and 22.0 cm) but have close average widths (8.1 cm and 8.7 cm). Finally, the footprints from the D3b-5 subunit are biometrically close to those from the D3b-4 for both length (mean, 19.7 cm) and width (mean, 7.9 cm). The lengths and widths of the other footprints attributed to Neandertals fall within the ranges of those

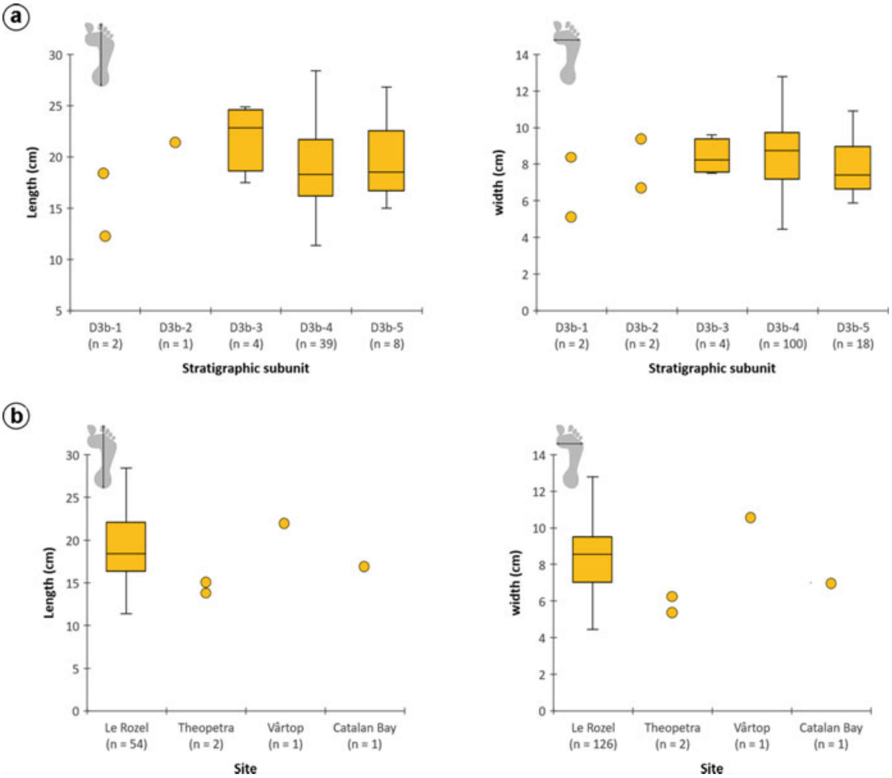

Fig. 11.5 Dimensions of the Le Rozel footprints digitized in 3D; (**a**) depending on their locations in the stratigraphic subunits; (**b**) compared to the other footprints attributed to Neandertals

from Le Rozel (Fig. 11.5b). The two footprints from Theopetra Cave (14 and 15 cm long, 5 and 6 cm wide) and the footprint from Catalan Bay (17 cm long and 7 cm wide) are relatively smaller than the averages of the Le Rozel footprints (19,2 cm long and 8,4 cm wide). On the other hand, the footprint from Vârtop Cave is relatively longer (22 cm) and wider (11 cm).

Human Handprints

The eight handprints all reflect a right laterality. As with footprints, their morphology is variable. Six handprints are longitudinally complete with lengths ranging from 11.4 to 16.1 cm. The two other handprints show fingerprints but not clearly the base of the palm. The handprints are characterized by a broad palm, deep and long fingerprints (relatively longer than toe impressions) and a short thumb with a capacity for abduction.

Animal Tracks

Six animal tracks were discovered in the peripheral areas of the D3b-4 subunit. Their low level of conservation complicated their precise taxonomic attribution. Five of them are attributed to Carnivora (Felidae, Canidae and Mustelidae) and the last one to a Ruminantia (probably a Cervidae).

Discussion

Since 2012, the field missions yielded a large ichnological assemblage that makes Le Rozel a major track site. First of all, the 257 footprints represent to date the largest footprint sample attributed to a hominin taxon other than *Homo sapiens*. In particular, they form more than 95% of all the footprints attributed to Neandertals since only nine footprints had so far been attributed to this taxon (Fig. 11.1). Moreover, even for footprints attributed to *Homo sapiens*, such a large number is exceptional; the sites from the Willandra Lakes (e.g. Webb et al. 2006; Webb 2007) and the Hawaii Volcanoes National Park (Moniz Nakamura 2009) are among the few sites that yielded more footprints than Le Rozel. Also notable are the eight handprints recorded at Le Rozel that are to date the only Neandertal handprints available with the hand discovered at Maltravieso (Hoffmann et al. 2018). Besides the well-known positive and negative painted hands in rock art (e.g. Bahn 1998; Guthrie 2005), only a few handprints are known for Pleistocene hominins (Zhang and Li 2002; Mietto et al. 2003; Ledoux et al. 2017; Panarello et al. 2018). In addition, animal tracks provide information on fauna that lived near the site during the Palaeolithic occupations. For example, they attest to the presence of several carnivores of which no osteological remains had been found on the site (Cliquet et al. 2018a, b). Le Rozel tracks also represent an important discovery because of their association with archaeological material that attests to the occupations of the site by Neandertals. Such occupation contexts are rare among the other hominin footprint sites (Altamura et al. 2018); the majority of them only reflect passage areas (Masao et al. 2016; Roach et al. 2016; Bustos et al. 2018).

Except for the dimensions (Fig. 11.5b), it is difficult to morphologically compare the Le Rozel footprints with other footprints attributed to Neandertals because of their rarity as well as the differences in conservation and deposition conditions. Few anatomical details are reflected by these other footprints. Only a gap described as important between the hallux and the second toe has been reported for the most complete footprint discovered at Vârtop Cave (Onac et al. 2005). Such a space is not observed on the Le Rozel footprints, but this may be related to the nature of the substrate.

In that vein, some morphological features of the Le Rozel footprints, such as the lack of clear toe impressions on relatively complete footprints, raise a question: the possibility of shod feet. Such a feature could have a significant impact on our knowledge of Neandertal culture. No direct remains of shoes are known for Neandertals, and the earliest occurrences were discovered in Holocene sites (e.g. Kuttruff et al. 1998; Pinhasi et al. 2010). However, anatomical studies on the robustness of phalanges suggested a possible wearing of shoes as early as 30,000 years ago (Trinkaus and Shang 2008; see Trinkaus et al. Chap. 7). In addition, some footprints, such as one of those discovered at Theopetra Cave (Manolis et al. 2000; see Kyparissi-Apostolika and Manolis Chap. 10), have been described as prints of shod feet. Nevertheless, the associations between footprints and footwear are not certain, being generally based on qualitative criteria or on outliers in footprint dimensions (Bennett et al. 2010). Experimental studies on the same substrate conditions as at Le Rozel, and investigating morphometric differences between barefoot footprints and footwear (including shoes of varied rigidity), may provide significant information on this issue in the future.

Finally, we have shown that the 2012–2017 assemblage described here could provide direct information on the size and composition of the trackmaking groups; the assemblage from D3b-4 stratigraphic subunit represents a small group, most likely composed of 10–13 individuals, and 90% of the footprints correspond to children or adolescents (Duveau et al. 2019). This high proportion of children and adolescents raises questions about the distribution of activities (hunting, carcass transport, lithic industry, etc.) within the group. It is also currently impossible to know why so few adults were on the site at this time. Future analyses of the spatial distribution of footprints and their relationship to associated archaeological remains could provide valuable information on these important issues. Importantly, the two last field missions in 2018 and 2019 allowed the discovery of around 800 new potential footprints (most of them coming from the D3b-4 subunit). Ongoing studies of these new tracks will first have to validate or not their identification as hominin footprints. Then, morphometric analyses will aim to clarify our knowledge of the size and the composition of the groups who occupied Le Rozel 80,000 years ago.

To sum up, the tracks discovered at Le Rozel represent the most important ichnological assemblage attributed to Neandertals to date and more generally the most important for hominin taxa other than *Homo sapiens*. The analysis on the footprints provides not only essential data in order to understand the Palaeolithic occupations at Le Rozel 80,000 years ago but also could provide access to unique information on the composition of groups at a timescale unusual in prehistoric archaeology, that of a snapshot. In this perspective, the crossing of ichnological data with archaeological data (occupation structures, spatial distribution of activities, etc.) will bring closer to the life history of the Pleistocene human groups.

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Chapter 12
Hominin Footprints in Caves from Romanian Carpathians

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Abstract The Romanian karst hosts numerous caves and shelters that over time provided remarkable archaeological and anthropological vestiges. Altogether they show that humans must have entered caves in Romania at least as early as 170,000 years ago. However, ancient human footprints are very rare in the fossil record of East-Central Europe, with only two known locations in the Apuseni Mountains of western Romania. Vârtop Cave site originally preserved three fossil footprints made about 67,800 years ago by a *Homo neanderthalensis*, whereas Ciur Izbuc Cave was probably home of early *H. sapiens* that left almost 400 footprints (interspersed with spoors of cave bears), which were indirectly dated to be younger than ~36,500 years.

Keywords Karst · Cave · Prehistoric people · Footprints · Romania

Introduction

The major karst areas of Romania occur in the East and South Carpathians, Apuseni Mountains, and Dobrogea (Onac and Goran 2019) (Fig. 12.1), all hosting key archaeological cave sites (for comprehensive reviews, see Boroneanț 2000; Anghelinu and Boroneanț 2019). Over the last 150 years, archaeological and paleontological researches focused on a significant number of shelters and cavities, most of them concentrated in the south-western part of the South Carpathians and

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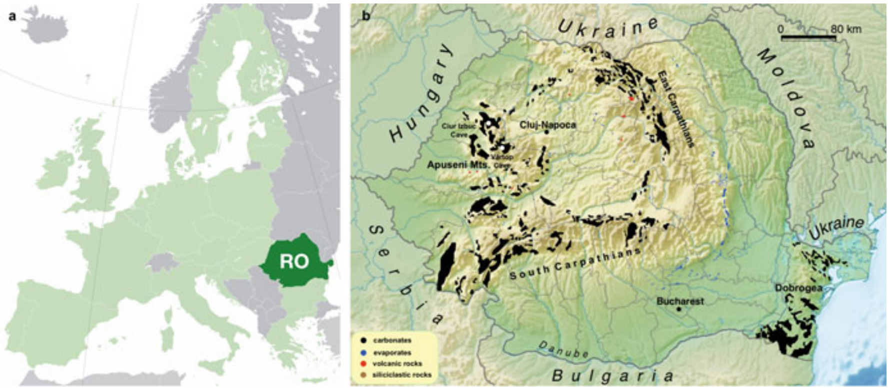

Fig. 12.1 (**a**) Romania within Europe; (**b**) location of Ciur Izbuc and Vârtop caves in Apuseni Mountains karst

Apuseni Mountains that also produced human remains (e.g. Cioclovina, Muierii, Polovragi, Oase). These investigations documented important Middle to Upper Palaeolithic sites, with the latter ones being far more abundant (Mertens 1996; Cârciumaru 1999; Păunescu 2001). Other archaeological and anthropological findings indicate that the early modern humans had a more constant presence in the Romanian caves (Cârciumaru 1988; Trinkaus et al. 2003; Olariu et al. 2005; Soficaru et al. 2007; Clottes et al. 2012; Webb et al. 2014; Harvati and Roksandic 2016). Until very recently, the cave-based Middle and Upper Palaeolithic in Romania offered almost exclusively archaeological collections with limited reliable chronological control (Cosac et al. 2018; Anghelinu and Boroneanț 2019). Abri 122 from Vârghiș karst (East Carpathians; Veres et al. 2018) has produced so far the most important Middle Palaeolithic lithic assemblage in the Carpathian region, including evidence of use-wear on fragmented bone tools and cut marks on a bos/bison tibial diaphysis (Cosac et al. 2018). Multiple-method luminescence dating indicates that human use of this site commenced sometime between 141 ± 12 ka and 174 ± 37 ka (Veres et al. 2018). These ages corroborate other evidence of Middle Palaeolithic occurrences in that chronological span within the Dobrogean karst and loess records near the Black Sea (Balescu et al. 2015).

Except for a handful of sites worldwide, human footprints are not that common in the fossil record. Onac et al. (2005) showed that the earliest footprints documenting direct human incursions into a Carpathian cave also come from Middle Palaeolithic (i.e. *Homo neanderthalensis*) and date back to more than 62,000 years ago. The only other ancient footsteps preserved in a Romanian cave were made in soft clay that partly hardened and then remained undisturbed until recently (Rusu et al. 1969; Rișcuția and Rișcuția 1970). Their age could be as old as 36,500 years, which heralds them as the oldest direct traces left by anatomically modern humans in a European cave (Webb et al. 2014). The two sites from which these footprints were documented, i.e. Vârtop and Ciur Izbuc caves in western Apuseni Mountains (Fig. 12.1), deserve further attention.

Vârtop Cave (Bihor Mountains)

Forty-five years ago, cavers from Emil Racoviță Speleological Club in Cluj-Napoca, led by the late Iosif Viehmann, organized a winter camp at Casa de Piatră (Stone House), a remote hamlet that counts only a few scattered houses in the heart of the Bihor Mountains. One of the objectives of this camp was a study visit into the Vârtop Glacier Cave (hereafter Vârtop), a short (340 m), but very well-decorated cavity discovered in 1955 and declared a natural monument in 1957 (Bleahu and Viehmann 1963). In the middle section of the cave, just before entering the Dome's Room (Sala Domului), a small, east-trending side passage opens, with its floor covered almost completely by a shallow lake. As the access to this section of the cave was somewhat more difficult prior to this expedition, no one ventured beyond the small chamber hosting the lake. However, in February 1974, Iulia Szekely and Ioan Bucur passed the lake and climbed a steep flowstone in the north-eastern part of the Lake Room (Sala Lacului). After barely passing between two large stalagmites, they entered a rather small, low-ceilinged chamber. Just behind the stalagmite obstruction, over a flat surface of ca. 1.5 m^2, they noticed a well-preserved single human footprint (Fig. 12.2a). When I. Viehmann investigated the site, two other less clear prints were noticed, one of a heel and the other made by the toes. A few months later, the cave site was visited by Cantemir Rișcuția, a well-known Romanian anthropologist who after some preliminary ichnological measurements suggested a possible age of ca. 15,000 years (Viehmann 1975). After numerous other biometric measurements and photographs were taken in situ, the decision was made to cut out the best preserved footprint and safeguard it in the Museum of the Institute of Speleology

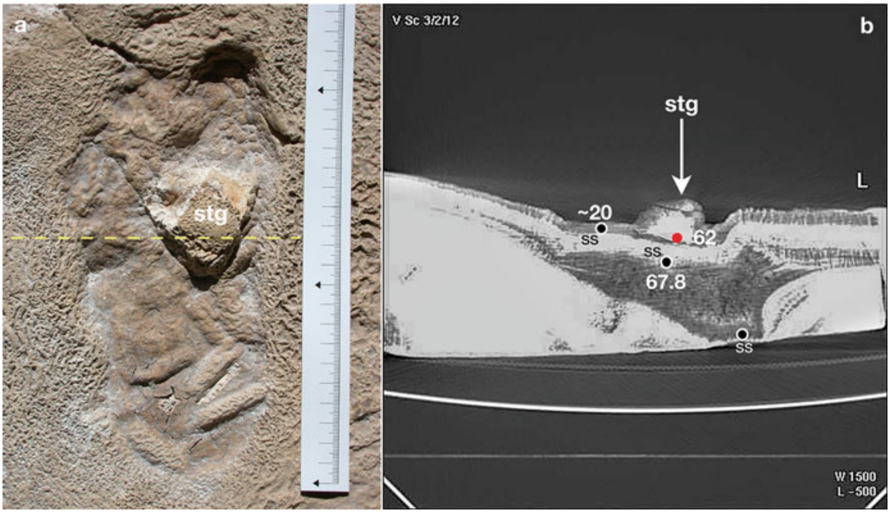

Fig. 12.2 (**a**) Vârtop footprint (*dashed line* represents the CT cross-section shown in b); (**b**) transversal CT image of the footprint displaying the stalagmite (*stg*), embedded soda-straws (*ss*), and the U-series ages (in thousands of years)

in Cluj-Napoca. Although the decision to remove the print from the cave sparked controversy at the time, a few years later, when the illegal disappearance of the other traces was discovered, the usefulness of the undertaken approach was understood.

Room of the Steps and the Vârtop Footprints

The area of the cave that hosts the footprints consists of a small chamber (Room of the Steps) that continues into a short ascending gallery, with its floor covered with limestone boulders and red-brownish clay. The presence of these materials indicates an older cave entrance at the upper end of this corridor that collapsed more than 15,000 years ago (Onac et al. 2005). The age has been established after dating the base of one of the scattered stalagmites growing over the clayed cave floor by means of U-series technique. The existence of a different cave access point makes total sense, since it is unlikely that the prehistoric human crawled and climbed into the Room of the Steps using the present-day cave entrance.

The footprints were fossilized into a moonmilk deposit that accumulated between the cave wall and an alignment of stalagmites (Fig. 12.2). At the time the human left the prints, the moonmilk blanket covering the floor must have been soft and pliable, but later hardened into a calcareous tufa type deposit. The best preserved footprint is 22 cm in length and rather wide (10.6 cm) and shows a wide gap (1.6 cm) between the great toe of the foot and the rest of the toes (Fig. 12.2a). This is not necessary a distinctive feature of the foot (i.e. hallux varus), but likely the gap formed when stepping in soft clay, barefoot. This could also be the reason for the overall width of the footprint. These two observations and a comparison with the human footprint from Bàsura Cave (Toirano, Italy), then assigned to a Neanderthal (Blanc and Pales 1960), led Viehmann (1987) to suggest (without any dating information) that the Vârtop Cave footprint is ca. 80,000 years old. However, the antiquity of the human footprints discovered in the Italian cave was revised (based on radiometric dating) to be just 14,000 to 12,000 years old (Molleson et al. 1972; De Lumley et al. 1984), a fact that called for a re-evaluation and a better way to estimate the age of the Vârtop Man.

Geochronology

As described below, a suite of favourable settings allowed an international group of researcher to successfully date the Vârtop footprint using the U-series method (Onac et al. 2005). The moonmilk deposit accumulated in the Room of the Steps was an ideal surface and material for casting human footprints, especially because it hardened, becoming a compact calc-tufa layer. Computer tomography (CT) imaging suggests the upper 1 cm of this deposit has a low density (grey), followed by a higher density (brighter) indicating less porous calcite, and a more compact layer (1 cm).

The lower part (~4 cm) instead shows a rather low density (dark) material, which would correspond to a porous but homogeneous texture (Fig. 12.2b). Our interpretation of the CT is that the human stepped in the denser and mechanically more competent layer, causing lateral displacement of the softer material below. Since the moonmilk's porous nature is far from ideal for U-series dating, we applied the isochron method to correct for admixed detritus with uniform $^{230}Th/^{232}Th$. Based on seven coeval subsamples having different U and Th concentrations and consequently distinct detrital components, an isochron age of 97,000 years (1σ) was obtained for the lower 5 cm of calc-tufa deposit. Statistically speaking, the age is not very robust due to a large uncertainty, but nevertheless implies a rapid accumulation of the moonmilk sometime during MIS 5.

Constraining the footprint age was possible due to the presence of a small stalagmite that grew over the footprint mould right below the big toe (Fig. 12.2) and a piece of soda straw embedded in the calc-tufa layer directly overlying the human print. The latter one was revealed by the CT scan (Fig. 12.2), which also showed the depth to which the footprint was imprinted on moonmilk. The soda straw from this undated layer returned a U-Th age of ~67,800 years. Three ages obtained from the base of the small stalagmite that was growing in the footprint mould cluster around 62,000 years. The last layer of moonmilk that partly filled the footprint was dated to 22,300 years, whereas a calcite fragment from of a soda straw cemented on the surface of the uppermost calc-tufa layer appears to have formed 20,000 years ago and then broke and fell to the floor. To further consolidate the chronology of the entire sequence, the base of a stalagmite which precipitated directly over the reddish clayey floor was dated to 15,400 years. This could be considered the earliest time at which the old entrance collapsed, preventing soil and other sediments from entering the cave.

Based on the calc-tufa stratigraphy and the above chronology, our interpretation of the Vârtop footprint is as follows: some 97,000 years ago, a period with documented speleothem growth near Vârtop Cave (Onac 2001), and other parts of Romania (Onac and Lauritzen 1996), moonmilk accumulated on the floor of the Room of the Steps. A prehistoric human entered Vârtop Cave using a different entrance than today and left her/his footprints impressed in the upper, more competent layer of the moonmilk deposit not earlier than 67,800 years ago, when a soda straw of this age fell off the cave ceiling and was later embedded in a thin (undated) moonlike layer that covers the footprint. In Romania, the period between 78,000 and 67,000 years ago was mild and wet, favouring speleothem precipitation (Onac and Lauritzen 1996; Staubwasser et al. 2018). Similar conditions must have existed ~62,000 years ago when the small stalagmite nested in the middle part of the footprint mould begun its growth. Since the publication of the original paper reporting these footprints (Onac et al. 2005), the newly dated soda straw (67,800 years) indisputably confirms that the Vârtop prints cannot be younger than 67,800 years; thus they clearly belong to a *Homo neanderthalensis*.

Ciur Izbuc Cave (Pădurea Craiului Mountains)

Ciur Izbuc Cave is part of the Toplița-Ciur-Tinoasa karst system located in the south-eastern part of the Pădurea Craiului Mountains on the Runcuri Karst Plateau (Rusu et al. 1970). Although the cave entrance must have been known to locals for centuries, the first documented visit happened in 1962 when T. Rusu, I. Viehmann, and S. Avram surveyed ~150 m out of its total length of 1030 m (Viehmann et al. 1970). During the exploration and mapping of the cave, a team of researchers from the Emil Racoviță Institute of Speleology in Cluj-Napoca (I. Viehmann, T. Rusu, G. Racoviță, and V. Crăciun) discovered in November 11, 1965, about 400 barefooted human footprints (Rusu et al. 1969; Viehmann et al. 1970). These imprints are interspersed with cave bear (*Ursus spelaeus*) footmarks in the clayey floor of the cave's upper level, in what is now known as Sala Pașilor (Footprint Room). Within 3 years from the time of the discovery, ~230 of the best-preserved prints were tagged with numbered metal flags, some of which still at their original position (Fig. 12.3). This process served two purposes, (i) inventory (for systematic observations) and (ii) raising awareness (protection), to those entering the cave. Nevertheless, decades of indiscriminate visitation of the cave led to the disappearance of many of these flags. Since most footprint casts were anyway hard to see in the red-brown clay and others became filled with bat guano, covered by a sub-millimetre-thick calcite dust, or affected by mud cracks, many of them were damaged or even completely destroyed.

Following the discovery of the human footprints in Ciur Izbuc Cave, an article announcing the findings was published by Rusu et al. (1969) in Ocrotirea Naturii (Nature Conservation), a Romanian popular science magazine. Despite the nontechnical character of the publication, the paper includes very important

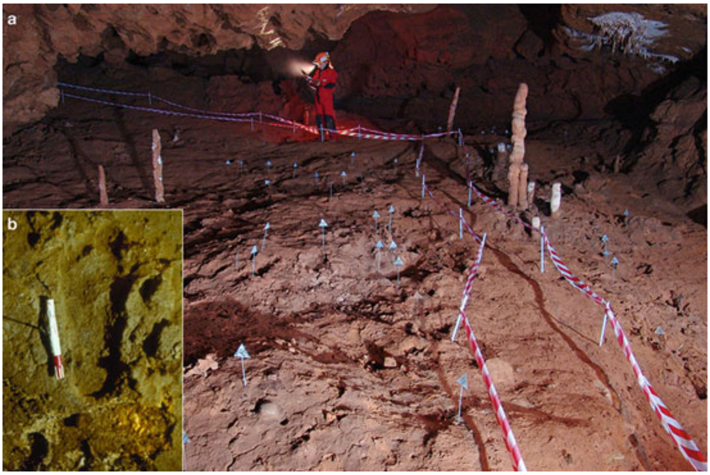

Fig. 12.3 (**a**) Photo of the Footprint Room in Ciur Izbuc Cave showing part of the tagged footprints (Photograph A. Posmoșanu); (**b**) close-up view of a well-preserved footprint. (Photograph G. Ponta)

scientific information regarding the evolution of the cave, documents the traces left by the cave bears, and for the first time illustrates the human footprints. It was also noticed that there was a lack of any footprints or cave bear bones between the current entrance and the Footprint Room, whose northern end is only 50 m away and 8–10 m below the sinking point in which Tinoasa stream disappears into the cave. Due to this geomorphological setting and because the Footprint Room is too far and difficult to reach using the present day cave entrance, it has been speculated that in the past, humans and cave bears likely used a different access point (Rusu et al. 1969). Relying solely on the presence of some polished cave bear bones (used as tools?) and a human figurine rudimentarily engraved on the root of a cave bear canine tooth, the authors attributed the footmarks to a *Homo sapiens* who lived ~15,000 to ~10,000 years ago.

Three other studies appeared in a book printed on the occasion of Emil Racoviță's (founder of the world's first Speleological Institute in Cluj, Romania) birth centenary. The paper by Rusu et al. (1970) tackles the geomorphology and hydrology of the Toplița-Ciur-Tinoasa karst system but also includes a paragraph on the prehistoric footprints, along with a photograph. Viehmann et al. (1970) present a couple of observations that shed light on the presence of human and cave bear footmarks. Without having any radiocarbon ages, but from the apparent relationship between the human and *Ursus spelaeus* prints, the authors claimed that the human footmarks must be younger than those of Solutrean people (21,000 to 17,000 years). The same study suggested based on the large number of prints that the visits were not occasional and the humans had deliberately entered the cave.

The first standard ichnological analyses were undertaken by Rișcuția and Rișcuția (1970), who measured five morphometrical parameters for 188 footprints. By relating the maximum length of the foot (Fl) with the height of individuals (h), using the classic relationship $Fl = 15\%\ h$, the authors concluded that two adults and a child were the Ciur Izbuc cave trackmakers. They reported a height of 157 cm for the woman and 174.9 cm for the man, but for the child, they only indicated an age range (9 to 11 years old).

A more recent study conducted by Webb et al. (2014) measured the width for the ball and heel and the maximum length of 51 footprints that were still visible on the cave floor. Using the print lengths (range between 157 and 318 mm), the authors estimated the minimum number of individuals and their stature range. Contrary to the previous studies, Webb et al. (2014) suggest a group of six to seven individuals left their footprints in Ciur Izbuc Cave. Considering that the printmakers travelled only ~75 m from the former cave entrance towards the inner part of the Footprint Room, the same study concluded that it would have taken 9 min for an individual (and far less for 6–7 people) to leave behind those 400 footprints originally counted. The estimations regarding the human stature (calculated by either regression or percentage method) overlapped well, both studies reporting heights between 106.4 and 216.1 cm.

The real novelty in the study of Webb et al. (2014) is the approach taken by the authors to estimate the age of the footprints. In the absence of any artefacts or human remains, the direct dating of the tracks was impossible. Nevertheless, considering that a few human footmarks appear to be overprinted by cave bears, and having radiocarbon dated two bear bones, the study concluded that the Ciur Izbuc people might have ventured in the cave anytime since ~36,500 years ago. Based on this age, the authors suggest that the footprints belong to either early *H. sapiens* or *sapiens/ neanderthalensis* hybrids, but without being able to place them in a clear cultural context. It is now known that even if the humans were as old as 36,500 years, they would probably have been too young to be direct hybrids, as they post-dated the last known appearances of Neanderthals in Europe (Higham et al. 2014).

It is not surprising that human footprints have been found within the Romanian Carpathian caves. The area has often been considered a refugial area for humans and ecosystems during stadials (Staubwasser et al. 2018), and the potential dispersal routes into Central Europe intersect those north of the Black Sea along the Carpathian arch and the Danube Valley (e.g. Iovita et al. 2012). As such, south-eastern Europe has long been considered one of the most likely routes for hominin spreads across the continent, including anatomically modern humans, with the Oase Cave fossils amongst the oldest modern human fossils in Europe (Trinkaus et al. 2003). It is thus expected that more intensive research will significantly augment the number of cave archaeological sites, as well as our understanding of migration routes, genetic turnover, and past human population dynamics.

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Chapter 13
Episodes of Magdalenian Hunter-Gatherers in the Upper Gallery of Tuc d'Audoubert (Ariège, France)

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Abstract The Tuc d'Audoubert cave (Ariège, France) offers unique insights into the life of Late Pleistocene hunters-gatherers due to its exceptionally good preservation conditions. This is especially true for the 300 footprints in the upper gallery of the cave. Even for the layperson, some trackways are easily recognized. Short episodes of past life become tangible. The spectrum of scientific analytic methods used in western science has not yet provided an option to interpret these visible episodes satisfactorily. For this reason, tracking experts, i.e. indigenous ichnologists, were invited to analyse the footprints in Tuc d'Audoubert. With their dynamic approach of identification, they are able to do justice to the dynamics embodied in the footprints. In total, eight main concentrations in four different locations were studied. Two hundred fifty-five footprints were identified and grouped into 24 events. In view of the group compositions and the assumption that humans did not climb alone into the upper gallery for security reasons, it can be concluded that a maximum of five visits by two to six subjects were carried out. Among the events, the couple of an adult man and an adult woman, who appear together in a total of ten different spots, is particularly noteworthy. Altogether, this study is a first step of a multi-stage procedure. Further analyses based on measurements and plantar pressure analyses will follow.

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Introduction

Over the past years, ichnology has acquired a new relevance in prehistoric archaeology of caves, as shown in a number of scientific studies (e.g. Ledoux 2019; Romano et al. 2019; Ortega Martínez and Martín Merino 2019; Pastoors et al. 2017; Pastoors et al. 2015) and the International Conference on Prehistoric Human Traces held in Germany (Cologne, May 2017). It is within this framework that the prehistoric human tracks in Tuc d'Audoubert are analysed in a multi-stage procedure, combining static with dynamic approaches. In the first phase the tracks have been studied by indigenous ichnologists in 2018, and their results will be presented in this contribution. As static analyses, i.e. Cussac, Fontanet, Bàsura Cave and Pech-Merle of human footprints in caves have shown, this method is not appropriate for exploring the entire information potential of human tracks (cf. Ledoux 2019; Romano et al. 2019; Duday and García 1983). A dynamic method of reading footprints in a morpho-classificatory way offers significantly more possibilities. The good preservation of most of the footprints in Tuc d'Audoubert provides an ideal framework for this investigation.

Quantitative, static analyses are not yet done but will in a next step serve as an important complement and cross-check. In this way, a maximum of information can be drawn from the prehistoric footprints of Tuc d'Audoubert.

At this point, it is important to note that this contribution focuses exclusively on the footprints which are not directly related to the making of drawings or clay models, in the broader sense of art. This clear separation of the aforementioned spoors in terms of activity and space makes such a distinction meaningful. The results of the analysis of the spoors from the Salle des Talons are only included here in particular cases as far as they are published.

The following chapter examines traces that document the locomotion in space and the interaction between humans and bear bones in the various locations along the upper gallery. But it is the intention to go beyond the reconstruction of the activities of every subject. The focus is on the identification of events from the lives of the individual subject as well as groups.

Design of the Project

For the study, three indigenous ichnologists were engaged who have already worked in the Tracking in Caves project (Pastoors et al. 2015, 2017; Lenssen-Erz et al. 2018) but also as professional trackers for commercial hunting and, especially, as economic support for their families and villages through traditional hunting practices. Eight main concentrations of human tracks in the upper gallery of Tuc d'Audoubert

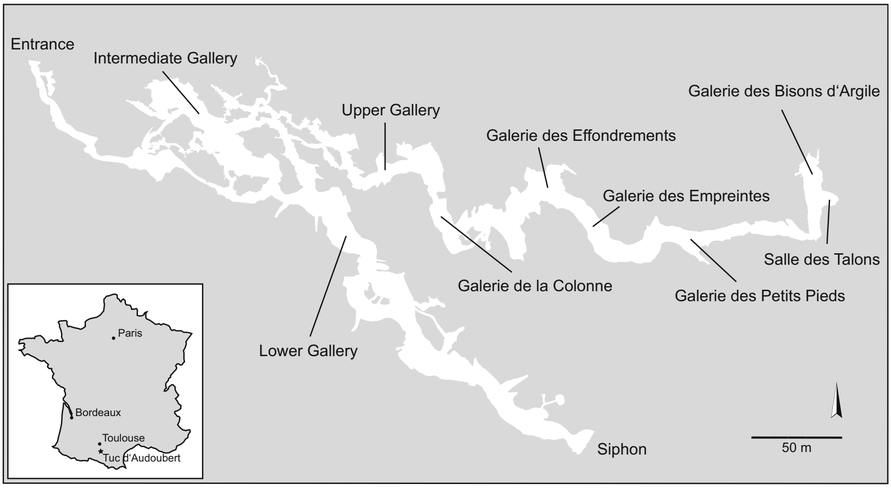

Fig. 13.1 Simplified plan of Tuc d'Audoubert with designation of the locations mentioned in the text. (Illustration Association Louis Bégouën)

were selected according to a list of priorities for the quality and quantity of human footprints in the following locations: Galerie des Effondrements, Galerie des Empreintes, Galerie des Petits Pieds and Salle des Talons (Fig. 13.1). There, the three ichnologists were asked to investigate the discernible footprints and other traces, while the archaeologists accompanying them were assigned to document their analysis. The research in Tuc d'Audoubert took place from 10 to 21 October 2018.

Participants

The main researchers of this project were three indigenous ichnologists from the Nyae Nyae Conservancy around Tsumkwe (Namibia): Thui Thao, /Ui Kxunta and Tsamgao Ciqae. The first two of them are certified Master Trackers of the Cyber-Tracker system (see www.cybertracker.org), while the third, having learned tracking in a traditional way, has mainly helped to translate into English the analysis of the other two ichnologists, which were in Jul'hoansi language. In addition, T. Ciqae also holds a level 2 certificate as a tourist guide and is currently preparing a Namibian hunting licence, so he is very familiar with species terminology (English and Latin).

Materials

The Volp Caves

The three caves of the Volp, Enlène, Trois-Frères and Tuc d’Audoubert, have already been widely described in previous publications (cf. Bégouën et al. 2009, 2014, 2019) and will be presented here only in short form.

The caves are located in the extension of each other under a limestone massif mostly forested, covered with dolines and bizarre rocks with channel-like furrows (southeastern France, Ariège). The limestone massif runs from east to west in this northern Pyrenean part formed of parallel ranges between the Plantaurel in the north and the Arize massif in the south. It is placed in the territory of the community of Montesquieu-Avantès, 14 km southwest of Mas d’Azil. The landscape is contrasted, since the regular and undulating forms of the Cenomanian hills are brutally opposed to the classical phenomena of karst. Under one of these hills, only a few kilometres after its source, the Volp has carved out a large three-level hydrographic network. The lower gallery is the one where the Volp flows, interspersed with two impassable siphons, making the 875 m course impossible to navigate between its loss and its resurgence. The intermediate gallery only exists in the downstream zone at 3 m above the Volp bed. It is in the uppermost level that the upper gallery of Tuc d’Audoubert and the caves of Enlène and Trois-Frères are located.

The Cave of Tuc d’Audoubert

The cave of Tuc d’Audoubert is 640 m long with the resurgence of the Volp as its entry, and because the Volp did not flow during certain periods of the late glacial (Bégouën et al. 2009), this allowed humans easy access to the intermediate gallery (Fig. 13.1). This gallery has preserved many archaeological findings and parietal art, remains of diverse prehistoric activities. A 12-m-high chimney leads from the Salle Nuptiale to the upper gallery, which extends over 465 m. The course in this network, sometimes very difficult, is closely marked for preservation reasons by two cords up to the Bisons d’Argile, a unique masterpiece of its kind. Throughout the route, traces of the humans’ passage are visible on either side of the trail: footprints and heels of adults and children, fingerprints in the clay on the ground, broken bear skulls with extracted teeth, jewellery objects placed on the ground, etc. Parietal art is present in the entire intermediate gallery and in the first part of the upper gallery.

Archaeological Context

From 1992 to 2009 a comprehensive research project was carried out in Tuc d’Audoubert (Bégouën et al. 2009). The aims of this 17-year project were to carry out a broad prospection to evaluate the archaeological potential; to develop a systematic investigation of divers find categories, their documentation and analysis (rock art, depositions, excavations, sondages and dating); and to publish an encompassing monography (Bégouën et al. 2009).

According to this publication, a total of 356 graphic elements were recorded, 101 of which show motifs from the animated world. Among these, depictions of steppe bison (41%) clearly dominate over horse (16%). Reindeer, ibex, snake, lion, bear and unreal beings complete the ensemble of these motifs. In addition, the 140 P- and Q-shaped claviform signs stand out. Apart from these numbers, the multiple depictions of bison couples (male and female) is exceptional. But, most spectacular are the clay sculptures preserved in Tuc d'Audoubert. They represent a male and a female bison, each being 60 cm long and placed in the centre of the last chamber of the upper gallery. On their surfaces human traces as marks of the production process are well preserved (e.g. smoothing with hands and fingerprints on the mane). Furthermore, technical details of the production are still visible: Horns and ears were attached, eyes modelled as craters or elevations and beards cut with a sharp tool.

The cave walls were not only used as canvas for drawings, but their niches and fissures serve for the deposition of various artefacts. A total of 18 objects were found in Tuc d'Audoubert in such situations. Usually these are bone fragments, but lithic artefacts, projectiles and red ochre were also found. The objects are wedged or ready to hand. Only in rare cases they are hidden and difficult to find.

Human presence in Tuc d'Audoubert is evinced for autumn-winter, between 17,200 and 16,500 calBP. Only one single find layer was found at each of the five limited excavations in different chambers. Remarkable is the diversity of the reconstructed activities, their probable contemporaneity and relation to the cave topography (Pastoors 2016).

Various reconstructed activities reflect concrete movements in space and show that the cave as a natural structure has been anthropogenized. This is important to memorize for the analysis of the prehistoric footprints in the upper gallery.

In Tuc d'Audoubert, 21 specific find concentrations were identified at which, on the one hand, substantial activities (N = 2) and, on the other hand, limited, qualified activities were carried out (Fig. 13.2). These limited, qualified activities include drawing activities (N = 16) and the consumption of introduced provisions (N = 2). All 21 find concentrations are in the dark zone of the cave.

The selection of chambers for the various activities of prehistoric humans in Tuc d'Audoubert shows a clear pattern (Fig. 13.2). While substantial and consumption activities were carried out in chambers that were wide and high, drawing activities were carried out in the entire spectrum of chamber types used in Tuc d'Audoubert. It is noticeable, however, that concentrations with only drawing activities are located in narrow or low chambers. From the picture emerge two chambers with substantial or consumption activities in narrow, low chambers (Galerie du Bouquetin and Diverticule des Dessins).

Find concentrations with substantial or consumption activities do not show any pattern at first sight due to their placement in the path network (Fig. 13.2). They are

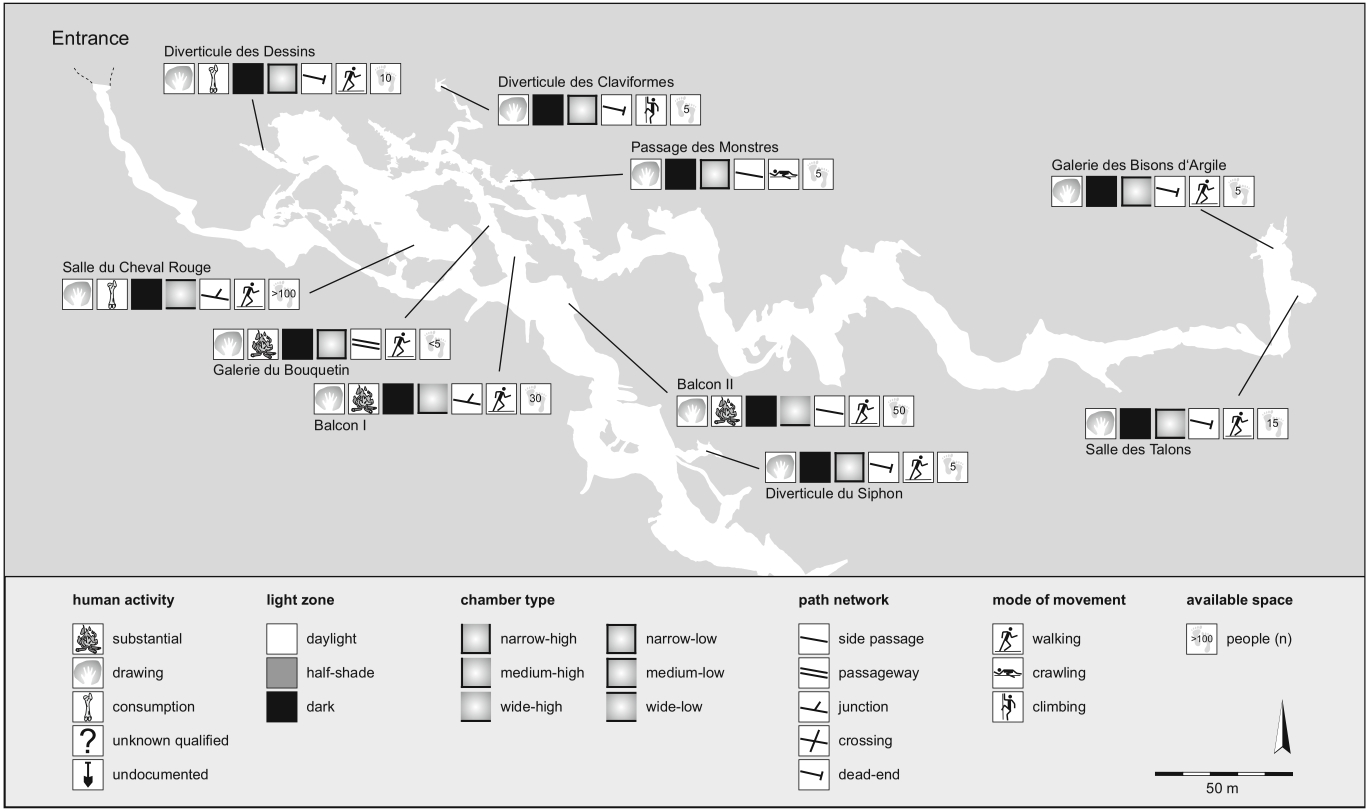

Fig. 13.2 Distribution of concentrations of prehistoric remains with structured information on the use of space in Tuc d'Audoubert. (Illustration Association Louis Bégouën)

located at junctions, at a side passage, at passageway and in a dead end. The differentiated consideration of the two types of activities shows that at least the concentrations with substantial activities are in a strategically favourable position in Tuc d'Audoubert path network due to their immediate proximity to the central traffic axis of the lower gallery. The concentrations with drawing activities, on the other hand, show a clear relation to certain components of the path network. In particular, dead ends and side passages were selected. It is interesting to note that junctions were selected for drawing activities when also other activities were carried out there. Passageways seem to have been of little interest.

The concentrations with substantial or consumption activities are comfortably accessible upright (Fig. 13.2 'mode of movement'). This also applies to the majority of concentrations of drawing activities. In addition, two concentrations can only be passed crawling. Another two concentrations have to be climbed. A total of three concentrations require combined modes of movement: walking and crawling or climbing and crawling.

For the substantial and consumption activities, premises were selected that offer sufficient space for several people at the same time (Fig. 13.2 'chamber type'). Small chambers were avoided for these activities. Exactly the opposite is true for the drawing activities. Here, space was selected that could accommodate a maximum of five people at the same time.

The spatial distribution of the depots corresponds very well with that of the concentrations with substantial or consumption activities. Here a direct relationship between the different activities seems to be evident. The only exception is a fragment of bone deposited at the branch of the Diverticule des Claviformes diverting from the Galerie du Bouquetin in a niche 6 m above the ground in a shaft leading upwards.

The analyses of the archaeological finds exhibit a short stay in Tuc d'Audoubert with different activities of basic supplies, consumption, raw material extraction and drawing activities. In the course of this stay, the entire cave was explored with sporadic visits to the upper gallery. This large spectrum of qualified activities in connection with substantial activities is similar to base camp activities in open-air sites. Thus Tuc d'Audoubert plays a comparable role within the network of sites of Magdalenian hunter-gatherers in the Pyrenees for a limited period of time and represents in this respect an autonomous subsystem.

The inferences from this detailed picture for the basic understanding of the episodes fossilized in the floor of the upper gallery are the following:

- Base camp activities suggest the presence of the entire group of hunter and gatherers with members from each age class.
- The anthropization of the intermediate gallery of the cave testifies to a behaviour based in experience with the conditions of a complex cave system.

Human Tracks

Tracks of humans and cave bears were noticed and respected right from the first day of the discovery of the upper gallery (10 October 1912). This is a very thoughtful behaviour for that time and the basis for the preservation of all tracks into the twenty-first century. For the monograph of 2009, a first tentative count of the human tracks was carried out (Table 13.1).

Of the total of 302 human footprints, passage-related traces are by far the most abundant, and among them, the heels are mainly grouped in the Salle des Talons. Apart from the latter, whose count corresponds to all that is visible in this place, the 87 feet inventoried elsewhere represent only a sample. To preserve the soil, the distant identification of human tracks in the vicinity of bear tracks has proven to be difficult, sometimes impossible (human presence always after that of the cave bear). Moreover, the entire gallery could not be prospected because the virgin surfaces were too fragile. The actual number of footprints must be significantly higher.

Moving towards the deep part of the cave, the first footprints appear in the Salle des Lacis. They can be related to the last engravings when coming from the entrance but also to the first displaced bear bones and accumulated concretions. This association of footprints and manipulated objects, moved or broken, becomes a constant phenomenon in the deep part of the upper gallery. However, two categories can be distinguished: on the one hand, footprints reflecting dynamic movement and, on the other hand, concentrations of imprints over small areas, indicating a stopover or short-distance comings and goings. The former are related to the progression of humans in the gallery and the latter to activities requiring a stopover. The activities during the stopover were sparse because there is no intense trampling as the footprints are clearly discernible and overlaps are infrequent. Thus in the Galerie des Effondrements, about 20 footprints, fingerprints and broken concretions encircle the mandible of a cave bear. Further on, about 40 footprints are spread over 30 m in four concentrations: about 20 in the first, then 8 around the broken cave bear skull, 19 at least in an area with scattered manipulated cave bear bones and finally some at

Table 13.1 Number of prehistoric human tracks in the upper gallery of Tuc d'Audoubert (Bégouën et al. 2009)

Location	Footprint	Heelprint	Div. spoors	Total
Salle des Lacis		1		1
Galerie du 10 Octobre		1		1
Galerie de la Colonne		1	1	2
Galerie des Effondrements	11	6	8	25
Galerie des Empreintes	72	3	1	76
Galerie des Petits Pieds	4	1		5
Galerie des Bisons d'Argile			4	4
Salle des Talons		183	5	188
Total	87	196	19	302

the end of the gallery. Five footprints are concentrated at a prominent location in the Galerie des Petits Pieds.

The next important concentration is none other than the Salle des Talons (Fig. 13.1). Since 1912, these prints have raised many questions, most of which remain unanswered. We have seen that the asymmetrical shape of the cups and their level of sinking into the ground correspond well to heels. Rare circular cups represent knee imprints. It was until more than 100 years after the discovery that complete footprints were discovered for the first time by indigenous ichnologists (Pastoors et al. 2015) in 2013. The distribution of heel imprints indicates activities around the extraction of clay and the making of various drawings on the cave floor (Bégouën et al. 2009; Pastoors 2016).

In summary, for the Salle des Talons initially there were the assumptions that young individuals have left behind five to six sequences of tracks. According to Bégouën, ritual dance or initiation (Bégouën 1928) was the motivation for this. Vallois is much more neutral and sees here young individuals, deliberately walking on heels (Vallois 1931). A further interpretation of the events in the Salle des Talons that led to the distribution of the footprints was carried out by the indigenous ichnologists in 2013 and 2018. They identified two subjects who crossed the chamber twice to a clay extraction pit (Pastoors et al. 2015). In addition, further footprints are associated with drawing activities on the floor.

Investigations about the identity of the trackmakers in the upper gallery of Tuc d'Audoubert were carried out only unsystematically up to the present work. Vallois examined a selection of the best-preserved footprints and took the first measurements. Two complete footprints measure 218 mm or 200 mm in length and 53 mm or 62 mm in heel width. Further dimensions were taken from heel prints, which accumulate at various points in the cave. Accordingly, the examined heels have a maximum width of 72, 68, 67, 60, 54 and 52 mm (Vallois 1931). The step width of these heel imprints is between 25 and 28 cm. In the Salle des Talons, also measures of the maximum width of the heels were taken. Thus they are 58, 55, 53, 52 and 50 mm wide. The step width of these prints examined is a maximum of 20 to 25 cm.

Methods

Prehistoric human traces are considered to be the most personal, nonmaterial legacies that have remained. These are mainly footprints, but also traces of hands, knees and other body parts. Curiously, it does not yet seem possible to do justice to these information-rich traces with synthetic classification and quantitative methods. A critical inspection of the possibilities and above all the limits of current methods clearly shows that on empirical basis only the number of different trackmakers can be calculated (Bennett and Morse 2014; see Chap. 2). In the ideal case, statements about the gait and the walking speed are also possible. On the basis of quantitative analyses, it is currently not possible to say anything dependable about the identity of people and the episodes stored in the tracks. It looks as if these static analyses are not appropriate for exploiting the information potential of this multifaceted find category of dynamic processes (see Chap. 6).

To pursue this issue more closely, the methodological process for the analysis of prehistoric footprints in Tuc d'Audoubert follows a multistage procedure. This includes the identification of the traces left behind by prehistoric humans according to the principle of the preiconographic description by Panofsky (see next paragraph; Panofsky 1962). Traces are recognized, put in relation to each other and summarized as events. In a further step, the identified human tracks are analysed quantitatively following basic measurements (cf. Bennett and Morse 2014). Footprint outline- and landmark-based geometric-morphometric analysis (cf. Bennett et al. 2009; Bennett et al. 2016) and pixel-based quantitative analysis of the whole plantar pressure (cf. Crompton et al. 2011) are also planned.

Practical experience (familiarity with objects and phenomena) is an absolute prerequisite for a successful application of the preiconographic description, from which a positive correlation between experience and descriptive accuracy can be derived. In the case that the spectrum of personal experience is not sufficient, this spectrum must be extended by consulting publications or experts. Practical experience, in turn, helps to determine which publication or expert is to be consulted (Panofsky 1962: 9). In prehistoric archaeology, it is a common practice to compensate the lack of practical experience with experiments (e.g. Bourguignon et al. 2001). In the layout of the current research project we decided against the generation of experience through experimental archaeology. Instead, we use expert knowledge of indigenous ichnologists building on their outstanding experience in reading tracks (Liebenberg 1990; Gagnol 2013; see also Chap. 6 and 19).

The process of recording the workflow of the indigenous ichnologists in reading prehistoric human spoors has been substantially further developed compared to the one applied in 2013. First of all, lists were compiled with information on each individual footprint examined. The following aspects were documented:

- Subject number: The subject number identifies each individual (trackmaker) independently of the study area within the cave. This makes it easy to follow each subject through the cave.
- Age: The results of the morpho-classificatorical analysis of age are given very precisely by the indigenous ichnologists. In consideration of the fact that such a precise age indication by means of footprints seems problematic and should always be seen against the background of the reference collection used or personal experience, the data of the indigenous ichnologists are grouped together in age classes according to Martin (Martin 1928) – neonatus, infans I (0.5–6 years), infans II (7–13 years), juvenis (14–20 years), adultus (21–40 years), maturus (41–60 years) and senilis (>60 years).
- Sex: If the sex of the subject can be identified, it is recorded as female or male.
- Physique: Under this aspect, information about the body shape is given. Here, too, it is more a matter of deviations from a normal physique than of a precise definition of a certain shape.

- Handicap: Under handicap, observations are recorded that relate to deviations from a well-balanced human being. No statements are made about the medical causes.
- Spoor number: The spoor number designates each individual human trace examined and listed in the project. Subject and spoor number together form a distinctive unit. They are continuous and thus allow an unambiguous assignment of the human traces in each part of the cave.
- Spoor type: Specifies the exact body part that caused the traces. This includes the foot, hand, knee, elbow and others (e.g. tools).
- Side: If the side of the body part can be identified, it is recorded as left or right.
- Additional weight: The additional weight refers to the characteristics of a subject that deviate from the normal gait or depth of imprint.
- Gait: Under this point, statements are made about the manner of the executed locomotion. This includes safety and speed, as well as movement in a group or alone.
- Direction: The direction of movement is documented in cardinal direction. Specific local information is given for better orientation in the cave.
- Trackway: Hereunder it is noted whether the footprint is part of a series of footprints of the same subject or whether it is isolated.
- Event identification: Summary of traces of individual or several subjects in temporal, spatial and content-related connection with each other.
- Taphonomy: This aspect refers to the state of preservation of the various traces which can be influenced by both natural and anthropogenic factors.
- Substrate: The substrate refers to the sediment in which the spoor was formed.
- Reliability of identification: Particularly important for the comprehensibility of the analysis is the judgement of its reliability on the basis of preservation and visibility. For this purpose, a subjective five-stage classification was carried out from very good (1) to unsatisfactory (5). The intermediate stages are good (2), satisfactory (3) and sufficient (4).
- Remarks: An open field for comments of any kind.

The position of every spoor was located on plans or sketches. All work sequences were recorded on film. In this way, not only the results can be checked and compared with each other, but also further linguistic research can be carried out. At the end stands a database (catalogue) with the results of the morpho-classificatorical analysis and event identification. For future work, photogrammetric records of the examined footprints will be generated with the help of Structure from Motion (e.g. Mallison and Wings 2014).

In order to understand how a combination of footprints is identified as a track, and how several tracks sometimes are being interpreted as a coherent event, it is helpful to look at perception psychology and Gestalt principles in particular. By Gestalt is meant:

> a unitary whole of varying degrees of detail, which, by virtue of its intrinsic articulation and structure, possesses coherence and consolidation and thus detaches itself as a closed unit from the surrounding field. (Maynard 2005: 501 citing Gurwitsch 1964).

The concept of Gestalt was introduced by Max Wertheimer (Wertheimer 1923), and since then research into Gestalt formation focuses on the perception and interpretation of grouped objects as well as on small entities within larger environments and is of relevance still today (Wagemans et al. 2012a, b). So-called Gestalt laws (Fitzek and Salber 1996) or principles are particularly vital in the advertisement industry (e.g. Graham 2008), and, besides psychology (e.g. Wörgötter et al. 2004), they have also received quite some attention in computer science and mathematical approaches (e.g. Zhu 1999; Elder and Goldberg 2002; Wen et al. 2010). Some of the Gestalt principles are figure-ground articulation, proximity, common fate, similarity, continuity, closure, past experience and good Gestalt (Todorovic 2008). All these principles are at work in perception when regarding spoor, single or in trails, and making sense of their complex and combining information.

Results

In the following part, the results of the identifications of the prehistoric footprints from Tuc d'Audoubert by the indigenous ichnologists are presented in spatial units, advancing into the depth of the upper gallery. Starting point in each section is the specification of the chamber with its prominent finds and features, which are based on the descriptions by Bégouën et al. (2009). After this intro, the results are grouped according to the events identified. In this chapter, two different systems are used to identify the individual spoors. On the one hand, the numbering of the spoors as published by Bégouën et al. (2009) (e.g. TUC-291) is used as a reference while on the other hand, since it is more detailed, the project-internal numbers of the tracks (e.g. S8–1, S8–2 . . .) (for cross-references, see Table 13.2). The rating of the reliability of identification is assembled in the same table.

Galerie des Effondrements

This gallery is about 50 m long and comprises a passage between various geological phenomena that have marked this place (Fig. 13.3). Prehistoric humans followed this itinerary, leaving their traces throughout this same passage. The floor of the Galerie des Effondrements is largely made up of stalagmitic floors, especially on the southern side of the path. On the northern side there are clay areas with various human spoors. Apart from these traces, the most spectacular testimonies are the bear bones removed from their original deposits and placed along the path. After a large chute, the gallery widens but remains marked by bear bone deposits, still located in the axis of the passage.

Just after a stalagmitic obstacle, the path makes a sharp turn to the right. On its left side, at 60 cm from the passage, a human heel (TUC-266) is visible with its well-marked clay ridge. Not far from the previous one, over a length of about 1 m, there

Table 13.2 List of prehistoric tracks identified by the indigenous ichnologists in the upper gallery of Tuc d'Audoubert

Spoor n°	Reliability of identification				Event	Cross-reference	Location
	Toes	Ball of foot	Midfoot	Heel			
S3–1	1	2	2	2	E24	TUC-331	Galerie des Petits Pieds
S3–2	3	4	4	4	E15	TUC-308	Galerie des Empreintes – eastern centre
S3–3	5	5	5	3	E15		
S4–1	1	1	1	2	E24	TUC-332	Galerie des Petits Pieds
S4–2	5	4	4	3	E21	TUC-330	
S5–1	3	4	4	3	E22	–	
S6–1	2	3	3	3	E23	–	
S7–1	5	3	3	1	E17	TUC-308	Galerie des Empreintes – eastern centre
S7–2	5	5	4	4	E17		
S7–3	5	5	4	3	E16		
S7–4	2	3	3	3	E16		
S7–5	1	3	3	2	E17		
S7–6	4	4	4	4	E17		
S7–7	5	5	5	2	E13	TUC-303	
S7–8	5	5	5	2	E13		
S7–9	5	5	2	2	E13		
S7–10	5	4	2	2	E13		
S7–11	4	4	3	2	E13		
S7–12	4	4	4	3	E14	–	
S7–13	1	3	5	5	E11	TUC-293	Galerie des Empreintes – western centre
S7–14	5	5	4	4	E11		
S7–15	3	3	3	3	E10		
S7–16	5	5	3	2	E10		
S7–17	4	4	5	5	E10		
S7–18	4	4	4	4	E8	TUC-291	Galerie des Empreintes – western end section
S7–19	5	5	5	4	E8		
S7–20	2	3	5	5	E8		
S7–21	4	4	3	3	E8		
S7–22	4	4	4	3	E7		
S7–23	5	5	4	3	E7		
S7–24	4	4	3	3	E7		
S7–25	1	1	1	1	E2	TUC-273	Galerie des Effondrements
S7–26	1	1	1	1	E2		
S7–27	5	5	1	1	E2		
S7–28	1	1	1	1	E2		
S7–29	1	1	1	1	E2		
S7–30	3	2	1	1	E4	–	
S7–31	5	5	2	1	E1	TUC-267	Galerie des Effondrements
S7–32	buttock (2)				E1		

(continued)

Table 13.2 (continued)

Spoor n°	Reliability of identification				Event	Cross-reference	Location
	Toes	Ball of foot	Midfoot	Heel			
S7–33	5	4	3	3	E18	TUC-324	Galerie des Empreintes – eastern end section
S7–34	4	4	4	4	E18		
S7–35	1	1	4	3	E19		
S7–36	4	3	4	2	E19		
S7–37	2	4	2	4	E19		
S8–1	4	3	2	1	E17	TUC-308	Galerie des Empreintes – eastern centre
S8–2	5	5	4	2	E17		
S8–3	2	4	4	3	E16		
S8–4	2	3	4	5	E16		
S8–5	1	3	4	5	E16		
S8–6	1	2	5	5	E11	TUC-293	Galerie des Empreintes – western centre
S8–7	5	4	4	1	E10		
S8–8	4	4	4	1	E10		
S8–9	5	4	4	2	E10		
S8–10	4	4	4	3	E10		
S8–11	4	4	4	2	E9	–	Galerie des Empreintes – between western centre and western end section
S8–12	4	4	3	1	E9	–	
S8–13	5	3	2	2	E8	TUC-291	Galerie des Empreintes – western end section
S8–14	5	3	2	2	E8		
S8–15	2	2	1	1	E8		
S8–16	2	3	3	1	E8		
S8–17	2	4	4	3	E8		
S8–18	1	2	4	4	E8		
S8–19	1	3	4	4	E8		
S8–20	1	4	4	4	E8		
S8–21	5	5	2	1	E7		
S8–22	5	5	4	2	E7		
S8–23	5	3	2	1	E3	–	Galerie des Effondrements
S8–24	1	1	2	2	E4	TUC-285	
S8–25	5	3	1	1	E1	TUC-266	Galerie des Effondrements
S8–26	4	3	3	2	E18	TUC-324	Galerie des Empreintes – eastern end section
S8–27	4	4	4	4	E18		
S8–28	4	4	4	3	E18		
S8–29	4	4	4	3	E18		
S8–30	5	5	2	2	E19		
S8–31	1	2	3	3	E19		
S9–1	3	3	3	2	E20		
S10–1	3	3	3	3	E15	TUC-308	Galerie des Empreintes – eastern centre
S11–1	4	4	4	2	E15		
S12–1	5	5	5	3	E15		
S13–1	3	5	5	5	E15		

(continued)

Table 13.2 (continued)

Spoor n°	Reliability of identification				Event	Cross-reference	Location
	Toes	Ball of foot	Midfoot	Heel			
S14–1	2	3	4	4	E12	TUC-293	Galerie des Empreintes – western centre
S14–2	2	3	4	4	E5	TUC-291	Galerie des Empreintes – western end section
S14–3	3	3	2	2	E6		

Table 13.3 Quantification of tracks identified during the Tracking in Caves project in 2018; the published data refer to Bégouën et al. (2009). Tracks from Salle des Talons were not analysed equally detailed as all other tracks

Location	Number of footprints		
	Published	Identified in 2018	Proportion of published footprints
Galerie des Effondrements	25	11	44%
Galerie des Empreintes	76	67	88%
Galerie des Petits Pieds	5	5	100%
Salle des Talons	188	172	91.5%
Total	294	255	86.1%

are at least one footprint and a slide (TUC-267), on a relief near a depression. According to the indigenous ichnologists, the traces described above came from one single event.

The most visible human footprints are on the northern side of the passage, two small heels of probably identical dimensions and appearance (TUC-280 and TUC-281) heading to the east, facing the deep part of the cave. Another footprint (TUC-285) is 1.5 m from the path, close to a natural crack in the clay, perpendicular to the axis of the gallery. It is a right foot well printed in clay with five clearly visible toes. The most prominent area with human spoors is 3 m to the north from the path, in the largest part of the gallery (TUC-273). Their presences indicate human activities over an area of 6 m^2. Apart from footprints, the edges of a depression have retained two parallel and aligned finger marks, one of them near to a cave bear mandible without its canine. In this area there are about 15 well-preserved footprints.

So far, 25 human tracks have been published of the Galerie des Effondrements (Bégouën et al. 2009). In the course of the investigations by the indigenous ichnologists, two further footprints were discovered, so that now overall 27 footprints are known. Of these, only 11 were interpreted more closely by the trackers (44%) (Table 13.3). The other footprints were either hidden or there was nothing reliable to report about them. The 11 footprints were made by 2 adults, 1 female (subject S8) and 1 male (subject S7), and derived from 4 events:

- Event 1: Just in the sharp turn, two subjects, subject S7, male adult, and subject S8, female adult, walked together fast in direction to the entrance (Fig. 13.4). From subject S7, male adult, is a left footprint that results from slipping (S7–31) and led to a curiosity. The trackmaker couldn't keep his balance and has sat down on his buttocks (S7–32) right on the edge of the depression mentioned above.
- Event 2: The second event happened in the most prominent area with human spoors in the Galerie des Effondrements (Fig. 13.3). Here subject S7, male adult, has left several spoors in a sequence of five successive footprints – left (S7–25), right (S7–27), left (S7–26), right (S7–29) and left (S7–28). The subject was standing there, picking something up, probably the mandible of the cave bear that is in front of the footprints (Fig. 13.4). While working there with the body aligned to the northern wall of the gallery, the trackmaker was alone at the place. No footprints of other subjects are visible in this restricted area.
- Event 3: Just around 3 metres from the first event, there is a new isolated left footprint from subject S8 (S8–23), female adult (Fig. 13.3). It is on the north side, about 1.5 m from the path. The subject was walking in the direction of the deep part of the cave. At this point, the subject slipped a little and walked with slow speed.
- Event 4: The last event identified by the indigenous ichnologists is located near the natural crack in the clay perpendicular to the axis of the gallery (Fig. 13.3). Here, on a slightly rising ground, subjects S7, male adult, and S8, female adult, walked fast together to the entrance of the cave. Both trackmakers were carrying little additional weight at that place. From subject S8, female adult, a right isolated footprint has been identified (S8–24). The right isolated footprint (S7–30) from subject S7, male adult, was hitherto unknown.

The footprints in the Galerie des Effondrements document very well a short-term activity of a male adult (subject S7) in the environs of the mandible of the cave bear, a dynamic locomotion of a female adult (subject S8) in direction to the deep part of the cave and a dynamic and fast locomotion of the two adults (subjects S7 and S8) together carrying each a little additional weight back to the entrance of the cave.

Galerie des Empreintes

On a wide and not very calcinated surface, contrasting in this respect with the previous gallery, the Galerie des Empreintes measures nearly 60 m long and 7 to 8 m wide and high (Fig. 13.3). Coming from the Galerie des Effondrements, the entrance to the gallery is marked by an impressive stalagmite cascade. Shortly afterwards, the eye immediately catches the long marked path that follows the central axis of the gallery to its right. The left part is made up of a vast clayey expanse entirely covered by bear tracks. There is also evidence of human activities, but the fragility of the soil has not allowed a full exploration of this area. The omnipresence of the bear is evident throughout the entire path of the Galerie des Empreintes. Its

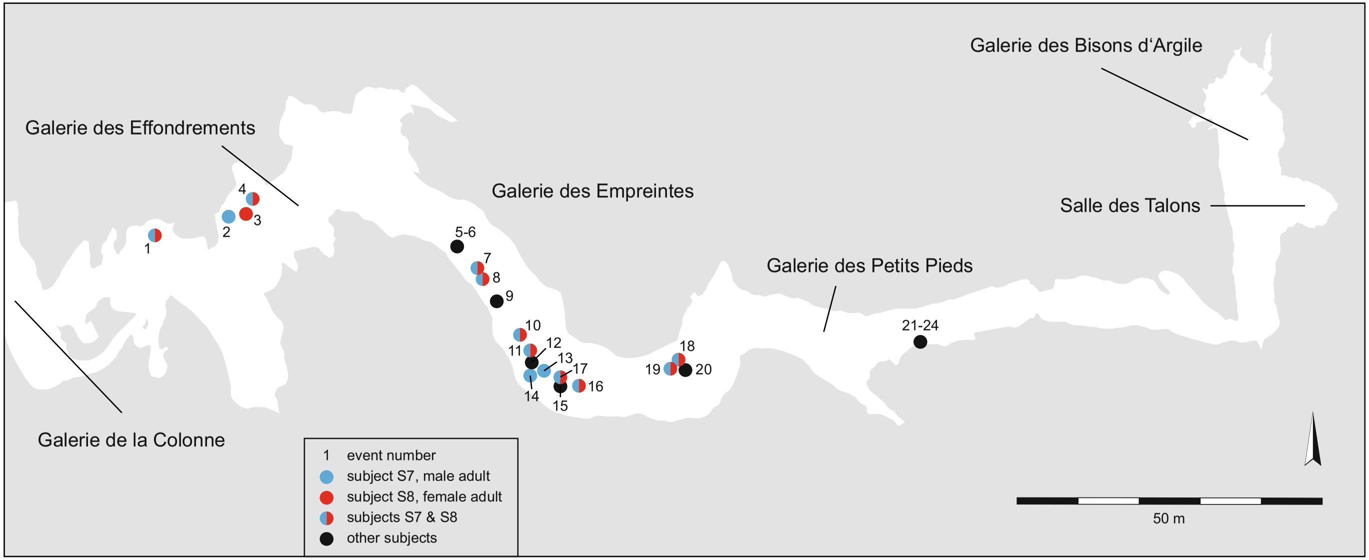

Fig. 13.3 Localization of the events in the upper gallery of Tuc d’Audoubert. (Illustration Association Louis Bégouën/Tracking in Caves)

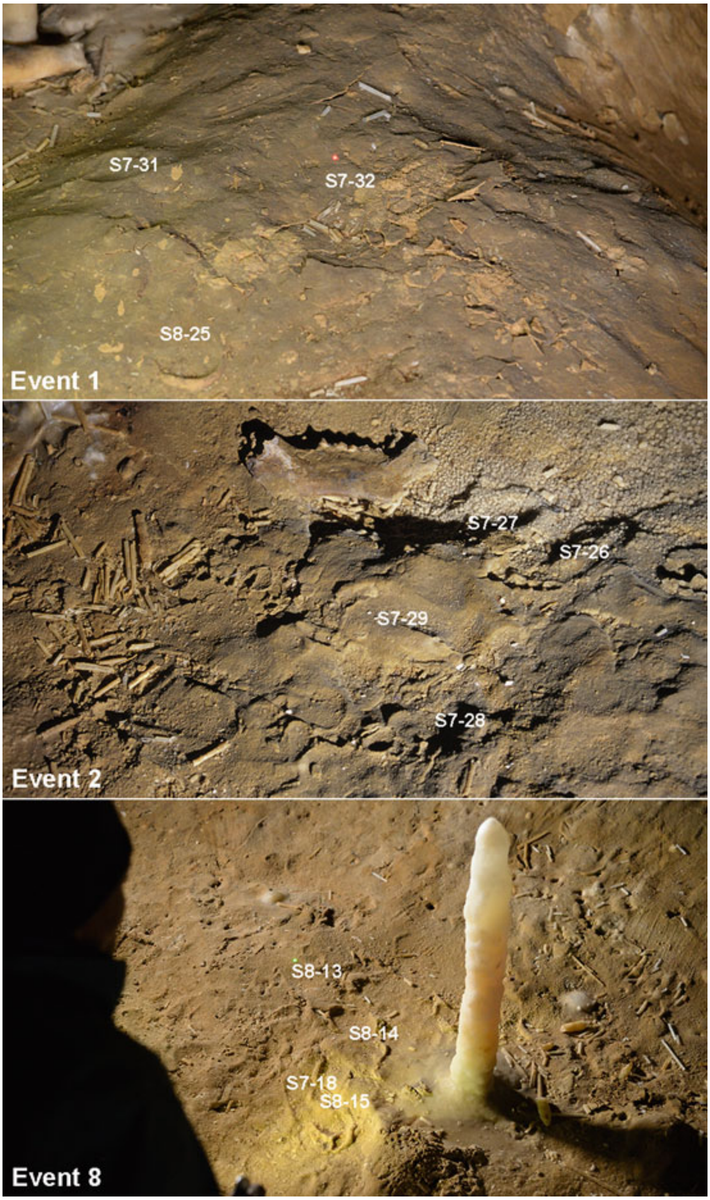

Fig. 13.4 Complete events 1 and 2 and excerpt of event 8 in the upper gallery of Tuc d'Audoubert with the respective spoor number. (Photo Association Louis Bégouën/Tracking in Caves) – the *red laser* points to a part of the buttock imprint (S7–32) of event 1, whereas the *green laser* points to the slip track (S8–13) in event 8

scattered bones are visible all over, and its tracks, slips and traces of hair and claws in the clay and on the walls, broken concretions, make the presence of the bear almost tangible.

A total of 76 human footprints were recorded during an initial counting. These tracks are mostly concentrated in a total of four well-defined sections (Fig. 13.3). At first, the right part of the path runs along a low ceiling (1.4 m) under which footprints are visible (western end section) in spatial relation to a drawing made by fingers on the floor. After about 20 m, the gallery widens to the right into a semicircular room. Here and a few metres before it, the soil has kept traces of passages and intense prehistoric human activities (TUC-293 to TUC-327) (western and eastern centres) (Fig. 13.3).

In the second part of the Galerie des Empreintes, the gallery then becomes slightly open where another concentration of prehistoric human activities is visible (eastern end section) (Fig. 13.3). A few metres further on, before a narrowing of the space between barriers of concretions, the right wall marks its end. This narrow place has been chosen to deposit three perforated teeth and red ochre on the floor, right against the wall.

Western End Section

Coming from the Galerie des Effondrements, on the right side, under the lower roof, 21 footprints printed in the loamy soil were counted over a length of 3 m, some of them later calcined (TUC-291). Nineteen of them were interpreted by the indigenous ichnologists. The most complete, a right foot, is located very close to the path (Fig. 13.3).

In the western end section, three subjects were identified. These are the same two subjects (S7 and S8), who were already identified in the Galerie des Effondrements and were underway together. There are four trackways with up to eight footprints of this couple. Furthermore, a third subject (subject S14) left two isolated footprints in the western end section. According to the observations of the experienced trackers, subject S14 was solo on this spot. The western end section is a passage zone along a low ceiling with various blocks and stalagmites on the floor. The passage was used for the way into the deep part of the cave as well as to the entrance. In total of four events can be summarized:

- Event 5: The isolated left footprint (S14–2) of subject S14, female infans II, describes the first event within this section of the Galerie des Empreintes. With a fast speed the trackmaker moved to the deep part of the cave, lost her grip and slipped with the toes against a rock which probably caused some pain.
- Event 6: From the same subject S14, female infans II, a second footprint is from her right foot (S14–3). Again with fast speed, she moved this time towards the entrance (Fig. 13.3).
- Event 7: The next event happened in a corridor with a low roof close to the right wall. Here the two subjects S7, male adult, and S8, female adult, walked fast

together in direction to the deep part of the cave (Fig. 13.3). From this event is left a first trackway of subject S7 that is composed of three footprints – right (S7–22), left (S7–23) and right (S7–24). In a shorter trackway with only two footprints, the way of subject S8 – left (S8–21) and right (S8–22) – is documented. Since the roof is very low in this part of the cave, subject S8 – moving through the lowest passage – had to walk bent over.

- Event 8: The last event in this section of the Galerie des Empreintes took place close to the actual path in the central axis of the gallery. Again, the two subjects S7, male adult, and S8, female adult, walked fast together, each carrying little additional weight in direction to the entrance (Fig. 13.3). Subject S7 is documented by a trackway of four footprints – right (S7–18), left (S7–19), right (S7–20) and right (S7–21). From subject S8, female adult, is the longest trackway known in the upper gallery – left (S8–13), left (S8–14), right (S8–15), left (S8–16), right (S8–17), left (S8–18), left (S8–19) and left (S8–20). Some tracks are missing due to the changing substrate conditions. Close to a stalagmite that disturbs the direct passage of subject S8, an interesting incident took place (Fig. 13.4). With her left foot (S8–13), subject S8 lost her grip and slipped. But it did not end in a fall because she found the balance by an interruption of her forward movement, regaining a firm stand again – (S8–14) and (S8–15) by putting both feet side by side. Quite rare in Tuc d'Audoubert are identifications of overlapping footprints. A very good example is provided within the described event 8. Footprint S7–18 was clearly overstepped by S8–15 and S7–19 by S8–19 (Fig. 13.4). This proves that subject S7 went in front of subject S8 at this point of the cave when walking back to the cave entrance.

Between western end section and western centre just close to the finger drawing (Bégouën et al. 2009: 262), no tracks were left by the artist. The only identifiable footprints come from subject S8, female adult who has passed this section. This short event is evinced by a short trackway with two footprints.

- Event 9: Subject S8, female adult, left two footprints – right (S8–11) and left (S8–12), which lead to the entrance (Fig. 13.3). She was solo at this point and passed fast this section close to the actual path.

Western Centre

Near the path, still on the right, about 15 footprints remain around a small prehistoric excavation (TUC-293), 11 of them interpreted by the ichnologists. On the left side at this point of the path, on the previously mentioned trampled slope, three barely visible footprints seem to descend towards the path (TUC-294 - TUC-296). They are too far from where one can regard them without damaging the substrate to identify any details.

The western centre, according to the footprints, is a passage zone that three subjects have passed. The path leads over a limestone block on the ground and past a second one. In three events the same subjects appear as already met in the western end section (S7, S8 and S14). They are represented here with three trackways with up to four footprints and two isolated footprints. The identified walking directions lead, in both directions, to the depth of the cave as well as to the entrance.

- Event 10: In the first and most complex event in this section, the two subjects S7, male adult, and S8, female adult, walked fast together one after another in direction to the entrance, both carrying something (Fig. 13.3). From subject S7 three footprints have been identified – left (S7–15), right (S7–16) and left (S7–17). The trackway with four footprints of subject S8 is longer – left (S8–7), right (S8–8), left (S8–9) and right (S8–10). It seems that the trackmaker has probably supported herself in the vicinity of the footprints S8–9 and S8–10 with her left hand on the rock jutting into the passage. On the basis of superposition – S8–7 and S8–8 were overstepped by S7–15 – it can be concluded that subject S8 was the first to pass this spot.
- Event 11: Beyond the limestone block crossed by both, traces of the subjects S7 and S8 can be found again, this time pointing in the other direction (Fig. 13.3). The two went together almost in the direction to the deep part of the cave. Subject S7, male adult, has left a short trackway of two footprints – right (S7–13) and left (S7–14). This time subject S8 has left only an isolated left footprint (S8–6).
- Event 12: The third event in this section happened in the same area as that of event 10, but this time with subject S14, female infans II, that has left only an isolated right footprint (S14–1) (Fig. 13.3). She was moving fast slightly slipping, in the direction to the deep part of the cave.

Eastern Centre

On the right side of the small room, the flat floor has abundant animal tracks, including very large claws. Over a distance of about 10 m, human activity focused on collecting and handling bear bones that would stick out from the clay soil. On the natural anvil formed by a nascent stalagmite, a skull of a bear was smashed with the probable purpose of extracting the teeth, none of which remain nearby (TUC-302). Eight footprints (TUC-303) are printed in the clay to the left-hand side of the skull. The face broke into fragments scattered all around the skull. A prehistoric excavation located 1 m further to the left (TUC-305) can reasonably be considered as the extraction site of the skull. On a strip 1.5 m wide, along the path, at least 19 footprints mark the bottom of a slight depression (TUC-308), all covered with calcite. A little further on to the deep part of the cave, 50 cm from the path, scattered on the ground, there is a coxal bear bone, a bear rib and a complete left human footprint (TUC-318). On the rib, there are clear traces of the brown clay crust that coated it before it was extracted. Twenty-three out of the mentioned 28 footprints have been identified by the indigenous ichnologists.

In the Galerie des Empreintes, the eastern centre represents the main activity area in which seven subjects left their footprints. It seems that there was the couple subject S7 and S8 again relocating bear bones, but also another group of subjects

(S3, S10, S11, S12 and S13) on their way. In total four trackways with up to five footprints and ten isolated footprints have been identified that constitute altogether six events.

- Event 13: The following sequence of footprints is certainly one of the most spectacular events (Fig. 13.3). These are five consecutive footprints of subject S7, male adult. The sequence begins with an isolated right footprint (S7–7). The following two belong together and indicate a squatting position – left (S7–8) and right (S7–9) (Fig. 13.5). The same applies to the following two footprints: right (S7–10) and left (S7–11). In this posture, an activity was performed close to the floor, turned in direction of the entrance. Since the skull of a cave bear described above is located directly in front of the footprints, a direct connection is most likely. At this point subject S7 acted alone.
- Event 14: Just behind the described event an isolated left footprint of subject S7, male adult (S7–12), is found (Fig. 13.3). The path leads in direction to the cave wall. Subject S7 was at this point alone.
- Event 15: Several metres deeper in the cave, a group of subjects (S3, S10, S11, S12 and S13) were identified that walked together at that point. The picture left by the footprints is not to be interpreted as clearly as it was the case in other events. The footprints point in different directions and are most likely to be understood as walking around the gallery (Fig. 13.3). Subject S3, male infans I, is represented by two isolated footprints. The first is a right isolated footprint (S3–2). With fast speed he went to the deep part of the cave. The second isolated footprint of subject S3 derives again from a right foot (S3–3). It also shows a fast walking speed towards the deep part of the cave. In the same area, a left footprint (S10–1) from subject S10, female infans I, is leading into the direction of the deep part of the cave. Furthermore, a left footprint (S11–1) comes from subject S11, female adult, who walked fast in direction to the entrance and carried something. She stepped over two footprints of the subject S7 (S7–1 and S7–6) (Fig. 13.5). Apart from this, a right footprint (S12–1) comes from subject S12, male juvenis, who walked in direction to the wall of the gallery. The last isolated track in this event comes from subject S13, male infans I, and represents a non-specific footprint (S13–1) pointing towards the deep part of the cave.
- Event 16: In the same area in which event 15 happened, the two subjects S7, male adult, and S8, female adult, walked fast together in direction to the entrance (Fig. 13.3). Subject S7 is present with a trackway that consists of only two footprints – left (S7-3) and right (S7-4). The best visible and even recognizable for a layperson is the trackway of subject S8, female adult, consisting of three footprints – right (S8–3), left (S8–4) and right (S8–5) (Fig. 13.5).
- Event 17: The last event identified in this section of the Galerie des Empreintes happened again with the two subjects S7, male adult, and S8, female adult (Fig. 13.3). This time they walked fast together towards the deep part of the cave after subject S7 had picked up probably some cave bear bones. This particular trackway from subject S7 consists of three footprints – left (S7–5), right (S7–6) and right (S7–1) (Fig. 13.5). From the squatting position (S7–5 and

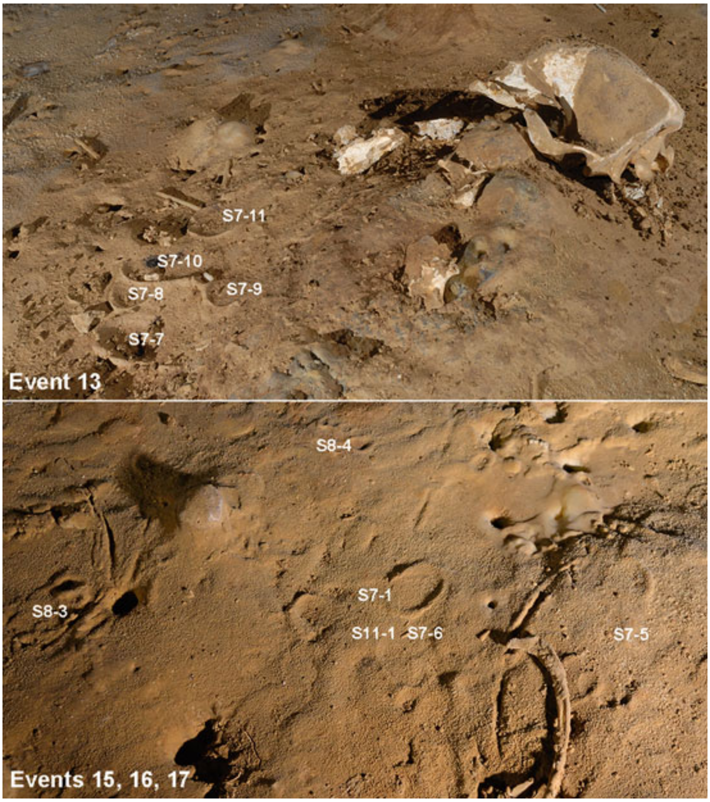

Fig. 13.5 Complete event 13 and excerpt of events 15, 16 and 17 in the upper gallery of Tuc d'Audoubert with the respective spoor number. (Photo Association Louis Bégouën/Tracking in Caves)

S7–6), facing the centre of the gallery, subject S7 turned the right foot to the right and produced the footprint S7–1. From here the subject moved towards the deep part of the cave. While sitting in a squatting position, subject S7 probably did something with the bone in front. Just close to this a right footprint (S8–1) of subject S8, female adult, was identified. Some metres from the described scenario the couple left again their traces. According to the indigenous ichnologists, they belong to the same event 17 as the other footprints just described. Subject S7 left an isolated left footprint (S7–2). Close to it a right footprint (S8–2) from subject S8 was identified.

Eastern End Section

Having passed the narrow passage at the sinter basin with the colubrid skeleton, the gallery widens again (Fig. 13.3). There are bear bones scattered around, including a right mandible placed on a rock, deprived of its canine tooth. Three metres further on, on the left, heels and footprints (TUC-324) precede a young bear skeleton (TUC-325) lying in the clay soil. The vertebral column is anatomically connected. There are also two holes made by a flat tool used as a lever to loosen the bones. Two vertebrae taken by prehistoric humans are deposited next to it. By its dimensions, a left mandible with missing teeth recalls the first one located 6.5 m away. Due to the connection with the results of the investigations at this place by the indigenous ichnologists, the following location 6 metres further on is remarkable. Here on the left side of the path, another bear skeleton (TUC-326) is scattered over a small area at the foot of the cave wall. The distance from walkable areas prohibits detailed observation, but it is an accumulation of diverse bones that are no longer in anatomical connection. At the end of the Galerie des Empreintes, three perforated teeth, two bison incisors and a fox canine, are aligned on the floor along the wall. Ten centimetres before these teeth, a niche in the wall is completely stained with red ochre.

According to the footprints, three subjects were on their way in this area. The indigenous ichnologists identified three events: again the couple of subjects S7, male adult, and S8, female adult, whose trackways lead exactly to a cave chamber in which bear bones were dug out and back towards the entrance of the cave. Furthermore subject S9, male infans II, has not yet been identified in Tuc d'Audoubert. The three subjects have left a total of four trackways with up to four footprints and one isolated track.

- Event 18: The first event describes a walk over a short distance of subjects S7, male adult, and S8, female adult, towards a passage to the chamber where bear bones have been excavated (Fig. 13.3). Subject S7 left one trackway of two footprints – right (S7–33) and left (S7–34). Another trackway of four footprints – left (S8–26), right (S8–27), left (S8–28) and right (S8–29) – has been identified.
- Event 19: The couple of subjects S7 and S8 appear in a second event (Fig. 13.3). This time their passage points from the bear bone site to the entrance of the cave. Both walked fast together. Subject S7, male adult, has left a trackway of three footprints – left (S7–35), right (S7–36) and left (S7–37). One footprint indicates that its trackmaker lost for a short moment the grip and started slipping (S7–37). From subject S8, a trackway with two right footprints (S8–30, S8–31), missing the connecting left footprint due to a change of the soil conditions, is documented.
- Event 20: The last event in this section of the Galerie des Empreintes happened with subject S9, male infans II, who has left only a single right footprint (S9–1) (Fig. 13.3). It is located in close proximity to the vertebral column of the young cave bear; however, an immediate interaction could not be detected. Subject S9 walked slowly in direction to the deep part of the cave.

Of the 76 footprints published so far in 2009 (Bégouën et al. 2009) for the Galerie des Empreintes, indigenous ichnologists identified 67 (88%) (Table 13.3). In the course of the investigations, a concentration of footprints in the eastern centre that had previously been considered human was not confirmed. According to the indigenous ichnologists, these are imprints of a bear (TUC-308). Some human footprints were newly discovered, so that in total about 70 footprints are still counted in the

Galerie des Empreintes. These come from a total of eight subjects: four adults (two male subjects S7 and S12 and two female subjects S8 and S11), one female subject infans II (S14) and two subjects infans I (one male S3 and a female S10). No precise statements on identity could be made about another subject (S13).

Galerie des Petits Pieds

Just after passing through the passage with the perforated teeth that marks the end of the Galerie des Empreintes, the visitor enters the Galerie des Petits Pieds (Fig. 13.3). Continuing the path to the deep part of the cave, a series of large sinter basins obstructs the passage. To their right, on clay-coated sinter formations, five human footprints are located (TUC-331, TUC-332).

At 23 cm from the edge of the stalagmitic platform, a heel (TUC-330) is clearly visible. Near the edge of the same platform, a little further in the direction of the current path, there are small parallel footprints (TUC-331, TUC-332).

Four subjects have left their footprints in this relatively small area creating four events. These include two female adults (S5 and S6), one infans II (S4) and one infans I (S3). Not a single trackway could be detected. Only isolated footprints indicate slipping on the slanting ground (S3, S4, S5). Subject S6 stepped on a rock and stopped. The following events were identified:

- Event 21: Coming from the Galerie des Empreintes, a first footprint was identified (Fig. 13.3). It comes from subject S4, male infans II, and is found a few metres away from the concentration of footprints described later. It is a complete right footprint (S4–2) that is oriented towards the cave wall.
- Event 22: The next event is represented by a complete left footprint (S5–1) from subject S5, female adult that points to the entrance of the cave (Fig. 13.3). On slanting ground the footprint indicates that the trackmaker lost for a short moment the grip, which led to a slight slip.
- Event 23: Subject S6, female adult, provides a complete left footprint (S6–1) directed to the entrance of the cave (Fig. 13.3). Subject S6 touched the rock, which certainly irritated her.
- Event 24: The last event in the gallery is an often-described scenery (Fig. 13.3). Footprints of slipping younger subjects were seen as evidence of the presence of very young children in Tuc d'Audoubert. Vallois saw according to their little dimensions in the footprints S3–1 and S4–1 a single subject, a child of 4 years old (Vallois 1931). Following the indigenous ichnologists the trackmakers represent two different subjects with also different ages (infans I and infans II) nevertheless acting in a single event (Fig. 13.6). Subject S3 (S3–1), male infans I, left a complete left footprint. He slipped towards the centre of the gallery due to the slanting floor. Subject S4, male infans II, has also left a complete left footprint (S4–1) at the same location as subject S3. Like subject S3, subject S4 also slipped

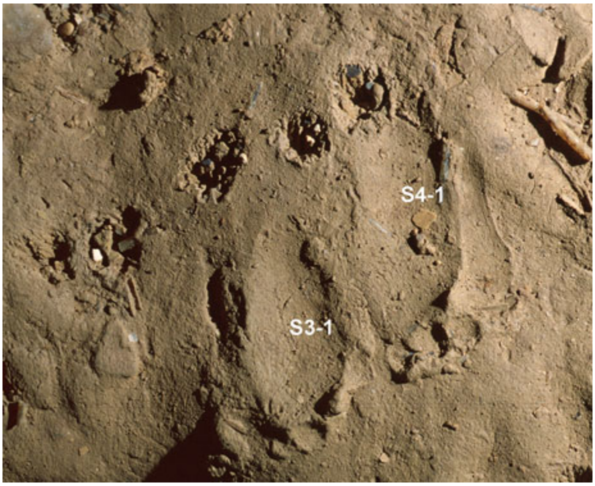

Fig. 13.6 Event 24 in the upper gallery of Tuc d'Audoubert with the respective spoor number. (Photo Association Louis Bégouën/Tracking in Caves)

towards the centre of the gallery, due to the slanting floor. It is obvious that the footprint of subject S4 was stepped over by that of subject S3.

Salle des Talons

After passing the Galerie des Petits Pieds, at 620 m from the daylight zone, a sharp left turn marks the entrance to a long gallery where the bears have once again left their marks on the ground (Fig. 13.3). From the beginning of the gallery, it seems that the atmosphere of the cave has changed. The concretions, omnipresent until now, are suddenly rare, and only a row of stalagmites follows a longitudinal fault towards the middle of the gallery, limiting the view. The nature of the limestone also marks a rupture; the cretaceous limestone leaves the place now to a friable rock of the Middle Jurassic. Here is where the clay models and other remnants of human activities can be found in the Galerie des Bisons d'Argile and the Salle des Talons. The other human traces, finger dots (TUC-333), aligned lines engraved on the ground (TUC-336), digital dots on the ground (TUC-337) and impacts of baguettes demi-rondes (TUC-338) (cf. Bégouën et al. 2009), were not part of the investigations of the indigenous ichnologists.

After about 20 m in the gallery, the ground suddenly plunges to the right, towards a small room, 3 m below. The bears left their marks on the clay slope that dominates the place. Following a path in the clay, one reaches the threshold of a rotunda whose arched roof gradually drops to the bottom, so that very soon standing upright is no longer possible. The rotunda measures 8 m in its maximum width and 6 m deep from the edge of the current path area delimiting the Magdalenian soil. Being absolutely flat, it evokes the small clay pond that the room once was, after the passage of the bears, because no trace of them is visible there while they abound on the slope that leads to it. This virginity of the soil and the quality of the very fine clay obviously attracted the Magdalenians.

According to the first inventory, 183 more or less marked depressions (heels) in the ground were counted (Bégouën et al. 2009). Others may exist, but they were out of sight during the first investigations. The heels are mainly distributed in the right half of the chamber (where the roof is the lowest), while the majority of the drawings is on the left (claviform and barbed signs) and on the far right, beyond the clay extraction pit.

After an initial review in 2013, the indigenous ichnologists identified two subjects in this Salle des Talons whose tracks were not found elsewhere in the cave (Pastoors et al. 2015). These are subject S1, male adult, and subject S2, male juvenis, which went in two passages to a clay extraction pit, deliberately walking on their heels. While the footprints on the way towards the pit are only a little deepened into the clay, on the way back they are up to 5 cm deep. This shows that an additional weight probably in the form of lumps was taken up at the pit. This clay was transported to the adjacent Galerie des Bisons d'Argile and there modelled into the sculptures.

Due to the complexity and scope of the episodes, the detailed results of the identification of the spoors associated with the creation of art in the broadest sense by the indigenous ichnologists resulting from research in 2018 will be presented separately. These new results represent an extension of the episodes already identified in 2013, but the results already published (Pastoors et al. 2015) remain valid and can be included in the overall picture.

Synopsis

Eight concentrations with prehistoric human footprints were examined as part of the project in 2018. A total of 255 footprints were described in more detail, yet the count of 172 footprints in the Salle des Talons was carried out on the basis of the published distribution plan and is only marginally part of the present chapter. Consequently, the detailed identifications presented here are based on a total of 83 spoors. Other footprints visible in these areas were not readable by the indigenous ichnologists. On the one hand this results from the difficult conditions under which they can be inspected and, on the other hand, from the indigenous ichnologists who had nothing significant to say about these footprints, and they were not specifiable from their point of view.

The 83 footprints do not indicate any direct path in the sense of economic mobility, leading from the entrance of the upper gallery to the Galerie des Bisons d'Argile. Rather, the footprints result from numerous movements within the different sections that represent various qualified activities mostly in relation to cave bear bones.

With regard to the authorship of these 255 footprints, the indigenous ichnologists identified a total of 14 subjects. Some subjects were represented only by a single spoor (subjects S5, S6, S9, S10, S11, S12 and S13), whereas the maximum of

99 traces represents subject S2 (Table 13.2). The number of spoor per subject can be arrayed into two groups: one with a maximum of three footprints (subjects S3 to S6 and S9 to S14) and another with a larger number (subjects S1, S2, S7 and S8).

The different sections are linked by three subjects: subject S3 (Galerie des Petits Pieds and Galerie des Empreintes), as well as subjects S7 and S8 (Galerie des Empreintes and Galerie des Effondrements). This is not surprising, as there is only one access to the upper gallery, but it shows the exceptional perception of the indigenous ichnologists. It is interesting to note that subjects S1 and S2 were not identified in other parts of the cave, as access to the Salle des Talons inevitably passes through the other gallery. There are several possible explanations: Either the footprints are among the number of footprints that the indigenous ichnologists could not say anything about, or the passages followed other paths (the part of the cave that was inaccessible to us), or traces have been destroyed by the following visitors (prehistoric or modern). On the other hand, the observation that, in the Salle des Talons, no footprints of the other 12 subjects can be found seems to reflect a fact, as it is located outside the central axis and must be deliberately searched. Therefore, the 12 subjects had a priori nothing to do with the activities in the Salle des Talons.

Identity of the Trackmakers

Examination of the demographic data of the 14 identified subjects shows a negligible majority of male subjects, of which seven were identified (Table 13.4), while six

Table 13.4 Identity of the trackmakers in the upper gallery of Tuc d'Audoubert grouped in age classes according to Martin (1928)

	Age class (Martin 1928)			
Subject	Infans I (0.5–6)	Infans II (7–13)	Juvenis (14–20)	Adultus (21–40)
S1				Male
S2			Male	
S3	Male			
S4		Male		
S5				Female
S6				Female
S7				Male
S8				Female
S9		Male		
S10	Female			
S11				Female
S12			Male	
S13	–	–	–	–
S14		Female		
Total	2	3	2	6

subjects were counted as females. Sex could not be recorded for a single subject (S13).

With regard to the age of prehistoric explorers, a wide range of age classes from infants I (up to 6 years) is present up to adultus (21–40 years) with a clear focus on the last age class. It is interesting to note that the footprints of subjects in the mature age class (41 to 60 years) are missing. Perhaps a whole family – without the elders – was therefore involved in the visits to the upper gallery of Tuc d'Audoubert. As far as the physical aspect is concerned, all subjects seem to have been normally proportioned. In the group as a whole, no anomalies could be detected in relation to a possible handicap of the locomotive system.

Identified Events

In the upper gallery, 24 events were identified by the indigenous ichnologists (Table 13.5). The events with only one acting subject (N = 12) are equally frequent as those in which several subjects were involved (N = 12). Events in which subjects S7 and S8 acted together should be emphasized. Both parts of the couple do the same thing at ten different places where they were together (Fig. 13.3). They were both carrying something (E10) probably something light (E4, E8); they were both looking for bones (E18) or both walking through the cave in direction to the deep part (E7, E11, E17) or to the entrance (E1, E4, E8, E10, E16, E19). It is noticeable in this context that in all locations where bear bones were picked up, only subject S7 was active (E2, E13, E17) – even if subject S8 was around and part of the event (E17). This speaks for a clear specialization.

Another striking event (E15) in the upper gallery of Tuc d'Audoubert is the visit of a group of at least five subjects (subjects S3, S10, S11, S12 and S13). Based on the observation that subject S4 acted in the Galerie des Petits Pieds together with subject S3, it can be assumed that subject S4 belongs also to the large group, especially as subject S4 is a child of the age class infans II. The group did nothing else than going through the Galerie des Empreintes.

Track Details

After the synopsis of the identified events in the upper gallery of Tuc d'Audoubert, the focus here will be on the most notable track details.

Spoor Type, Side and Trackways

Among the 83 identified spoors, there is interestingly a trace of the buttocks of subject S7 (S7–32) (Fig. 13.4). All other 82 are footprints – 41 left, 40 right and 1 without determination. Although postulated in a previous publication (Bégouën et al. 2009), there are no knee traces in this part of the upper gallery that the

Table 13.5 Results of the event identification in the upper gallery of Tuc d'Audoubert

Event	Identity	Walk	Slip	Stand	Squat	Sit	Total	Direction	Note
Galerie des Effondrements		3	2	5		1	11		
E1	S7 (S7–31, S7–32)		1			1	2	Entrance	
	S8 (S8–25)	1					1	Entrance	
E2	S7 (S7–25 to S7–29)			5			5	Side	Picking bones
E3	S8 (S8–23)		1				1	End	
E4	S7 (S7–30)	1					1	Entrance	Carrying something light
	S8 (S8–24)	1					1	Entrance	Carrying something light
Galerie des Empreintes (WES)		12	3	2			19		
E5	S14 (S14–2)		1				1	End	Bump on a rock
E6	S14 (S14–3)	1					1	Entrance	
E7	S7 (S7–22 to S7–24)	3					3	End	
	S8 (S8–21, S8–22)						2	End	Walking bent
E8	S7 (S7–18 to S7–21)	4					4	Entrance	Carrying something light
	S8 (S8–13 to S8–20)	4	2	2			8	Entrance	Carrying something light, keeping balance
Galerie des Empreintes (WES-WC)		2					2		
E9	S8 (S8–11, S8–12)	2					2	Entrance	
Galerie des Empreintes (WC)		10	1				11		
E10	S7 (S7–15 to S7–17)	3					3	Entrance	Carrying something
	S8 (S8–7 to S8–10)	4					4	Entrance	Carrying something, hand on a rock
E11	S7 (S7–13, S7–14)	2					2	End	
	S8 (S8–6)	1					1	End	
E12	S14 (S14–1)		1				1	End	

Galerie des Empreintes (EC)		16			7		23		
E13	S7 (S7–7 to S7–11)				5		5	Entrance	Picking bones
E14	S7 (S7–12)	1					1	Side	
E15	S3 (S3–2) + (S3–3)	2					2	End	
	S10 (S10–1)	1					1	End	
	S11 (S11–1)	1					1	Entrance	Carrying something
	S12 (S12–1)	1					1	Side	
	S13 (S13–1)	1					1	End	
E16	S7 (S7–3, S7–4)	2					2	Entrance	
	S8 (S8–3 to S8–5)	3					3	Entrance	
E17	S7 (S7–1, S7–5, S7–6) + (S7–2)	2			2		4	Centre, end	Picking bones
	S8 (S8–1) + (S8–2)	2					2	End	
Galerie des Empreintes (EES)		11	1				12		
E18	S7 (S7–33, S7–34)	2					2	Side	Looking for bones
	S8 (S8–26 to S8–29)	4					4	Side	Looking for bones
E19	S7 (S7–35 to S7–37)	2	1				3	Entrance	
	S8 (S8–30, S8–31)	2					2	Entrance	
E20	S9 (S9–1)	1					1	End	
Galerie des Petits Pieds			4	1			5		
E21	S4 (S4–2)		1				1	Side	
E22	S5 (S5–1)		1				1	End	Slanting ground
E23	S6 (S6–1)			1			1	End	Stepping on a rock
E24	S3 (S3–1)		1				1	Centre	Slanting ground
	S4 (S4–1)		1				1	Centre	Slanting ground
	Total	54	11	8	7	1	83		

indigenous ichnologists could identify. All footprints are from barefoot subjects, whereas no statement could be made about the buttocks regarding clothing.

Most of the 82 footprints belong to connected trackways (59 footprints), of which 18 were determined. Trackways consist of two to eight footprints; in mean, it is 3.3 footprints per trackway.

Carrying Additional Weight

Of the 14 subjects, 5 carried additional weight, at least temporarily. These are subjects S1 and S2 in the Salle des Talons; subjects S7 and S8 in the Galerie des Effondrements, in the western end sector and in the western centre of the Galerie des Empreintes; and subject S11 in the eastern centre of the Galerie des Empreintes as well. It is difficult to say anything valid about what was carried, but according to the indigenous ichnologists, very plausibly clay was transported in the Salle des Talons and probably cave bear bones, a child or something else in the other locations.

With the exception of the trackways in the Salle des Talons, all other trackways with 19 footprints and 3 isolated footprints where the subjects carried additional weight lead towards the entrance of the cave. Even if the data basis is not very extensive, a pattern becomes apparent, namely, that things were carried out of the cave.

Body Postures and Gait

In addition to basic information on particular subjects, the indigenous ichnologists were able to identify the particularities of body postures reflecting various activities.

We distinguish between dynamic and static postures, even if in the static posture qualified activities were performed. Among the dynamic ones, the tracks from walking activity ($N = 56$) dominate. Two of them result from a bent walking posture as adaptation to the low room height (S8–21, S8–22). Also from the interaction with the spatial conditions, two footprints result where the trackmaker has supported herself on a rock jutting into the path (S8–9, S8–10). Eleven footprints indicate that the respective trackmaker lost the grip on the ground and slipped. On the loamy, partly slanting ground, this is not surprising (S5–1, S3–1, S4–1). The loss of the grip on the ground also led to the loss of balance several times. In one case, the trackmaker had to interrupt the forward movement by taking a stable stand (S8–14, S8–15); another time the trackmaker slipped and landed on the buttocks (S7–32) and in still another case bumped the foot on a rock (S14–2). In this way dynamic postures are connected with static ones. This may also be demonstrated by the standing posture of a trackmaker directly on a pointed stone on the cave floor (S6–1). In addition to the above-mentioned happenings, the trackmakers have mainly dealt with cave bear bones lying on the ground. These were achieved both standing (E2) and squatting (E13, E17).

During the dynamic postures, the speed of locomotion including slipping was fast at over 50% of the footprints. Only 13 footprints indicate a slow speed. For the indigenous ichnologists, fast speed means an expeditious, safe walk without searching and hesitating.

Group Configuration

In addition to the observations already described, the indigenous ichnologists identified, based on the spatial distribution and references of the footprints to each other, various subjects who moved in groups. Three small and one larger group could thus be identified:

- S1 (male, adultus), S2 (male, juvenis)
- S3 (male, infans I), S4 (male, infans II)
- S7 (male, adultus), S8 (female, adultus)
- S3 (male, infans I), S10 (female, infans I), S11 (female, adultus), S12 (male, juvenis) and S13 (nothing to say)

The data basis is too small to make statements about general human behaviour. Nevertheless, interesting observations can be made with regard to Tuc d'Audoubert. None of the mentioned groups included S5 (female, adultus), S6 (female, adultus), S9 (male, infans II) and S14 (female, infans II). Whether they were really on their own or in another unidentifiable constellation must remain open. In any case, with these hypothesized groups, it can be concluded that a maximum of eight visits in small to very small groups took place in the upper gallery. However, this is only true under the assumption that subjects climbed into the upper gallery alone. With a minimum size of two subjects per visit, in the given configuration of two pairs of a woman and a child, the total number of visits to the upper gallery reduces to a maximum of six expeditions (but see section Superimposition of Human Tracks). The difficulties in navigating the upper gallery make the latter number probable for safety reasons alone and because it would seem unlikely that children aged 7–13 years (infans II) would explore such a cave on their own.

Axis of Locomotion

The consideration of the axis of locomotion of the dynamic postures (walking and slipping) confirms the central observations already described. The two motivations for visiting the cave – passing through and looking for cave bear bones – become apparent. The fact that there are significantly more footprints pointing in the direction of the entrance of the upper gallery ($N = 36$) than into the deep part of the cave ($N = 20$) is to be seen as a logical consequence of the chronological sequence of events. The chronologically most recent footprints lead out of the upper gallery and partially overlap those that lead into the cave.

Human Interaction with Cave Bear Bones

Irrespective of how the bear bones were picked – standing or squatting – it was always the same trackmaker (subject S7, male adult) at work in all these places (Fig. 13.3). In the Galerie des Effondrements, a mandible was manipulated (E2), and in the Galerie des Empreintes, a rib (E17) and a skull (E13) were moved. In addition, footprints in the eastern end section of the Galerie des Empreintes which must not be entered today testify to the specific search for further cave bear bones, because the tracks point to exactly one spot where bones lie on the surface and where they were manipulated by humans.

Superimposition of Human Tracks

A total of eight superimpositions were identified where the identity of both trackmakers is known (Table 13.6). Subjects involved are S7 (male adult), S8 (female adult), S11 (female adult), S3 (male infans I) and S4 (male infans II). Against the background of the group configurations, it looks as if the subjects S7 and S8 were alternating in walking in ahead of each other. After the visit of these two, the large group with the subjects S3, S10, S11, S12 and S13 came into the upper gallery. Based on the observation that both subjects S3 and S4 were together in the Galerie des Petits Pieds, it can be assumed that subject S4 also belongs to the aforementioned large group. As a result, the maximum number of visits to the upper gallery would be reduced from six to five visits (cf. section Group Configuration).

General Conditions and Reliability of Identification

The general conditions for the generation and preservation of prehistoric footprints in the upper gallery are similar. All areas where spoors have been preserved are covered with a thin layer of calcite that has formed over time. Only in a few places this layer is more massive (E8 – S7–18, S7–19, S8–14, S8–15, S8–16), but also here details of the footprints are visible.

Table 13.6 Track superimpositions; each individual subject has a specific colour for better visualization

<table>
<tr><th colspan="9">Footprints</th></tr>
<tr><td>Upper</td><td colspan="2">S7-15
♂</td><td>S8-6
♀</td><td>S8-15
♀</td><td>S8-16
♀</td><td colspan="2">S11-1
♀</td><td>S3-1
♂</td></tr>
<tr><td>Lower</td><td>S8-7
♀</td><td>S8-8
♀</td><td>S7-13
♂</td><td>S7-18
♂</td><td>S7-19
♂</td><td>S7-1
♂</td><td>S7-6
♂</td><td>S4-1
♂</td></tr>
</table>

The quality of the identified footprints is extraordinarily good. Of the 83 tracks examined, 48 have a reliability of identification of the toes and at the same time the heel is at least sufficient, which makes it possible to take the necessary measurements of the identified footprints. The 48 footprints were left behind by 12 different subjects which will make a cross-check with scientific approaches possible. Problematic are the footprints of the two subjects S12 and S13 because only one footprint of each was identified with insufficient reliability of identification which will impede further measurements.

Discussion and Conclusion

This paper is a first step of a multi-stage analysis of prehistoric human spoors in the upper gallery of Tuc d'Audoubert. Only those traces that are related to the making of art are excluded in this presentation due to research strategy reasons. The wide range of events of dynamic processes – some of which can be easily grasped even by non-experts – call for appropriate dynamic research methods. Static methods, which usually are used to investigate prehistoric human footprints, are important tools to enrich the discourse about footprints with empirical data but should not keep the prerogative of interpretation alone. For this reason, the prehistoric human spoors in Tuc d'Audoubert have been first read by indigenous ichnologists and will then in a second step be completed by classical scientific analysis. In a morpho-classificatory way, the experienced trackers identified the trackmakers as well as the events stored in their spoor. The focus of the project was the identification of the cave explorers and the investigation of movements of humans in the cavity and their interaction with cave bear bones and between humans themselves.

Eight main concentrations in four different locations of the upper gallery with the most important spoors were selected for this project, which were studied by three indigenous ichnologists in October 2018.

Fortunately, important details are known about the context of the prehistoric spoors in Tuc d'Audoubert. Rock art, for example, consists of a specific, distinctive spectrum of motifs, execution and style which indicate their homogeneity. Excavations regularly show single-layer locations dating between 17,200 and 16,500 calBP. Archaeological analyses prove that the visit in the cave took place in autumn-winter season. Furthermore, conspicuous distribution patterns between different parts of the cave, consistent material culture and best preservation and conservation conditions testify to a short stay of a single group of people in the entire cave system of Tuc d'Audoubert. The panoply of various analyses allows the control of the results through cross-check. So far, there have been only complementary results that allow a colourful mosaic of insights into the settlement history of Tuc d'Audoubert (Bégouën et al. 2009; Pastoors 2016).

Even without the inclusion of spoors in the upper gallery, it is evident that people have moved throughout the entire cave and have completely anthropogenized it by active interventions. The kind of installation in the cave testifies to the existence of a previous planning or system that speaks of great experience in dealing with cave systems. Evinced by excavations, in some parts of Tuc d'Audoubert, base camp activities similar to open-air sites took place. Thus the cave becomes an autonomous subsystem within the prehistoric subsistence network. In addition to substantial activities, qualified activities such as drawing activities and consumption of introduced provisions were carried out in the cave.

This mesh of information about the context of the prehistoric spoors in the upper gallery is consistent. It can be assumed that a single group of cave-experienced hunter-gatherers with members of all ages stayed in Tuc d'Audoubert over a short time.

After first interpretations of the spoors in the upper gallery, only a few visits to this difficult part of the cave took place (Bégouën et al. 2009). According to this first estimations, five to six subjects (female and male adults plus one child of age class infans I) are said to have made in total two visits. First, they realized an exploration of the upper gallery and second an expedition to execute the clay sculptures and further drawings (Bégouën et al. 2009: 415). This small group of five to six persons is said to have been part of a larger group who stayed in the intermediate gallery. Considering the small amount of archaeological material, it is estimated that this total group counted 15–20 subjects (Bégouën et al. 2009: 395.). The new counts based on the work of the indigenous ichnologists have modified these first estimates. Thus, in the upper gallery, there were 14 subjects from adults to infans I, but no subject from maturus age class. Not only a small part of the whole group climbed into the upper gallery, but at least three-quarters of the estimated group size did the difficult climbing. Maybe the subjects with maturus age did not go along or were not in the cave at all. Interestingly, the locations where substantial activities were carried out offer sufficient space for this number of subjects. According to calculations of the available space, a maximum of 30 to 50 subjects fit into the relevant locations at the same time: certainly enough space for a group of 15–20 subjects.

Of the 14 subjects that climbed up in the upper gallery, only four could not be assigned to a group of at least two subjects. Accordingly, ten subjects entered the upper gallery as part of at least a small group, and it can be assumed that the other four subjects were also not alone in this problematic terrain. In view of the group compositions and the assumption that humans did not climb alone into the upper gallery, it can be concluded that a maximum of five visits by two to six subjects were carried out. Among the visitors was a couple, subjects S7 and S8, who were walking together in ten locations and showed a certain repetitive pattern in their behaviour. It was only the male subject who manipulated the bear bones, although at every place they did the same things with the woman possibly managing the light. Even without considering the detailed observations of the spoors that are directly related to the making of drawings or modelling, an equally high resolution of the events that happened in Tuc d'Audoubert is not available at any comparable site.

The direct comparison of the results of the identifications of the prehistoric spoors by the indigenous ichnologists and western academic scientists shows deviations mainly in the identity of the trackmakers (see Chap. 1). This concerns the number of subjects as well as age and sex. Events are identified by both groups of specialists, whereas those of western academic scientists are much more fragmentary than the often consistent event identifications of experienced trackers. These aspects have to be discussed in detail but make more sense on a broader database from Tuc d'Audoubert that is under construction as part of the multi-stage studies on the prehistoric human spoors. Based on photogrammetric images, prominent landmarks of the plantar imprints will be systematically measured. In addition, complex morphometric analyses and plantar pressure analyses will follow. In the same way, the events related to drawing activities will be investigated. Only on the basis of all data available a more intensive analysis of the differences and similarities of the results of the indigenous ichnologists and western academic scientists seems to be reasonable.

But the first step of the multi-stage analysis of human spoors already brought important new insight that fits into the general picture of the use of the upper gallery of Tuc d'Audoubert as well as the settlement pattern in the entire cave system. Tuc d'Audoubert has shown several times in the past that the excellent preservation and handling allow high-resolution analyses. This unique characteristic will also mark the future work in Tuc d'Audoubert.

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Chapter 14
Following the Father Steps in the Bowels of the Earth: The Ichnological Record from the Bàsura Cave (Upper Palaeolithic, Italy)

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Abstract The chapter summarizes the new results of the Bàsura Revisited Interdisciplinary Research Project. The integrated interpretation of recent archaeological data and palaeosurface laser scans, along with geoarchaeological, sedimentological, geochemical and archaeobotanical analyses, geometric morphometrics and digital

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photogrammetry, enabled us to reconstruct some activities that an Upper Palaeolithic human group led inside a deep cave in northern Italy within a single exploration event about 14 ka calBP. A complex and diverse track records of humans and other animals shed light on individual- and group-level behaviour, social relationship and mode of exploration of the uneven terrain. Five individuals, composed of two adults, an adolescent and two children, entered the cave barefoot lightening the way with a bunch of wooden sticks (*Pinus* t. *sylvestris*/*mugo* bundles). While proceeding, humans were forced to move on all fours, and the traces they left represent the first report of crawling locomotion in the global human ichnological record. Anatomical details recognizable in the crawling traces show that no clothing was present between limbs and the trampled sediments. Our study demonstrates that very young children (the youngest about 3 years old) were active members of the human groups, even in apparently dangerous and social activities, shedding light on behavioural habits of Upper Palaeolithic populations.

Keywords Upper Palaeolithic · Cave exploration · Animal and human footprints · Morphometric analysis · Human locomotion · Cave bear extinction

Introduction

The Bàsura Cave (Grotta della Bàsura) opens at 186 m a.s.l., about 1 km north of Toirano (Savona) at the foot of Mount Carmo of Loano (436253.433 E; 4887689.739 N) in western Liguria (Fig. 14.1).

The discovery of the inner rooms of the Bàsura Cave represented one of the most spectacular events of the Italian prehistoric research of the 1950s of the twentieth century (Giacobini 2008). Up to that time, only the atrial part of the cavity was known where, towards the end of 1890, archaeological remains of Neolithic and late Roman Age were discovered (Maineri 1985).

The inner rooms, developed along a main branch of about 400 m in length, became accessible in 1950, when a group of young boys broke a stalagmite column placed a few dozen meters from the entrance (Tongiorgi and Lamboglia 1954; Blanc 1960; Lamboglia 1960). The cave revealed its palaeontological value following a site inspection by Virginia Chiappella (1952). Chiappella identified several remains of *Ursus spelaeus* and traces of human frequentation (footprints, charcoals, digital tracks, lumps of clay adhering to the walls).

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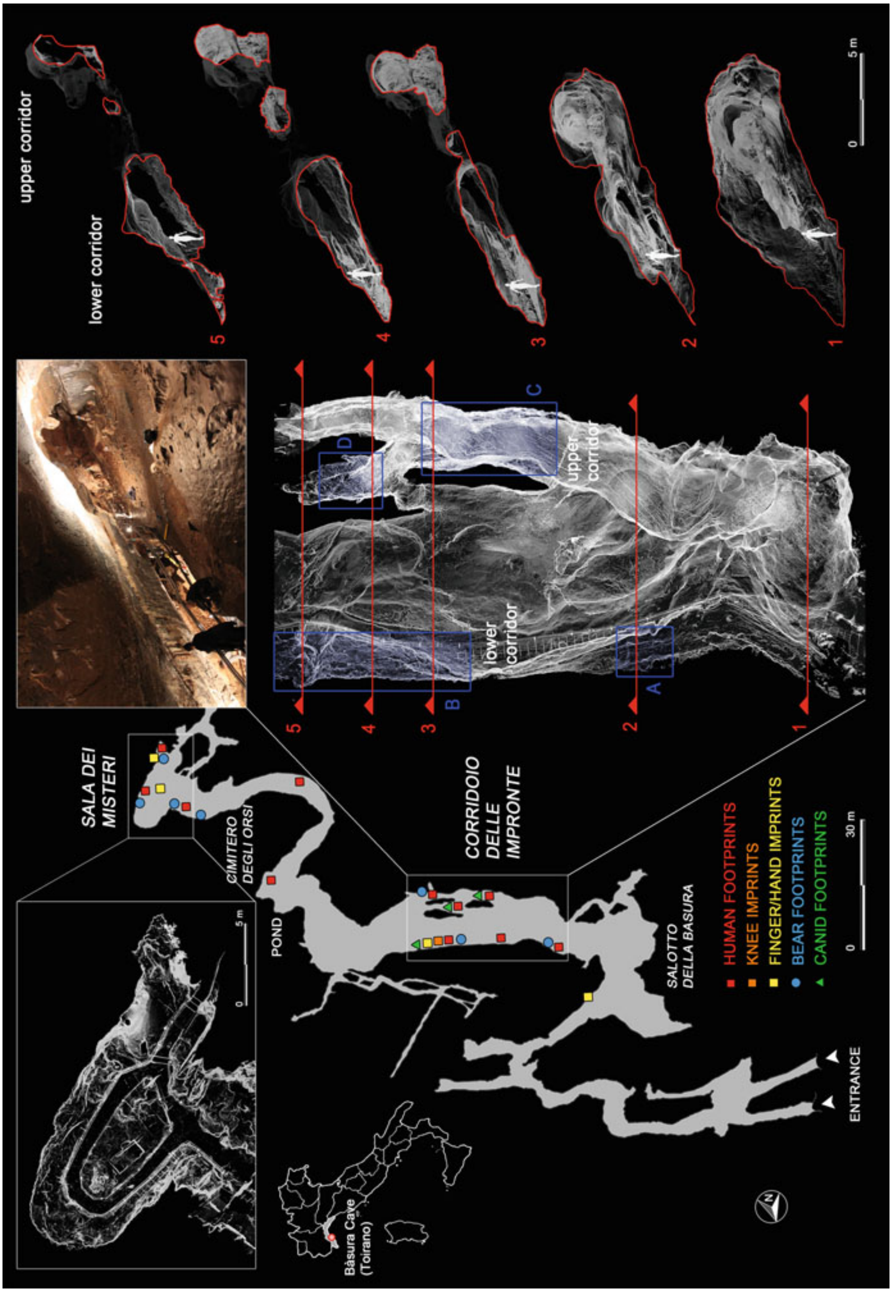

Fig. 14.1 Planimetry of the Bàsura Cave and location of human, bear and canid footprints. *White rectangles* enclose the three-dimensional reconstructions, obtained via laser scanner, of the innermost room (Sala dei Misteri – *left*) and the main gallery (Corridoio delle Impronte – *right*) of the cave, where the human footprints are preserved. Cross-sections obtained from the three-dimensional reconstruction of the main gallery are *highlighted in red* and show the branching of the lower and upper corridors, respectively. *Blue rectangles* indicate the four areas within the main gallery where most of the human footprints are concentrated (A and B for the lower corridor, C and D for the upper corridor)

Unfortunately, uncontrolled access to the cave of visitors and numerous curious peoples that followed the days of its discovery led to the destruction of most of the prehistoric human and animal footprints imprinted in the clay of the cave floor (Blanc et al. 1960; De Lumley and Giacobini 1985). Only those tracks consolidated enough and/or covered by calcite concretions survived. In the following years, other footprints were inadvertently damaged during the construction of the touristic pathway for the opening of the cave to the public (De Lumley and Giacobini 1985).

Human Footprints of the Bàsura Cave: Previous Studies

A first study of human footprints from the Bàsura Cave was conducted by Pales (1960), based on the observation of the originals and 13 plaster casts of the best-preserved specimens found in various sectors of the cave. Pales recognized two footprints size classes: the first characterized by an average foot length of 22.5 cm and the second with a length of 27 cm. The analysis of the foot bone architecture of the footprint authors, and their apparently association with the remains of *Ursus spelaeus*, led Pales to attribute the footprints to Neanderthal-type authors. Subsequent reanalysis of the context (De Lumley et al. 1984), coupled by the first set of absolute dating, placed the prehistoric frequentation of the Bàsura Cave in the Upper Palaeolithic, between 12,000 and 14,000 years BP (De Lumley et al. 1984; De Lumley and Giacobini 1985). Radiocarbon dating of charcoal samples, collected from the trampled surface, provided a more precise age for the human frequentation of the cave at 12,340 ± 160 BP (14,534 ± 417 calBP) (Molleson et al. 1972; Molleson 1985).

According to the interpretation proposed by Blanc (1960), some individuals attended the cave traveling towards the inner rooms and imprinted traces of feet, hands, and knees, sometimes overlapped or deformed by the subsequent passage of bears and wolves. Based on the ichnological study of Pales, Blanc proposed that the innermost Sala dei Misteri (Fig. 14.1) was reached by a group of some individuals, among which a juvenile. Moreover, Blanc (1960) described from the same room a group of seven footprints identified by heel tracks, imprinted on the floor a few centimetres far from the main wall of the room, in which numerous small lumps of clay were stuck. This evidence has been interpreted as the traces of prehistoric ritual activity, in particular possible initiatory rites perhaps involving young hunters. This hypothesis seemed supported by the presence at the end of the Sala dei Misteri of a stalagmite concretion (defined by Blanc (1960) as acephalous sphinx or zoomorphic stalagmite), whose surfaces are almost entirely covered by finger fluting drawing sinuous furrows, tracked intentionally by several individuals.

In 2014, the Soprintendenza Archeologia, Belle Arti e Paesaggio per la Città Metropolitana di Genova e le province di Imperia, La Spezia e Savona, Genova, has launched a multidisciplinary study of the cave (Bàsura Revisited) in cooperation with the Municipality of Toirano under the direction of two of the present authors (ES, MZ) (resp. Elisabetta Starnini), involving a careful reanalysis of the prehistoric traces left in the cave, the taphonomy and chronology of the cave bear deposit and the first stratigraphic excavation in the deposit of the innermost room, namely, the Sala dei Misteri.

Geology of the Bàsura Cave

The Bàsura Cave is part of an ancient and larger karst system carved in a Middle Triassic limestone-dolomite massif (Collina dei Roccai, 400 m a.s.l). Deeply entrenched valleys separate it from other ridges. It entirely developed in the Costa Losera and overlain Dolomie di San Pietro dei Monti Fm. of Anisian to Ladinian age (Menardi Noguera 1984). The karst system comprises four distinct levels. The upper level, hydrologically inactive, corresponds to Grotta del Colombo (247 m a.s.l.) while the lower to Bàsura Cave (186 m a.s.l.). The network of cavities is developed along bedding planes, and NW-SE or WNW-ESE trending tectonic structures (fractures and joints) related to the main phase of the Alpine-Apennine chain uplift which took place within the Plio-Pleistocene.

The speleogenesis of the cave systems was recently interpreted by Chiesa et al. (2019). The genesis of these karst systems may be related to a weak thermalism and possibly to the rising of mineralized waters which are fed by freshwater via a complex regional hydrogeological flow path (hypogenic caves). In fact, a thermal spring (20 °C, $Q \approx 100$ l/s) is present in Toirano at 70 m a.s.l. along the contact (fault) between the permeable Triassic carbonate formation and impermeable quartzites (Calandri 2001). Moreover, the main horizontal passages of the cave system are short and terminate with a vertical conduit (feeder), and several forms of small and large sizes, generated by condensation-corrosion processes above the water table, can be observed along the cave ceiling and walls (e.g. sets of coalesced ceiling cupolas, dome pits). However, remains of fluvial sediments are preserved throughout the caves, indicating the overlap of epigenetic process cycles.

The ages of the different stages of the karst evolution are poorly constrained, but they can be placed within the framework of the Early Pleistocene morphologic evolution of the area, during which depression of the sea level played an important role.

The Bàsura Cave presents a sub-horizontal trend and has a total spatial development of 890 m and height difference of +20/−22 m with respect to the entrance. The air temperature of the caves is constant (about 16 °C), and the relative humidity, during all the seasons, is nearby saturation (Bruzzone et al. 2006). Water is still present in two little lakes, but the water dripping is relatively widespread everywhere. Different fluvial sediments and speleothems fill the passage, and sometimes large flowstone masses were deposited over the older sediments.

Flooding dynamics and cave geometry produced two different situations for sediment deposition and transport inside the cave. Detrital sediment comprising silty clay and well-sorted sandy sediment are most abundant on the floor of the Sala dei Misteri. Coarse lithologies comprising gravel-sized and larger (>2 mm) grains include a few fragments of bear bones. The sandy fraction comprises allogenic, surface-derived siliciclastic sediment. The Sala dei Misteri appears to have undergone episodic filling and erosion as a result of catastrophic storms.

Sediment in the Corridoio delle Impronte comprises a large mud fraction and includes many coarse lithic fragments which are mainly carbonates (calcite and dolomite), suggesting an autogenic origin. Here, the trampled substrate is poorly consolidated and superimposed on a stalagmite crust. At the time when humans and other large mammals left their traces, the cave substrate differed in different areas of the cave. In some areas, the substrate was plastic, and in other areas, it was waterlogged or submerged. Differing moisture content of the substrate accounts for the variable preservation of detail of the tracks (e.g. registration of plantar arch, heel and metatarsal regions, digit tips, track walls), particularly of the associated extra-morphologies (e.g. expulsion rims, slipping traces). The surface of the substrate and the footprints are cross-cut by mud cracks, suggesting a loss of moisture in sediments after trampling. Carbonate crusts (comprising both calcite and dolomite) cover many of the footprints in areas subjected to more intense dripping. Iron and manganese oxide coatings were found in the crust, probably due to repeated immersion in ponded water.

Ichnology of Bàsura Cave

Footprints, Handprints, Finger and Human Body Traces

A total of 117 human traces, including complete footprints, rear foot imprints, fore foot imprints, knee traces, finger traces and body traces, were recorded in the Bàsura Cave (Fig. 14.2) (Romano et al. 2019).

The morphology and dimensions indicated five distinct morphotypes. Morphotype 1 includes footprints with a mean length of 13.55 ± 0.49 cm. It shows a not well-developed plantar arch but a heel area proportionally wider than longer tracks. These characters, coupled with the morphology and dimensions of digit traces, indicate an early ontogenetic stage of the producer. Morphotype 2 comprises footprints with a mean length of 17 cm and can be easily distinguished from morphotype 1 on the basis of a more pronounced plantar arch. This morphotype is characterized by footprints with a wide range of variability, which is correlated to the nature of the substrate (Webb et al. 2006; Morse et al. 2013). Morphotype 3 includes footprints with a mean length of 20.83 ± 0.51 cm and is featured by a pronounced plantar arch (Fig. 14.2, SM15). This area is characterized by a medial embayment

Fig. 14.2 Selected traces from the Bàsura Cave. C33, human footprint referred to morphotype 3 (lower corridor). SM15, human footprint referred to morphotype 3 (Sala dei Misteri). CA8, human footprint referred to morphotype 3 (upper corridor). C72, handprint (lower corridor). SM44, finger traces (Sala dei Misteri). SM55, finger flutings on the clay floor (Sala dei Misteri). SM12, adult bear footprint (Sala dei Misteri). C12, immature bear handprint (lower corridor). CA12, well-preserved Canidae footprint (upper corridor)

and a strongly convex lateral margin. The trace of digit I is highly adducted, and all the digit traces show an overall larger divarication and an apparent separation between adjacent digit trace couples II–III and IV–V. Morphotype 4 incorporates bigger footprints with an overall length of 22.80 ± 0.42 cm. Both the medial and lateral margins are straight and correlate with a less pronounced medial embayment if compared to that characterizing morphotype 3. Digit tip traces are aligned, roughly parallel to each other and oriented forward parallel to the main footprint axis. Morphotype 5 encloses the biggest human footprints of the Bàsura Cave, with an overall length of 25.73 ± 0.45 cm (Fig. 14.3c1). This morphotype shows slightly concave margins and a variably pronounced plantar embayment. On the whole, the footprints included in this morphotype appear more robust with respect to those of morphotypes 3 and 4. They share the adducted digit I trace with morphotype 3 and the straight and forwardly oriented digit tip traces with morphotype 4.

In the main gallery, some footprints referred to morphotypes 3, 4 and 5 are associated with subcircular, proximally tapered, trace interpreted knee imprints (e.g. Fig. 14.4, C41–C42). These imprints are sometimes associated with fore foot imprints, to which also result strongly aligned, and show the completely muscular structure of the joint and of the next regions.

In the same area, at least six handprints are preserved (Fig. 14.2). Handprints are mostly represented by isolated, didactyl to tridactyl digit prints and complete pentadactyl prints. These traces can be regarded as unintentional traces left during the exploration of the lower corridor, both during producers' progression and in stance phase, and interfere with forefoot imprints (e.g. Fig. 14.2, C72).

Heel imprints are mainly distributed in the proximal portion of the lower corridor and close to the left cave wall. These traces appear similarly oriented to each other and in some cases preserve the proximal portion of the medial embayment related to the plantar arch. Sixteen isolated heel traces are also preserved in the innermost room (Sala dei Misteri) of the cave. Ten of these traces are grouped in a small area of about 1 m^2. These traces mimic the morphology of the heel of the producer and in some cases preserve the proximal portion of the medial embayment of the plantar arch. The mean width of the proximal portion of these traces resulted 5.67 ± 0.12 cm, a dimension comparable to that characterizing morphotype 2 (Citton et al. 2017).

Finger Flutings

Finger flutings are preserved in several sectors of the cave (e.g. Fig. 14.2, SM55). The most spectacular and continuous are visible in the Sala dei Misteri. On the terminal wall of the hall, cluster of flutings are imprinted into moonmilk, and it may be classified as both Rugolean (the fluter stands still while fluting, and each unit comprises more than one line) and Mirian (the fluter moves while fluting each unit, and each unit comprises more than one line) following Sharpe and Van Gelder's (2006) terminology. On the stalagmite concretion (acephalous sphinx or zoomorphic stalagmite) placed against the terminal wall of the karst room, the main group of

Fig. 14.3 3D scan of human and bear imprints; (**a1**) cast of the 1950s reproducing the human footprint C60 (morphotype 5) preserved in Sector A of the lower corridor (see Fig. 14.1); (**b1**) digital terrain model of the cast obtained from the HDI 3D Scanner; (**c1**) topographic profile with contour lines, obtained from b1 with interpretive draw. A superimposed partial canid track is recognizable in the metatarsal area of the human footprint; (**a2**) cast of the 1950s reproducing a manus-pes bear couple; (**b1**) digital terrain model of the cast obtained from the HDI 3D Scanner; (**c1**) topographic profile with contour lines, obtained from b2 with interpretive draw superimposed

finger fluting is recognizable. Most of them are of the Mirian type and have been imprinted by at least two individuals who have smeared soft clay on the stalagmite surface. The width of the I–IV finger group varies between 2.7 and 5 cm. At the base of the stalagmite are recognizable sinuous lines left by the hands of a young individual (not exceeding 5 years – morphotype 1?), while in the medium-high

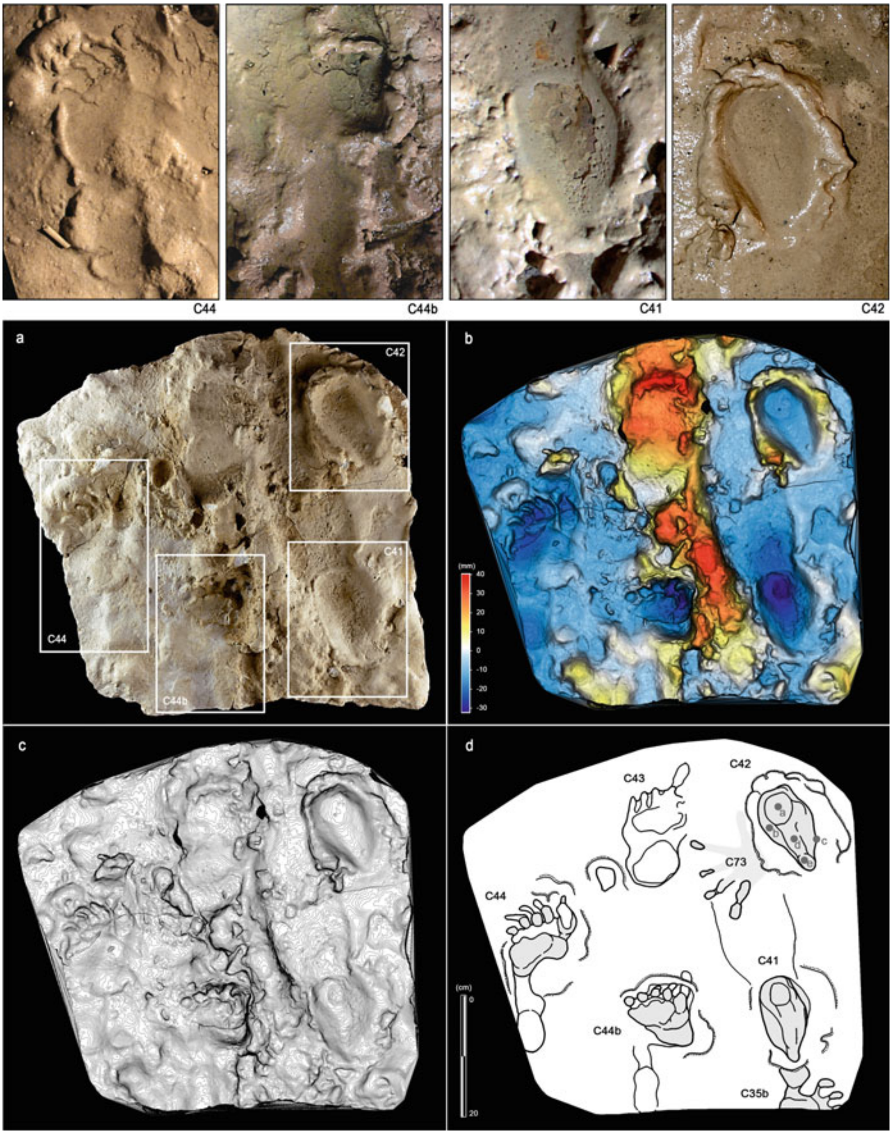

Fig. 14.4 Selection of semi-plantigrade and knee traces from the lower corridor of the Corridoio delle Impronte in the Bàsura Cave, indicating crawling locomotion of the producers. Semi-plantigrade and metatarsal traces (C44–C44b) and knee traces (C41–C42) imprinted on a plastic, waterlogged muddy substrate; (**a**) cast of the 1950s reproducing two knee (C41, C42) and two metatarsal (C44, C44b) traces preserved in the area B of the lower corridor (see Fig. 14.1); (**b**) digital terrain model obtained from the HDI 3D Scanner; (**c**) topographic profile with contour lines, obtained from b; (**d**) interpretive draw. In the knee trace C42 are located the impressions of the patella (*a*), vastus medialis (*b*), fibular head (*c*), patellar ligament (*d*) and tibial tuberosity (*e*)

part, there are recognizable traces impressed by a larger individual (adolescent or subadult morphotype 3–4?). An ongoing analysis suggests working out the lines' overlay and underlays and hence temporal sequence of their compilation. Overlays tell the temporary sequence in which units in a cluster were fluted and the direction in which the cluster was composed. Some geometric compositions have been yet identified as the result of nonrandom superimpositions (trellis and sinuous lines).

Clay Pits and Related Finger Traces

In the Sala dei Misteri, some hole and pits are excavated on the clay floor. The holes are small (10 × 10 cm) and can be interpreted as being used to casually extract clay with one hand. The two best-preserved pits are elliptical depressions (70 × 50 cm) up to 30 cm deep, showing widespread traces of excavation with bare hands along the edges. The clues identified at Sala dei Misteri, suggesting that the adults and the younger child were collecting clay to cover the stalagmite, laid down only 2–3 m away from the clay pit.

Animal Traces

The palaeoichnofabrics generated by bears and canids was found in several sectors of the cave and is still under study and only briefly reported in this chapter.

Bear bioglyphs were made either by locomotion (Fig. 14.2, SM12-C12) (footprints and scratch marks: claw marks made on walls, cave floors and terrace slopes) or by habitation (hibernation or gestation nests, nest scratch marks).

Several well-preserved bear footprints belong both to juvenile and adult specimens with maximum length dimensions between 70 mm and 120 mm for the manual print and between 17 mm and 22 mm for the pedal ones (Fig. 14.3c2). These dimensions are smaller than those of the cave bear (Robua et al. 2018) and strictly comparable with those of the extant bear (*Ursus arctos*) to which we attribute them.

Some bear nests have been also identified, measured and surveyed. The majority of the nests were found very close to the cave walls. Of all the nests, only few were measurable (N = 4), the remaining ones being partly destroyed or partly covered by flowstone. The distribution of the nests gives no indication of a pattern: sometimes they are overlapping (collective), sometimes they are lined up next to one another, or they are situated at considerable distance (tens of meters) from one another. The mean dimensions of the bear nests (length 140 cm, width 90 cm and depth 25 cm) indicate that their shape is ellipsoidal with low depth.

The diversity of the bear scratch marks from Bàsura Cave is complex. The claw marks, made either in sediment, on cave walls or on altered limestone, can be explained as exploration of the subterranean environment (or trying to escape from cave traps) and digging nests for hibernation.

Several canid tracks are preserved on the floor of the Corridoio delle Impronte (Fig. 14.2, CA12). All the footprints can be easily separated into two main groups: the first with a stout general morphology (L, 9.5 cm; W: 9 cm) and the second slender (L, 9 cm; W, 8.5 cm). The two morphotypes seem to correspond to manual and pedal prints. While canid tracks are well preserved and easily distinguishable, doubts remain concerning the precise canid species represented in the Bàsura Cave.

The ongoing statistical analyses seem to indicate that a single specimen entered the cave, but the interaction with the human footprints is still under study.

Approaches and Methodologies

All recognized tracks were analysed directly in the field through a morphological approach using available landmarks (Robbins 1985; Ledoux and Boudadi-Maligne 2015). The differential depth of each individual impression was analysed directly in the field to infer the complex and multiphase biomechanics. All footprints were drawn in the field on plastic film. All morphological and dimensional data collected in the field were double-checked by using photos and photogrammetric models. In addition, the original casts of the footprints from the 1950s were also used and analysed (Figs. 14.3 and 14.4).

High-Resolution Digital Photogrammetry

We use the photogrammetric method (Falkingham et al. 2018) to digitally acquire and reconstruct the ichnological material from the Bàsura Cave. Digital 3D models have been reconstructed for both humans and animal traces, including canid and bear footprints (see Citton et al. 2017 and Romano et al. 2019). For each single footprint, an average of 40 photos has been taken around the subject using a 24 Megapixel Canon EOS 750D (18 mm focal length). The software used to reconstruct the 3D photogrammetric model is Agisoft PhotoScan Standard Edition, version 1.4.0 (Educational License), which enables automatic generation of point clouds, textured and DSMs/DTMs and polygonal models and to georeferenced true orthomosaics from still images. High-resolution digital photogrammetry is based on multi-view stereo (MVS) and structure from motion (SfM) algorithms (Ullman 1979; Seitz et al. 2006); the accuracy for close-range photography is up to 1 mm.

In the case of the lower corridor, a total of 327 photos for several angulations have been taken to cover all the trampled surface. The obtained model, with a dense cloud made by 60,742 points and a final mesh with over 31 million faces and 15 million of vertex, represents a really useful and crucial tool to recognize the different morphotypes and to interpret the complex locomotion. In addition, the separate high-definition 3D models of each single footprints help to recognize and describe the more solid and appropriate anatomical homologous point for morphological and morphometric analyses.

3D Scanning

The principal cave sectors characterized by the highest concentration of ichnological data have been digitally acquired via laser scanner ScanStation2 Leica and ScanStation C10 Leica. Each scan was performed at 360° (acquisition grid of the point cloud of 2×2 cm a probe 7 m and in correspondence to the areas with the highest concentration of traces, an acquisition grid of 0.5×0.5 cm probe 7 m), with a total of 23 stations run using 38 targets. The acquired date was then processed via Leica Geosystems HDS Cyclone 9.1 software, with a final alignment error of 1 mm for the Corridoio delle Impronte and 2 mm for the model of the Sala dei Misteri.

The acquisition of the principal cave sector via high-definition laser scanning allows to contextualize the 3D photogrammetric model in a broader digital environment, improving both the knowledge and communication of the general framework. In addition, the obtained 3D models allow to digitally preserve really unique site as the Bàsura Cave, which, in the long time, could be damaged by both anthropic activities and natural geological processes.

The original cast performed in 1950 were digitally acquired via HDI Advance structured-light 3D Scanner R3x, with a resolution of 0.25 mm at 600 mm FOV (field of view). The data were processed with FlexScan 3D Software (Figs. 14.3 and 14.4).

Morphometric Analysis

Principal component analysis (PCA) represents a really powerful tool to summarize in a two-dimensional scatter plot the morphological variability for the studied specimens, even starting for a large number of morphological variables. The scores and loadings provided by the PCA help to identify the morphological variables that greatly influence the variance of the considered dataset and thus the more important anatomical landmarks for morphological description and grouping of similar objects.

A morphometric study has been performed on the best-preserved human and canid footprints. To build the raw dataset, we use the anatomical foot landmarks proposed by Robbins (1985 – for human) and Ledoux and Boudadi-Maligne (2015 – for canids), and the log-transformed data that have been subjected to a principal component analysis in software PAST 3.10 were used (Hammer et al. 2001). The PCA result (Fig. 14.5) identified five different clusters of human footprints, with well-separated convex hulls, showing reduced explored morphospace. Thus, the morphometric analysis supports the morphological ones and strongly suggests that a minimal number of five individuals entered and explored the cave.

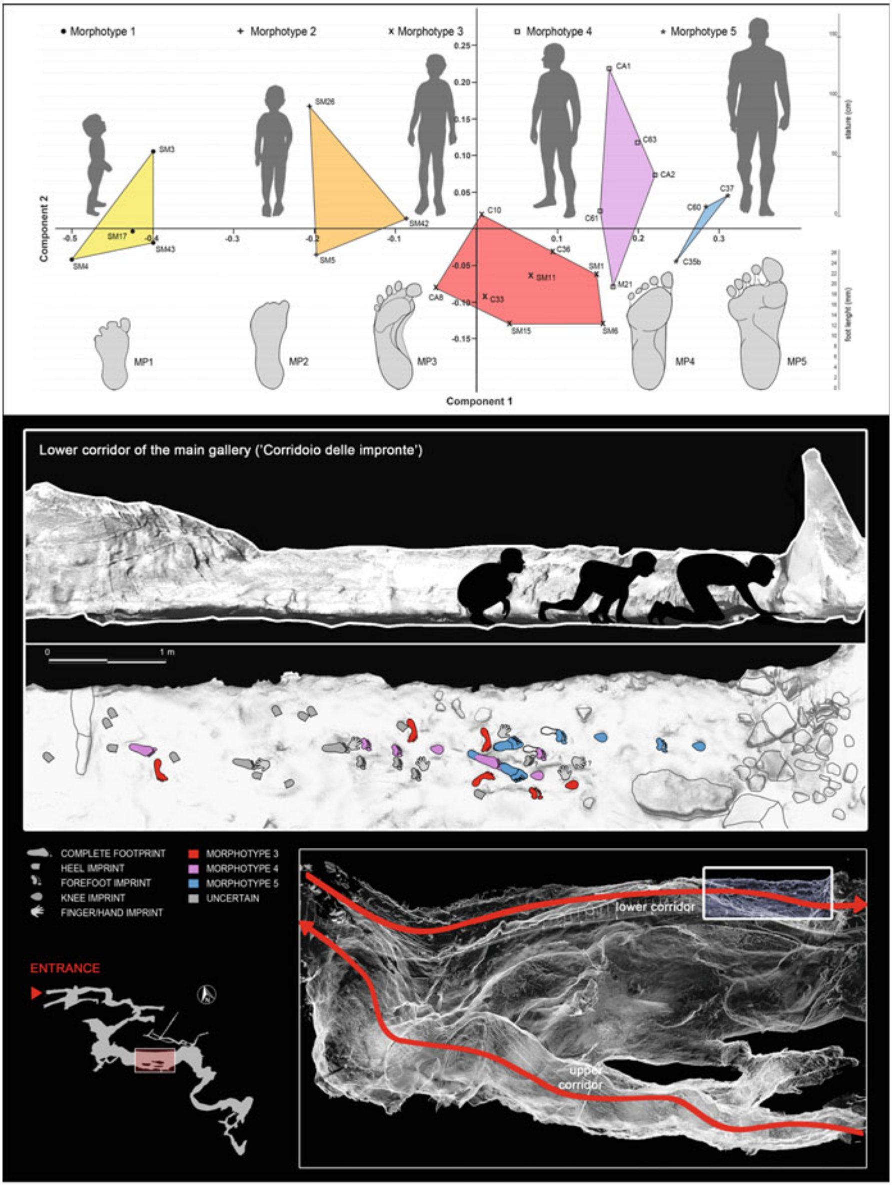

Fig. 14.5 Principal component analysis (PCA) based on the best-preserved footprints from the Bàsura Cave and reconstruction of crawling locomotion in the Corridoio delle Impronte. The five morphotypes to which footprints have been referred are shown. The sketch below illustrates the crawling locomotion adopted by the producers to cross the Corridoio delle Impronte (Sector B in Fig. 14.1) and access to the innermost rooms of the cave

The Archaeological Approach and New Absolute Dating

Prehistoric human activity inside the Bàsura Cave has been the subject of speculation and interpretative theory since the discovery of the traces left in the Sala dei Misteri. Our understanding of it is still changing as excavations and modern scientific techniques yield more information. The first known excavation at Bàsura Cave was undertaken indeed in the 1950s in the Cimitero degli Orsi by the late Virginia Chiappella (1952), who investigated an approximately 70 cm thick palaeontological deposit of cave bear bones composed by two main accumulation levels and attributable to the Upper Pleistocene.

More recently, a further programme of excavations, led and conducted by two of the authors (ES and MZ), was carried out in 2016 with the aim of testing, for the first time, the existence of an anthropogenic deposit in the Sala dei Misteri and the thickness of the palaeontological deposit. The area selected for the test trench corresponds to the centre of the inner room, where the original clay surface has been trampled by the first explorers of the 1950s and during the construction of the touristic pathway, and no other traces except for modern boot sole imprints are preserved. The excavation grid has been positioned in correspondence of some preserved charcoal traces on the above cave ceiling attributable to prehistoric anthropic activity. The clay deposit was excavated for an extension of 6 m^2, and it has a depth of maximum ca 40 cm. The deposit was carefully water-screened with 3 and 5 mm meshes; however, no traces of artefacts have been noticed, except for numerous charcoals from the first centimetres of the deposit usually located in correspondence of the ceiling traces above. Some animal bones have been collected and identified as belonging to *Ursus spelaeus.* Bones of cave bears are rare, badly preserved and pertain for the most part to infant and juvenile specimens; adult bears are represented only by few bones recorded in the lower levels. In all the investigated squares, numerous milk teeth are present highlighting how many bear cubs have died between few months of life and 2 years of age (Andrews and Turner 1992; Debeljak 1996). In addition, some *Ursus arctos* teeth have been found in the upper unit of the stratigraphic section.

The profile has been sampled for micromorphological, geoarchaeological and archaeobotanical (pollen analysis, charcoals) investigations. New radiocarbon dates have been produced and are in progress from charcoal (*Pinus* t. *sylvestris*/*mugo*) and bone samples (*Ursus spelaeus*) collected in the different excavated units (Romano et al. 2019: Table 14.1). Preliminary results (12,310 ± 60 BP, GrA-69,598 and 12,370 ± 60 BP, GrA-69,597 from charcoals) confirm the human presence in the cave in the time span of 12,720–12,110 calBC/12,830–12,165 calBC, while the cave bear bones belong to at least two main accumulation episodes dating, respectively, to >48,500 calBP (GrM-10,848), >45,000 BP (GrM-11,615) and 29,475–28,805 calBP (GrM-10,849: 25,090 ± 120 BP). The last date shows that the Bàsura Cave of Toirano should be added to the list of MIS 2 cave bear sites known in Europe (Terlato et al. 2018).

Table 14.1 Elaboration data (foot index, stature, body mass and age) from measurements based on the best-preserved tracks from the Sala dei Misteri and Corridoio delle Impronte

ID	L/R	FL (cm)	FW (cm)	Arc angle (degree)	Foot index	Stature (cm)	Body mass (kg)	Age (year)
Morphotype 1								
SM3	R	13	6	20	0.46	84.36	11.78(a)	
SM4	L	13.5	6.5	22	0.48	87.61	12.55(a)	
SM43	L	13.5	6.5	20	0.48	87.61	12.55(a)	
SM17	R	14.2	6.8	25	0.48	92.15	13.70(a)	
		13.55 ± 0.49*			0.48 ± 0.01*	87.93 ± 3.20*	12.64 ± 0.79(a)*	<3
Morphotype 2								
SM5	R	17	6.8	28	0.40	110.32	19.50(a)	
SM42	R	17	7.2	25	0.42	110.32	19.50(a)	
SM26	R	18		28		116.81	22.12(a)	
		17*			0.41 ± 0.02*	110.32*	19.5(a)*	5–6
Morphotype 3								
CA8	R	20.2	8		0.40	131.08	29.18(a)	8–10 boy/ 9–11 girl
C10	R	20.5	8		0.39	133.03	30.30(a)	
SM15	L	20.5	7	45	0.34	133.03	30.30(a)	
SM11	R	21	7.5	40	0.36	136.28	32.28(a)	
SM6	L	21.5	9	40	0.42	139.52	34.38(a)	
SM1	L	21.3	8.5	40	0.40	138.22	33.52(a)	
C33	L	22.2	10.5	48	0.47	144.06	37.55(a)	
C36	L	22.7				147.31	39.99(a)	
		20.83 ± 0.51*			0.38 ± 0.03*	135.19 ± 3.33*	31.66 ± 2.05 (a)*	8–11

Morphotype 4								
CA1	R	22.4	8.5		0.38	145.36	45.48(b) – 46.66(c)	
CA2	L	22.5	8.5	44	0.38	146.01	45.66(b) – 47.19(c)	
C61	L	23	9	45	0.39	149.25	46.57(b) – 49.82(c)	
C63	R	23.3	9	42	0.39	151.20	47.12(b) – 51.39(c)	
M21	R		9.8	42				
C9	R	22.5	8		0.36	146.01	45.66(b) – 47.19(c)	
C44b	L	21.5	10.5	50	0.49	139.52	43.84(b) – 41.93(c)	
		22.80 ± 0.42*			0.38 ± 0.01*	147.96 ± 2.75*	46.21 ± 0.77(b)* – 48.76 ± 2.23(c)*	>14 – adult
Morphotype 5								
C60	L	25.3	11	52	0.43	164.18	50.76(b)	
C37	L	25.7	10.5	55	0.41	166.77	51.48(b)	
C35b	R	26.2	10.5		0.40	170.02	52.39(b)	
C44	L	25	10	50	0.40	162.23	50.21(b)	
		25.73 ± 0.45*			0.41 ± 0.02*	166.99 ± 2.93*	51.54 ± 0.82(b)*	>14 – adult

ID individual footprint, *L/R* left or right, *FL* maximal foot length, *FW* maximal foot width, * mean/standard deviation, *body mass* (a) for individual smaller than 147 cm (weight kg = 2.2897 $e^{0.126\ FL}$ from Citton et al. 2017), (b) and (c) for the individual taller than 147 cm (weight kg(b) = 4.71 + (1.82 × FL) from Bavdekar et al. 2006 and weight kg(c) = −71.142 + (5.259 × right FL) from Grivas et al. 2008

Charcoal Remains and Insights on the Illumination of Caves

The first palynological analyses carried out on the sediments recovered in the Cimitero degli Orsi had allowed the reconstruction of the vegetal landscape during the Upper Pleistocene (final period of MIS 3) in the area surrounding the Bàsura Cave (Arobba 1986; Arobba and Caramiello 2008). Results show a clear prevalence of herbaceous taxa typical of steppe formations (*Artemisia*, *Centaurea*, *Carduus*, *Cirsium*), accompanied by low values of arboreal shrub elements pertaining to the Scots pine forest (*Pinus sylvestris*), as well as more rare elements belonging to the mixed oak forest (*Quercus deciduous* t., *Tilia*, *Corylus*) and to the wetlands of the valley floor (*Alnus* and *Salix*). This situation is consistent with that found in other areas of southern Europe in the same period, characterized by a cold-dry climate, which may have been mitigated along the Mediterranean coast.

Although it should be taken into account that the pollen of *Pinus sylvestris* t. is constantly over-represented, the data seem to indicate the real distribution in the area of this species – currently distributed in the mountainous and subalpine planes – during the Tardiglacial, a period during which the human frequentation of the cave is attested by charcoal remains.

More recent palynological investigations have shown a substantial overlap between the data described for the Cimitero degli Orsi and those conducted on a sedimentary sequence brought to light during the archaeological excavations carried out in 2016 in the Sala dei Misteri, located a few meters away.

On the surface level of the Sala dei Misteri series, i.e. in the first 3–4 cm, were found 56 fragments of charred wood of variable dimensions (3–65 mm), dated between 12,370 ± 60 (GrA-69,597) and 12,310 ± 60 (GrA-69,598) uncalBP (see Section The Archaeological Approach and New Absolute Dating). All belonged to the Scots pine/dwarf pine and are attributable to three species morphologically similar from the point of view of the anatomy of the wood (Schweingruber 1990): *Pinus sylvestris* (Scots pine), *Pinus uncinata* (mountain pine) and *Pinus mugo* (dwarf pine). The choice of harvesting this resinous wood with good flammability was certainly favoured by its presence in the immediate vicinity of the cave, as suggested by pollen analysis results.

In the prehistoric cave of Chauvet-Pont d'Arc (southern France), 171 charcoal remains have recently been recognized as *Pinus sylvestris/P. nigra* subsp. *salzmannii/P. mugo/P. uncinata*, and part of them were interpreted as residues of torches for lighting used between 37,000 and 28,000 years BP, i.e. in periods prior to that of the human frequentation of the Bàsura Cave. This suggests that the pine genus was one of the most suitable entities for this type of use (Théry-Parisot et al. 2018).

In our study, more than 80% of the material from which the fragments are derived comes from young branches, less than 2–3 cm in diameter, based on the curvature of the annual growth rings (Dufraisse and García Martínez 2011). Gathered in small bundles, these twigs could therefore have been elements of torches to be lit in sequence to achieve weak but effective lighting: this method was also documented, for example, in the protohistoric salt mines of Hallstatt (Austria), where was used twigs of *Abies alba* (silver fir) characterized by a non-resinous wood which therefore produces poor smoke. This choice is consistent with the work in a mine in which the human presence is prolonged (Barth 1983; Ast 2001; Grabner et al. 2010). On the other hand, in the Bàsura Cave, where the stay of man could be of short duration, it is understandable the choice of Scots pine resinous wood, even if it is more fume producing.

Experimental archaeology tests have shown that small-calibre sticks are more efficient in terms of ease and time of ignition, as well as durability, than torches made from large branches, dispelling the hypotheses made from the 1950s to the present day.

Another interesting aspect concerns the discovery of a greater quantity of charred wooden remains in the deposit in correspondence of the carbon traces present on the ceiling walls of the cave (Giannotti 2008). This suggests that those places were probably areas where the torches used by the ancient Palaeolithic visitors would have been revived.

Inferences from Human Tracks and the Reconstruction of a Scenery

The Human Trackmaker Identikit

Human plantigrade tracks allowed us to estimate stature, weight and ontogenetic stage of the producers basing on the collected biometric measurements (Table 14.1) and the adopted formulas (Citton et al. 2017).

The group of track producers entering the cave comprised a 3-year-old child about 88 cm tall (morphotype 1); a child at least 6 years old and about 110 cm tall (morphotype 2); a preadolescent, between 8 and 11 years old, about 135 cm tall (morphotype 3); a subadult to adult about 148 cm tall (morphotype 4); and an adult about 167 cm tall (morphotype 5) (Fig. 14.5). Estimate of the stature for the morphotype 5 is also sustained by the results obtained considering the length of the tibia derived from the available kneeling traces. Our results concerning morphotypes 4 and 5, which are referred to adult individuals, are in agreement with the average stature suggested during the European Upper Palaeolithic (162.4 ± 4.6 cm for males and 153.9 ± 4.3 cm for females) (Villotte et al. 2017).

Body mass estimates derived from footprints parameters suggest slender body size for all the trackmakers. Arch angle and footprint morphology suggest a possible male as trackmaker of the largest footprint group. For morphotypes 1, 2, 3 and 4, any inference of gender result possible although the presence of almost a female (morphotype 4?) seems probable.

Digitigrade and semi-plantigrade footprints informed on the pedal postures and the behaviour of the producers passing through different sub-environments of the cave. Both these footprint types were in most cases traced back to the same type of producer by comparison with complete footprints indicating complete foot support during locomotion. Some semi-plantigrade footprints (e.g. Fig. 14.4, C44–C44b) show a strongly adducted trace of digit I and an apparent alignment with the other digits, probably because of the intra-rotation movements of the distal portion of the foot during the thrust phase. Footprints included in morphotype 3 show a peculiar pedal morphology. While the resulting morphology of digit I trace is explained by walking on a waterlogged substrate, the separation between digit pairs II–III and IV–V allowed hypothesizing an inherited familiar trait or a pathological condition of the producer's feet. The producer was not incapacitated, showing the greatest mobility in the hypogeal environment.

The Exploration of the Cavity

The study of the tracks and their interaction with substrate allows us to reconstruct the main aspect of the cave exploration. In the initial part of the cave, no footprints were preserved, so we hypothesize that after a walk of approximately 150 m from the original opening of the cave and a climb of about 12 m, the group arrived at the Corridoio delle Impronte were the first main cluster is preserved (Fig. 14.1). They proceeded roughly in single file, with the smallest individual behind, and walked very close to the side wall of the cave, a safer approach also used by other animals (e.g. Canidae *incertae sedis* and bears) when moving in a poorly lit and unknown environment. The slope of the tunnel floor, inclined by about 24°, may have further forced the individuals to proceed along the only flat area in the lower corridor, a couple of meters from the left wall of the cave. About 10 m from the Corridoio delle Impronte, the cave roof drops to below 80 cm, and members of the group were forced to crawl, placing their hands and knees on the clay substrate (Fig. 14.5).

After a few meters, the group leader stopped, impressing two parallel calcigrade footprints, possibly to decide on the next movement and proceeded to cross the parts where the cave roof was at its lowest. The other individuals also stopped at the same place as the leader and then proceeded along the same path by crawling and following the group leader, as indicated by the timing reconstructed from interactions between the tracks.

After passing a bottleneck of blocks and stalagmites, the party descended for about 10 m along a steeply sloping surface. The whole group traversed a small pond, leaving deep tracks on the plastic waterlogged substrate, climbed a slope of 10 m beyond the Cimitero degli Orsi and finally arrived at the terminal room Sala dei Misteri, where they stopped. On the walls, several charcoal traces, generated by the torches, are preserved.

Some charcoal handprints reaching up more than 170 cm on the roof of the Sala dei Misteri confirm that the tallest individuals (morphotypes 4 and 5) were able to touch this part of the gallery. The fact that their footprints are not preserved relates to the loss of the central portion of the hall floor. In the same room, the adolescent and children started collecting clay from the floor and smeared it on a stalagmite at different levels according to height, as suggested by the breadth and relative distribution of the finger flutings on the karst structure. During their sojourn in the innermost room of the cave, the young individual, which produced morphotype 2, imprinted ten clear heel traces (Citton et al. 2017), which are here interpreted as calcigrade tracks produced by a trackmaker who is momentarily standing still to excavate and manipulate clay as was also recorded for the Salle des Talons at Tuc d'Audoubert cave (Pastoors et al. 2015).

After stopping for several minutes (considering the quantity and ubiquity of the tracks), they exited and followed a route which did not always adhere to that followed on entry. After passing the small pond, they crossed the upper corridor following a more comfortable and safer route (Fig. 14.1). It is important to note that in the upper corridor, all the prints point in the direction of the exit while in the lower corridor, with the axis of the foot oriented parallel to the walls, most of the footprints are directed towards the interior of the cave (Fig. 14.5) (Romano et al. 2019).

Bàsura Cave in the Regional Context

The Palaeolithic human settlement in Liguria during the Late Glacial seems to be intensifying compared to the previous phases (Tomasso et al. 2014). In addition to scattered findings of Epigravettian lithic artefacts from open-air sites referable to short-term hunting camps, a more consistent evidence of long-term or pluristratified dwellings have been found in some shelters or caves, namely, in the archaeological area of Balzi Rossi (Grotta dei Fanciulli and Riparo Mochi), in the inner valleys of the Albenga Plain (Arma di Nasino, Arma dello Stefanin and Arma Veirana) and in the Finalese Area (Caverna delle Arene Candide).

These sites, mainly focused on hunting activities, are located both in the ends of the valleys and along the mountain terraces and ridges. At the Arma dello Stefanin, a cave located at the entrance of a valley rising towards the Alps, a high presence of ibex remains underlies the very specialized hunting vocation of the site (Barker et al. 1990). A high human mobility along the territory is also testified by the presence of a wide range of lithotypes used to make chipped stones; the lithotypes found in the Ligurian sites come from a very large area, which brackets, on the west, the Rhone Valley, in France, and, on the eastern side of the Italian peninsula, the Marche region (Negrino and Starnini 2003).

The most interesting behavioural features, involving social and ideological issues, concern however the burials. Burials have come to light at the Grotta dei Fanciulli (Gambier et al. 2001) and at the Caverna delle Arene Candide (Sparacello et al. 2018). Although, as for the Gravettian, the use of pierced sea shells as grave goods has always been widespread, new behaviours linked to funerary practices seem to arise. The Late Epigravettian levels of the Caverna delle Arene Candide, for example, have revealed a true cemetery dated at about 12 ka calBP and referring to about 30 individuals, including a bisome burial as well as neonates, infants and juveniles; it shows a complex rituality, as highlighted by the presence of millstones and ochre painted pebbles, by different animal species, probably totemic, associated with the burials, and by a voluntary displacement of some human remains (Riel-Salvatore et al. 2018; Sparacello et al. 2018). The bisome burial discovered at the Grotta dei Fanciulli, which takes its name from this finding (*fanciulli* means in fact children), belongs to two children, respectively, 4 and 5–6 years old; it has been dated at about 13 ka calBP. The burial objects consist of about a thousand of perforated marine shells of *Tritia* sp. placed in correspondence to the pelvis and the proximal part of the femurs, probably sewn to clothes or belts, underlying how these young individuals were the subject of particular attention within the group (Gambier et al. 2001). Remains of children (jaw bones) were finally collected, in a secondary position, from the top units of the same deposit (Palma di Cesnola 2001).

The rich archaeological evidence referred to the Late Epigravettian likely witnesses a demographic growth and perhaps even an increased territoriality; new rituals, including the presence of a cemetery, suggest a deep restructuring of Palaeolithic society during the final stages of the Upper Palaeolithic, not only in Liguria but also all over in Italy and Europe (Pettitt 2011; Riel-Salvatore and Gravel-Miguel 2013), whose phenomenon is perhaps not extraneous to an introgression of a genetic component related to present-day Near Easterners, along with new cultural inputs, as suggested by recent aDNA outcomes (Fu et al. 2016). Concluding, what has been observed at the Bàsura Cave fits perfectly into this picture, enriching it with an evidence that even more underlines the basic and not secondary social role of the youngest individuals within the bands of hunter-gatherers at the end of Palaeolithic.

Concluding Remarks

Based on the integration of laser scans, sedimentology, geochemistry, archaeobotany, geometric morphometrics and photogrammetry, we have interpreted the evidence of a small Palaeolithic group of people explored a deep cave about 14 ka calBP. Five individuals, two adults, an adolescent and two children, entered the cave barefoot and illuminated the way with a bunch of wooden sticks. Traces of crawling locomotion are well documented, and anatomical details recognizable in the crawling traces show that no clothing was present between limbs and the trampled sediments.

The tracks left in the Bàsura Cave indeed confirm us that hunter-gatherers' behaviour was not always driven by subsistence necessity, but as many ethnographic examples teach us, also by nonutilitarian activities.

However, what drove a small group of the Upper Palaeolithic with children younger than 3 years to venture into an unknown and dangerous environment like Bàsura Cave? Quite simply perhaps the innate and irresistible instinct of humans to the discovery, to leave the safe for the uncertain. The journey into the unexplored interior of the Earth of the restricted clan in the Bàsura Cave is a litmus test of how the predilection for the unknown and of the discovery is inextricably written in the human DNA.

The same impulse and sense of wonder drove a group of young guys, in the first half of the twentieth century, to venture with torches in the Bàsura Cave, after 14,000 years and about 500 generations, to follow the father steps in the bowels of the Earth.

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Chapter 15
Prehistoric Speleological Exploration in the Cave of Aldène in Cesseras (Hérault, France): Human Footprint Paths and Lighting Management

Philippe Galant, Paul Ambert†, and Albert Colomer†

Abstract Aldène Cave is a system of 9 km of extent, on four hydrogeological levels. Within the first two fossil levels, which comprise more than half of the system, many archaeological remains have been discovered. They represent a continuum of more than 350,000 years of human history. On the second level, we find the Paul Ambert gallery, discovered in 1948 by the Abbé Dominique Cathala. This gallery contains many human traces, with footprints and marks of torches that were brought into the cave. A recent geomorphological study of these elements concerned registration and systematic analysis of the lighting marks, as well as an initial determination of the footprints. This work confirmed the contemporaneousness and functional link of these archaeological remains. Lighting management could be determined precisely with the traces on the walls and the remains discovered on the floor in connection with the footprints. These data, investigated with a spatial approach in relation to the cave network, clarify the prehistoric passages and allow an interpretation of the behaviour of visitors. All elements together form the picture of a family at a speleological investigation, which is attributed to the Mesolithic.

Keywords Mesolithic · Footprints · Torches · Lighting system · Karst

Introduction

Aldène Cave is located in the south of France in the heart of the Minervois plateau. This region is situated at the foot of the Montagne Noire, overlooking the vast Languedoc coastal plain that extends to the Mediterranean Sea. Administratively, this territory is in the Occitania region, straddling the departments of Aude and Hérault.

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Fig. 15.1 Current view of the entrance to the first level of Aldène

The cave opens to the gorge of the Cesse, a river that rises in the foothills of the Montagne Noire and flows south to join the Aude River. During the crossing of the limestone plateau of the Causses de Minerve, it cut deep gorges that revealed the entrance to Aldène. But much earlier, it is also this river that, before sinking into its canyon, shaped the subterranean network.

The cave is developed over more than 9 km of galleries which are spread over four different hydrogeological levels. The first two levels, of which the first is known since ever and the second discovered in 1948, are completely fossilized. The third level discovered in 1992 has a temporary flow during flood periods, while the fourth level found in 1994 constitutes part of the permanent subterranean course of the Cesse downstream of its first losses located at the Moulin de Monsieur at the beginning of the gorges.

This cave is known since ever. It has always been very popular for different interests: nature, archaeology, history, tourism, speleology, fauna, picturesque setting, emotions and many others (Fig. 15.1). It is a major site in the Minervois that its inhabitants have always known and frequented with continuity and often in a tradition of family tradition. It follows logically that Aldène, as it is locally called, in this region always triggers an interest, a curiosity for everything that happens there, for everything that concerns it.

A Major Natural Cave for the Heritage

Aldène is the most important speleological network in the Minervois, and its speleological complex constitutes a subterranean drain in connection with the river Cesse. The galleries follow the natural slope of the surrounding rocks, towards the southwest and in the main directions of fracturing, which allows groundwater to reach the heart of the Aigne syncline and thus contribute to the constitution of the Cesse-Pouzols aquifer (Nou et al. 2013). The entire network is therefore integrated into this hydro-system and constitutes its main view of drainage and subterranean flows (Fig. 15.2).

The first level, known as the Bousquet level, has always been known as confirmed by the many archaeological remains that have been found there since the eighteenth century. Abbé Dominique Cathala discovered the second level, known as the Cathala level, in 1948. The third level, known as the René Azéma level, was discovered in 1992 by the speleologists of the Aldène Association. The same is true for the fourth level, known as the André network, discovered only in 1994 (Ambert 1998). The galleries that make up this network develop in the Eocene marine limestone of the tertiary era (known as alveolinous limestone), which rest in discordance on the Cambrian schisto-dolomitic series of the primary era. The corridors are cut in following regular fractures that give a very orthogonal appearance to the topography. Around main drains, many side connections become unexplored due to rocky barriers that prevent any passage. Several collapses also mark the ends of the main galleries.

The history of Aldène is very rich. In view of the many publications that recount this story, the researcher remains modest in the face of all these human, scientific and literary investments. Aldène has always intrigued passionate people without ever disappointing those who have been able to handle it. This cave has always had, locally but also regionally, a great scientific and tourist interest. This can be measured by the extensive bibliography concerning it. The census work currently being published by Yves Besset and Robert Marty reveals 700 references to books and articles relating to the cave (Besset and Marty forthcoming), more than a hundred of which were published before the twentieth century.

As early as 1776, Antoine-François de Gensanne published in his history of the province of Languedoc a very beautiful and complete description of the cave. At the very beginning of the nineteenth century, the paleontological interest of Aldène was recognized, in particular by the work of Marcel de Serres, who visited the site several times and identified many species following the discovery of fossil bones by his student Hyppolite Pittore. Throughout the nineteenth century, many publications, mainly for tourists, praised the beauty and interest of the cave. In particular, we can cite the text of Pierre Solomiac, known as Leg of Iron, a veteran who became a hermit of the cave and whose publication constitutes the very first tourist brochure on this cave (Solomiac 1885). He specialized in guiding visitors and has largely marked the history of the site with his legend. The greatest names of prehistory, a nascent science at the time, visited and wrote about Aldène. From 1880, the Narbonne

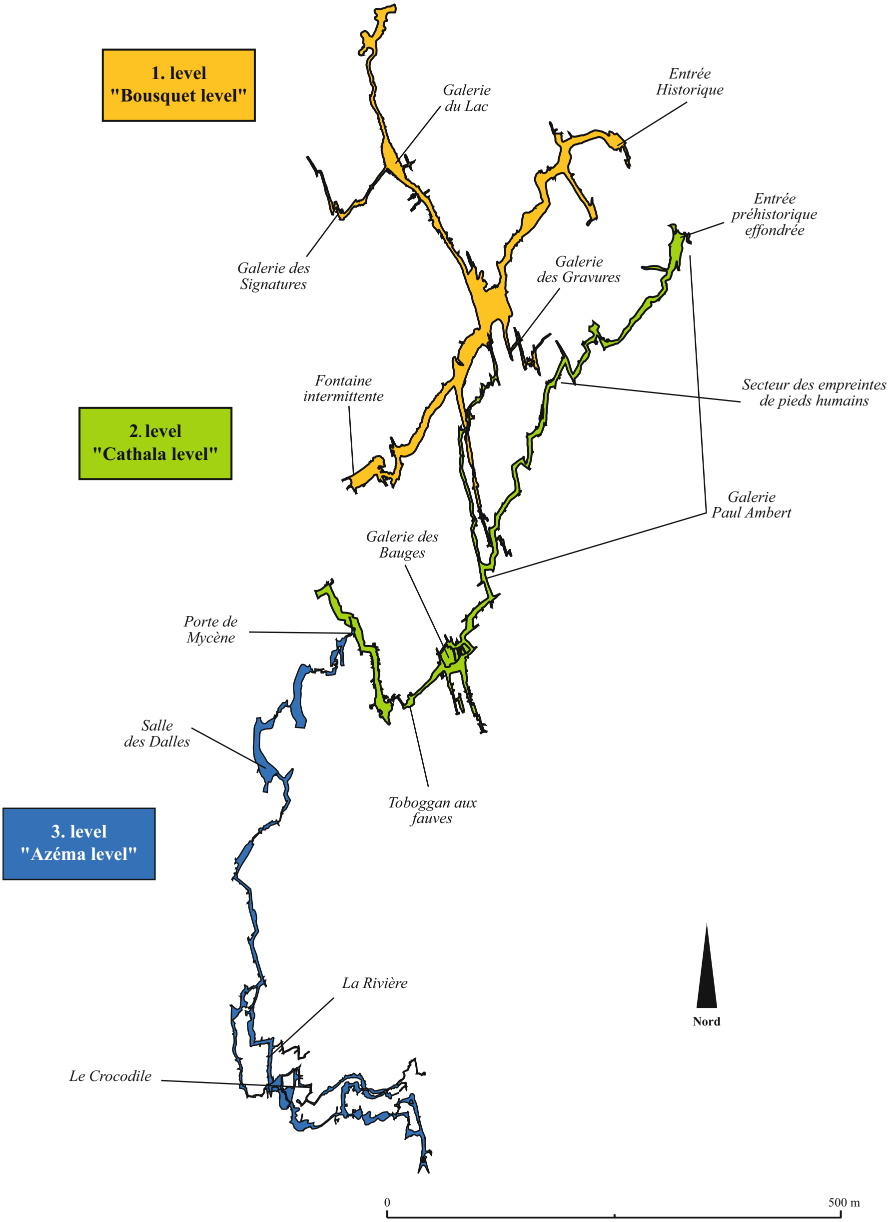

Fig. 15.2 Topographical survey of the first three levels of the cave and location of the main galleries (French Federation of Speleology – Technical UV instructor 1998)

geologist Armand Gautier identified the presence of lime and alumina phosphates in the cave and then called Minervite, which was in fact what researchers would later classify as guano-phosphates: the reaction between the large deposits of guanos due to the presence of bats and the clay fillings in the cave. This discovery led from 1888 to a systematic exploitation of the fillings on the first level, which, after many events, ended in 1943 in the field and with an administrative end in 1950. This exploitation was one of the most important for this type of substance in the whole Languedoc, even in the south of France. This work, which is estimated to have delivered 2840 tons of phosphates between 1888 and 1929, destroyed the paleontological stratifications that prevent the site from being studied forever (Gauchon 1997). Thus, almost all the archaeological and paleontological remains that had accumulated in these fillings over more than 400,000 years have disappeared! But what is contradictory is that this devastating exploitation has also allowed the discovery of remarkable remains that would have remained forever buried without it: in 1927 the gallery with Palaeolithic engravings (Guerret 1927) and in 1948 the access to the second level and the human paths (Cathala 1949). Throughout the exploitation, miners and other visitors collected various ancient objects that trace the prehistoric use of the cave. As an anecdote, noteworthy is the cave bear skull that was displayed in the office of the Director of Operations and was more than 1 m long, the tallest one Bernard Gèze had ever seen (Gèze 1994). Today, all these objects, which testify to the numerous Palaeolithic frequentations, the Neolithic, the Metal Ages, classical antiquity and the Middle Ages, are scattered throughout many private collections that remain unknown; only a few pieces are presented in the museums of Monaco, Montauban, Narbonne and Olonzac (Ambert and Galant 2007). From 1971 to 1998, the Museum of Prehistoric Anthropology of Monaco revealed, through the successive archaeological research of Louis Barral, Suzanne Simone and Patrick Simon, the chronostratigraphic Palaeolithic importance of the filling still preserved at the entrance to the cave. There is here a unique documentation for the knowledge of the frequentations of the entrance during the Lower Palaeolithic. The walls of the cave also contain many historical graffiti that remind us of the recurring visits since at least the Middle Ages and very importantly since the sixteenth century (Marty 2007). An object of curiosity, discovery and sensation, the cave has always been visited since then. This brief presentation of the heritage interests of the Aldène Cave allows us to argue that this cave has concealed for more than 400,000 years all the remains of the various human societies present in this region (Galant and Holwoet 2001). It can thus be classified as one of the most important archaeological sites in Europe.

Exceptional Deposit Conditions

The second level of the cave revealed, during its first exploration by Abbé Dominique Cathala (1899–1950) on first May 1948 (Fig. 15.3), very numerous palaeontological traces of bears and cave hyenas (dens, footprints, bones, claws) as well as exceptional archaeological remains in place: the path of human footprints and traces of torches. All these remains, present on the surface of the floors and walls, indicate the antiqueness and stability of the vestiges and the sedimentary structure in this part of the network. During the research program led by Paul Ambert

Fig. 15.3 Abbé Dominique Cathala (*left*) discoverer of the second level of Aldène on May 1, 1948 and human footprints, accompanied (*right*) by Antoine Solenelle, the miner who showed him the blower hole on March 30, 1948. (Photo N. Casteret, Daniel André-Association Martel Collection)

between 1996 and 2006, which aimed to date animal and human incursions into the Aldène network, a general geomorphological assessment was carried out (Ambert et al. 2000, 2005, 2007). This work made it possible to identify all the sedimentary dynamics of the cave network and their evolution over time (Ambert et al. 2010). In this scheme, the archaeological evidence had made it possible to establish the chronology of events for the most recent periods of the network's functioning. Thus, with regard to human footprints, it was possible to highlight the reasons for their conservation and, above all, the specificity of their situation in this part of the cave (Ambert et al. 2001).

For our part, we coordinated in this program the study of the traces of torches on the walls of the Galerie des Pas (Galant et al. 2007). This gallery, which extends over almost 700 m, originated from the outside with an entrance that has now collapsed. The study of this passage, the only one that allowed access for animals and humans in this part of the network during prehistoric times, showed a slow evolution, to such an extent that when humans used it, the passage was lowered several tens of metres long before giving access to a large chamber extended by a vast and long gallery (Guendon et al. 2004). Inside, the traces of lighting on the floors and walls show that the gallery has been visited by humans for more than 500 m. Our work made it possible to characterize the lighting system used (Fig. 15.4), to reproduce fairly accurately the passages used by humans on the way in and out of the cave and to understand the nature and origin of the traces of lighting still preserved. In addition, we were able to associate the lighting traces with the footprints, thus showing that this contemporaneity resulted from a single visit that corresponded to a speleological exploration of the network during the Mesolithic period. This characterization of a

Fig. 15.4 Restitution of a prehistoric torch from the elements found on the floors and walls of Aldène. The device consists of about 15 juniper wood limbs that burn to produce a very good quality light

specific subterranean behaviour related to speleological exploration undermines the poorly documented theories put forward by some authors who have no reference or archaeological competence despite their claim to want to rewrite the course of history in this theme (Bigot 2010).

A Problem of Complementary Study

While working with the human footprints (Fig. 15.5a), we also had the chance to discover, outside the already known area, a new sector with about ten footprints. Today five sectors with human footprints are now known in this cave, among them the main path extending over about 30 m. Due to the width of the gallery, the footprints of the main path can only be seen from the gateway that borders it laterally. To date no supporting document has been available to inventory or work on these traces. We were then satisfied with making simple visual observations. Thus, we estimated that the human group from which these traces originated was composed of about 20 people, mostly children accompanied by only a few adults. This group only made one round trip through the gallery which allowed us to study the traces of torches as contemporaneous phenomena (Fig. 15.5b). This is the first time that such observations were made in a cave on such remains.

With hindsight, we can now say that this project has remained unfinished. It seems important to us to document with new and reliable methods the relationship between the human paths and the parietal traces present on the walls as one of the

Fig. 15.5 (**a**) Detail of a human footprint of the sector C path well marked in the clay that forms the floor of the gallery; (**b**) human footprints on the path in sector C. These tracks, which go in different directions, clearly indicate the prehistoric group's round trip

main research interests. On the other hand, it also seems essential to us to better characterize the composition of the human group that carried out this speleological exploration more than 8000 years ago, our first assessment being too subjective. To do this, a more precise diagnosis of the footprints must be made. A comprehensive and complete inventory must be drawn up based on a global survey of the five sectors with human footprints known to date. This inventory must also allow to identify each track individually, to carry out biometric measurements in the hope of being able to characterize the stature and age of the trackmaker but also to try to consider a diagnosis of sex. The aim is to characterize the composition of the group as detailed as possible. It will be also important to try to identify and associate the footprints of the same subject in order to be able to define the step sequences and thus to try to approach human behaviour in the cave. These data will be complementary to all those already acquired.

The Contribution of the Traces of Torches

The human presence in the Cathala level of Aldène is also evinced by the presence of charcoal traces on the walls. Just after the discovery in 1948, these remains were interpreted as torch smears, and about 30 of these traces had been inventoried. The completion of a new systematic inventory based on a detailed examination of the floors and walls enabled us to identify 105 points related to lighting management during the prehistoric visit (Galant et al. 2007). These traces are present at the entrance to the cave network where a profusion of layers of charcoal is visible on the floor (Fig. 15.6). The experiments carried out within the framework of this study had revealed that this corresponded well to the lighting of the torches with the thin parts of fire sticks which burn down very fast. The traces found on the walls throughout the rest of the subterranean path could be divided into two types: accidental traces corresponding to unintentional impacts of the lighting systems under particular conditions related to the morphology of the network and advance (Fig. 15.7a) and voluntary traces, always preceded by impacts on the wall to break the longest ends of the torches and thus make a mark during the visit (Fig. 15.7b). Accidental traces generally correspond to lateral friction of the torches, leaving a very characteristic mark on the walls. On the contrary, the voluntary traces correspond to crushing of the end of the torch perpendicular to the wall. These two types of traces are very different.

More than 500 m from the entrance, a final voluntary trace of a torch on the wall seems to indicate the end point of this prehistoric visit to the cave. We then questioned the reasons for this interruption of the presence of traces further into the network, because this point constitutes a stop on nothing and the gallery still extends over vast proportions and a great distance: no natural obstacle hinders the progression at this level. Detailed examination of the walls beyond this passage revealed no trace of a torch; similarly, no charcoal remains or human footprints were seen on the floor. Observation of the geomorphological conditions of this part of the cave network also informs us that there is no reason for differential conservation of these types of remains. Their absence is therefore well linked to an act of omission. Can we then think that the prehistoric visitors of the network continued their visit without leaving a trace on the floors and walls? All the remains observed since the entrance to the network and over the first 500 m invalidate this hypothesis, because the conditions of the galleries in the rest of the network are similar and the observation of the nature and distribution of the traces in the area frequented indicates that we should have found some if prehistoric exploration had extended beyond this point. This last trace of a torch therefore corresponds well to the end of the prehistoric visit. So how to explain this end, when there is no commitment from a speleological point of view to stop the progression at this point of the network. The most probable hypothesis seems to us to be the one that is called in speleology a stop on autonomy. Indeed, it seems obvious that to embark on this exploration, visitors had to bring a certain number of torches necessary for the production of light. It is therefore easy to imagine that at this point, if they had consumed no more than half

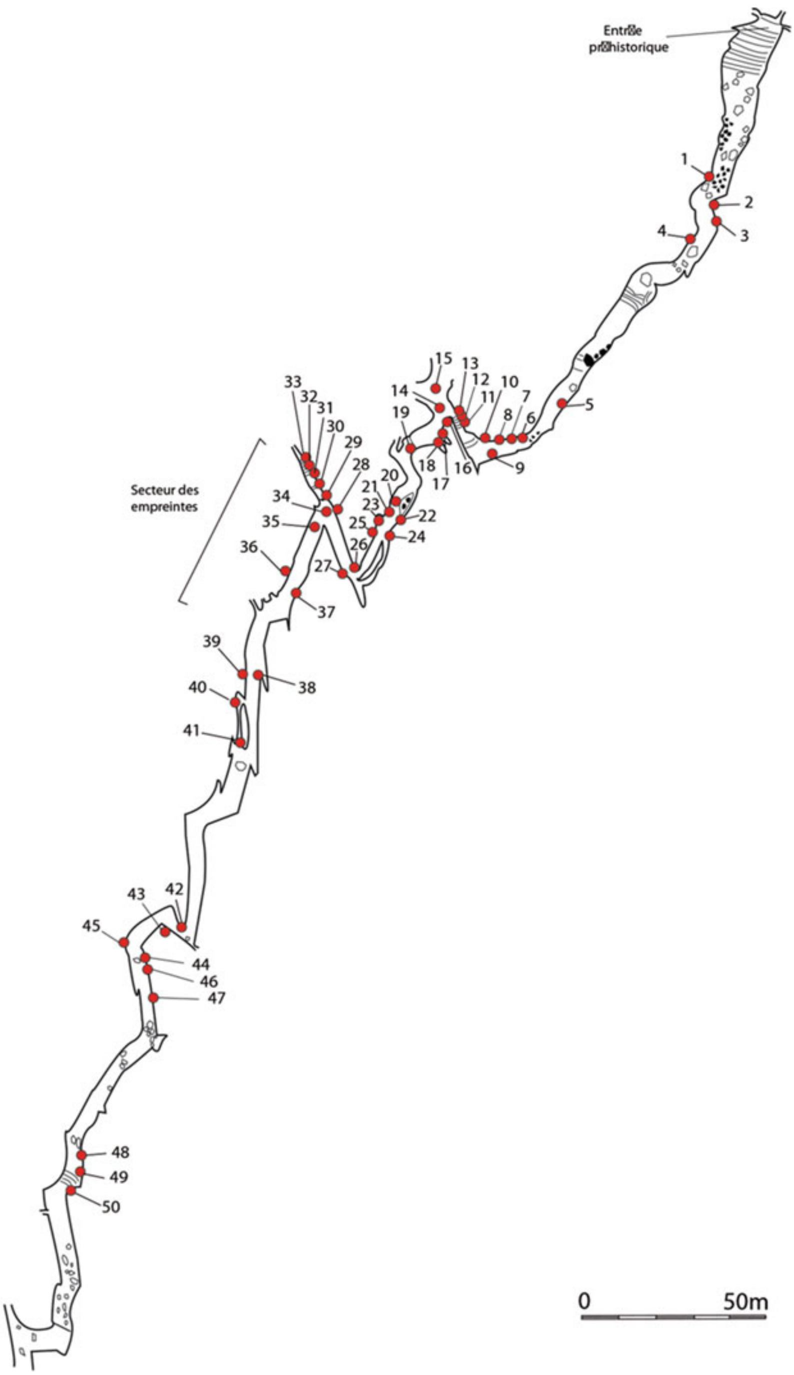

Fig. 15.6 Distribution plan of the different traces of torches found, indicating the area explored by prehistoric speleologists

Fig. 15.7 (**a**) Unintentional trace of a torch corresponding to a lateral friction of the lighting device. This type of vestige makes it possible to accurately reproduce the prehistoric path within the gallery; (**b**) voluntary trace of a torch, marked by an impact perpendicular to the wall. This element seems to correspond to a marking element

of their reserve, they would have thought of returning, light being crucial, even vital, in this kind of exercise. We therefore have here the very ancient testimonies of a prehistoric speleological exploration that has the same behavioural characteristics as those of current speleologists.

Human Footprints

These traces are distributed in a very limited part of the total space covered in the cave by the human group during the Mesolithic period. It is estimated that only 10% of the path taken is still partially marked by human footprints. This is due to two main phenomena: footprints are only marked if there is a passage on a plastic surface; after execution, the preservation conditions must allow the tracks to be kept in place. In the particular case of Aldène, it can be estimated that 40–50% of the substrate of the prehistoric paths could be appropriate for leaving tracks. This situation suggests that many traces have disappeared. This disappearance is mainly due to three reasons: there is a lateral water inflow into the gallery that has partially incised the clay filling superficially; this same water inflow and other flow sources have generated a partial hydrological loading of the galleries, a phenomenon that has resulted in a surface clay-silt inflow that has partially covered the clay floors; and the use of the network since its discovery in 1948 has resulted in extensive trampling of areas that may have borne human footprints. It can also be assumed that in a very specific way, other taphonomic phenomena have altered the conservation of footprints (falling stillation water from the vault, falling blocks, calcifications on the floor, trampling after the discovery, etc.).

These situations explain why human footprints are concentrated at several points over only about 50 m. In this space, five sectors can be identified that show human footprints. These sectors are classified in succession according to the current access to the gallery, i.e. by moving from inside the network to the prehistoric entrance which is currently blocked.

- Sector A: This is the newly discovered complex and the southernmost of all the footprints. They develop over a 4.4 m long space with an average width of 1.1 m. This area, where the original floors have been preserved despite modern circulation since the discovery, is located at the foot of the wall. It consists of a nine-footprint trackway on the east side of the gallery. On the other side of the gallery, to the west, there is a probable isolated footprint that remains to be confirmed and the suspicion of other faint spoors. These spoors were discovered on September 12, 2006 during the study of the traces of torches. They had not been seen during the discovery and owe their preservation only to a recent way marking (1994) put in place to prevent the trampling caused by current visits from spreading throughout the gallery.
- Sector B: This is a small set of poorly identified footprints in an old, very liquid clay puddle that is now dry and partially hardened, covering an area of 2 × 2.7 m. It is assumed that several tracks are present but remain very difficult to see. This sector is located just before the main path in the interior that forms the corner of the gallery to the southeast. It had been noticed upon the discovery and is protected by the installation of a railing.
- Sector C: This is the main human footprints path that occupies an entire section of the gallery oriented on a southwest-northeast axis (Fig. 15.8a). It covers an area of about 3 m wide and about 30 m long. Abbé Dominique Cathala had found almost 200 human footprints on its surface, but due to superimpositions, it would appear that this number must be much higher (Fig. 15.8b). Léon Pales has identified more than 300 footprints, and for our part, we estimate that the final result of the inventory will be closer to 400 footprints! However, this surface shows several areas without footprints for taphonomic reasons due to the normal functioning of the cave. The entire northern part of this path is partially covered by a stalagmitic floor that has also sealed human footprints which remain difficult to identify.
- Sector D: It is located on the same axis as the previous sector and only less than 1 m from its northeast end. It is a former dry sinter basin that was crossed by part of the prehistoric visitor group (Fig. 15.9). This area, measuring approximately 1.3 × 2.4 m, contains less than ten human footprints; they have the particularity

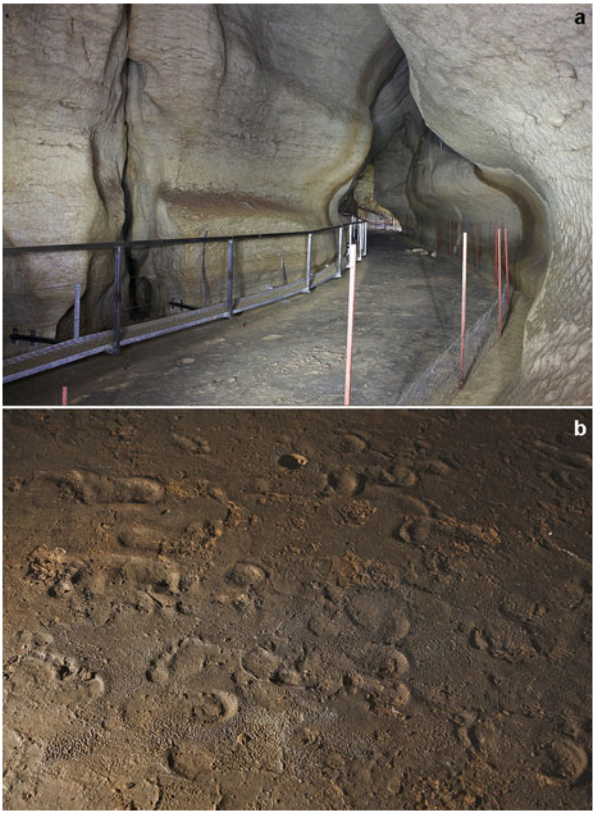

Fig. 15.8 (**a**) General view of sector C, taken from the southwest to the northeast; (**b**) concentration of human footprints in sector C (main path about 30 m long)

of being accompanied by two traces of sticks dragged through the clay in direct relation to the footprints.

- Sector E: This is the start of the gallery that opens in front of the previous sector to the left and north end of sector C. It seems that the group of prehistoric visitors entered this gallery, at the highest level of its vault, through an elongated sinter basin filled with fairly liquid clay. The floor is now totally calcified, freezing the footprints (Fig. 15.10). Many footprints are visible, more than 50 of them, in a space very constrained by the morphology of the passage which forms a surface of 1.5 × 2.8 m.
- Sector F: This footprint sector is the most remote in the network. It does not have a human footprint as such. The passage between the two ancient lakes shows a height of about 0.6–0.8 m. Bear paw prints, a human handprint and traces that can correspond to human knees can be found punctually on an area of about 10 m^2.

Fig. 15.9 Orthophotography of sector D generated from the photogrammetric survey

The Study of the Human Footprints of the Paul Ambert Gallery

The study of the human footprints of the Paul Ambert gallery in Aldène has never really been carried out since the site was discovered in 1948. The analysis begun by Abbé Dominique Cathala after his discovery of the network was not completed following his untimely death. It was only partially presented and then published by his sister at the first International Congress of Speleology (Cathala 1953).

Between 1952 and 1954, several members of the Société Méridionale de Spéléologie et de Préhistoire de Toulouse (SMSP), under the direction of Marguerite Cathala, carried out topographical surveys of the two levels then known in the cave. Similarly, they continued the analysis of the footprints from the main path (sector C in our classification) from the one initially studied by Abbé Dominique Cathala before his death. This work was carried out on the basis of the grid that Louis Méroc had advised Abbé Dominique Cathala to draw on the floor. In addition to the historical and documentary aspects of these surveys, the complete and detailed history of Abbé Dominique Cathala's discovery of the second level is given. To our knowledge, this is the only document that mentions these facts.

In 1973 and 1974, a study mission on these tracks was carried out under the direction of Léon Pales (1908–1988). These works, which have not been published, are only indicated by brief information in a notice of the site in the atlas of the decorated caves (Pales and Vialou 1984). According to this, copies of part of the main path were made by Michel-Alain Garcia, which are now in the Musée National de Préhistoire des Eyzies-de-Tayac-Sireuil (Dordogne). In addition to the copies, the

Fig. 15.10 Orthophotography of sector E generated from the photogrammetric survey

museum houses Léon Pales' personal archives, and it is likely that they contain other important documents about his work in Aldène.

A New Research Program

Faced with the lack of an exhaustive study of heritage remains as important as those present in terms of ichnology in Aldène (by their nature, quantity, quality, chronology), we have embarked on new research on this site. This work was initiated on the basis of the three-dimensional digitization of floors with human footprints carried out in collaboration with the Société Géomesure, the IUT de Nîmes for the scanning part and with Thierry Montécinos for the photogrammetric survey. The principle of an exhaustive inventory of all traces has been put in place through the definition of several criteria to be recorded on each footprint. This project will also address the biometric and paleoanthropological study of traces thanks to the collaboration with Henri Duday (PACEA laboratory). A large-scale experimentation project is also planned under the responsibility of Jean-Louis Orengo, founder of a theme park on ichnology named “Au Pays des Traces” (“In the land of tracks”, Ariège, France). Furthermore, the footprints of various sectors were examined by three indigenous ichnologists from Namibia (Thui Thao, /Ui Kxunta and Tsamgoa Ciqae) as part of a week-long campaign. This extraordinary visit was made possible by cooperation with the Tracking in Caves project (see Lenssen-Erz and Pastoors Chap. 6). This study project will therefore allow a comprehensive scientific approach to the footprints of Aldène. The progress of research in the field of prehistory therefore encourages us to perceive differently the remains that we thought we were studying. The new techniques made available to researchers are renewing the reading of the archaeological data still in place. The first results of this research already allow us to consider rather surprising results that will most certainly allow us to rethink the relationship between humans and the subterranean sphere during prehistory.

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Chapter 16
The Mesolithic Footprints Retained in One Bed of the Former Saltmarshes at Formby Point, Sefton Coast, North West England

Alison Burns

Abstract In the early Holocene period, extensive tracts of coastal land were submerged as the climate warmed and meltwaters flooded into the oceans. As the Irish Sea expanded, coastlines altered and large intertidal zones were created as tracts of low-lying land at the tidal margins were gradually submerged. In these areas, reed swamp and saltmarsh formed which, too, were inundated for varying periods of time. However, in the calmer warmer weather of the late spring and summer, birds and mammals were drawn on to the mudflats where they could feed on molluscs, or new reed and sedge shoots, wallow in the cooling mud, drink the brackish water or, for some predators, hunt. The behavioural tendencies of some species are revealed by their footprints which show their engagement within this environment – some breeds moved on to the marshes while others moved away. The humans who shared this landscape understood the opportunities offered by these predictable behaviours. Their trails run along and across those left by many species, leaving a visible network of human and animal activity preserved in the hardened mud. These will be described through an examination of the footprints recorded in three contexts which formed the stratigraphy of a Mesolithic bed at Formby Point in North West England. The persistent return to the mudflats by generations of people reflects an embodied knowledge of this coastal landscape, learnt in childhood and practiced in adulthood. The ability to modify movements in the landscape, to respond to the daily tides, the changing seasons and a fluctuating environment, all suggest a spatial-temporal relationship which not only encompassed a dynamic environment but also the other life that dwelt within it.

Keywords Formby Point · Mesolithic · Footprints · Sedimentary beds · Saltmarshes · Intertidal · Humans · Animals

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Introduction

Formby Point forms part of the Sefton coast which encompasses a length of coastline of sandy beaches backed by intermittent dune systems and located between the city of Liverpool to the south and Southport to the north (Fig. 16.1). This part of the coastline is suffering from erosional processes which act to reduce the height of a beach. In places, particularly at Formby, this causes the Holocene sedimentary beds to become intermittently visible, jutting out from the sand. The consolidated muddy outcrops appear at different times but the most northern are constantly visible. The different consistency and colour of the sediment indicates the various inland sources of the silt laden streams that conveyed material in suspension from inland during the Mesolithic period. Today, once exposed, they are at the mercy of the weather and the waves which act to gradually destroy them by alternately drying and eroding the layers by sea water. However, the beds are frequently re-covered by the sand either brought down from the nearby eroding dunes or from the sea. Therefore, the exposures are transient and their appearance unpredictable. This study will focus on one sedimentary bed. An analysis of the footprints preserved within it will offer insights into the lifeways of coastal populations during the late Mesolithic period. First, I would like to illustrate the palaeoenvironment which existed in the coastal

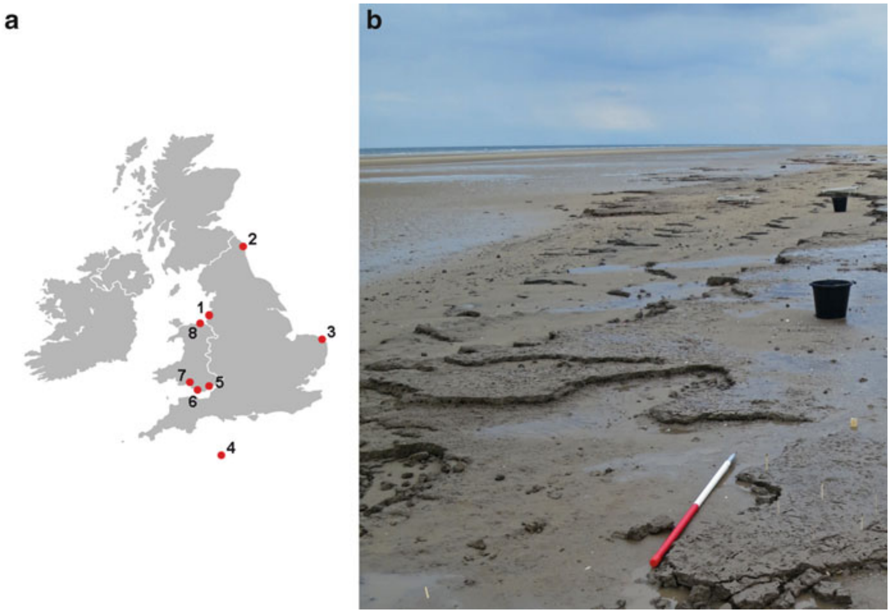

Fig. 16.1 (**a**) The location of the published footprint sites situated around the coastline of Britain. 1 **Formby Point,** Sefton Coast, Merseyside; 2 Low Hauxley, Northumberland; 3 Happisburgh, North Norfolk; 4 St Ouen’s Bay, Jersey; 5 Magor Pill, Gwent and Uskmouth, Newport, S. Wales; 6 Goldcliff, Gwent, S. Wales; 7 Kenfig, Pembrokeshire, Wales; and 8 Splash Point, Rhyl, Denbighshire, Wales. (**b**) The exposed bed at Blundell Path C. The scale is 1 m. (Photo June 2016)

zone of North West England. This provides the contextual background in which the footprints were left.

The Palaeoenvironment

Fluctuations in sea level during the Mesolithic period led to corresponding changes in the landscape. Brackish areas of wetland developed as fresh and saltwater mixed, which changed the ecology of an area as tracts of land were submerged (Fitch and Gaffney 2011; Tooley 1978). Waves and strong tidal currents reworked the mud, gravels and glacial till situated on the bed of the Irish Sea (Fitch and Gaffney 2011; Johnson 2009; Pye et al. 1995). Flood tides around the Liverpool Bay were much stronger in their velocities than the ebb tides. This created an overall landward drift of water-borne material which remained in suspension until it was released onto the upper reaches of the intertidal zones. Transgressive events during the mid-Holocene period also caused a significant amount of sediment to accumulate at the eastern edge of the Irish Sea where it formed sand bars and intertidal mudflats (Huntley 2008: 64; Kenna 1986; Pye et al. 1995; Tooley 1978). Within this diverse and fluctuating landscape, people would have utilised the ever-changing coastline to their advantage, using areas of higher ground as look-out points but retreating when the sea flooded over previously dry areas (Fitch and Gaffney 2011: 96).

Immediately inland, the terrain consisted of low-lying fen carr mixed with carr wood and scrub which extended to the coastal dunes and at the seaward margins an intertidal saltmarsh (Pye et al. 1995; Roberts and Worsley 2008). This coastal ecology covered an area from Anglesey, North Wales, all the way round the eastern edge of the Irish Sea to Walney Island in Cumbria, interrupted at intervals by estuaries running through them (Fitch and Gaffney 2011; Tooley 1976).

This chapter will discuss one footprint laden bed which was recorded in its entirety during a short period of exposure during June 2016. It consisted of two main contexts with a third exposed as a narrow strip on the seaward side of the bed. Contexts 1 and 3 were radiocarbon dated using plant macrofossil analysis. However, in order to contextualise the footprints within this bed it is important to mention other studies which have taken place at Formby and the processes which led to the retention of these footprints.

Previous Studies at Formby Point

Previous studies relating to Formby were published in 1978, the late 1990s and the early 2000s. These studies focussed on dune formation and on determining the pattern of sea-level rise during the early Holocene period. As part of this research, alder and oak roots growing into the sedimentary beds were dated. At Lifeboat Road, the initial dating of the then dune-edge woody dendritic peat, which has since been eroded, was undertaken by Tooley (1978). The sample recovered from a height of +5.08 m OD gave an age of 897–386 calBC (2510 ± 120 BP, Q-2086). In 1995, Pye et al. dated alder roots visible on the upper beach, north of Lifeboat Road, Formby Point (National Grid reference SD 269 065) to 800–100 calBC (2335 ± 120 BP, HV 4709) and 1690–1370 calBC (3230 ± 80 BP, Beta 47,682), respectively, providing a terminus post quem for the sediments which lay beneath the dunes and therefore a date after which the coastal dune system had formed. To establish the antiquity of the sedimentary beds further organic samples were taken. Gonzales et al. (1997) dated alder roots from a similar location to 1780–1430 calBC (3333 ± 80 BP, UB 3868) and 2400–1650 calBC (3649 ± 109 BP, UB 3869) and Roberts (2009) also dated alder roots near Lifeboat Road to 2040–1760 calBC (3575 ± 45 BP, OxA-10,075). However, it was recognised by Roberts that these dates did not establish the actual dates that the footprints were formed, partly because in the 1990s, Gordon Roberts had discovered a set of red deer antlers with good stratigraphic context in an outcrop of sediment close to the dune foot at Wicks Path. This lies approximately 100 m to the north of Lifeboat Road. The antlers yielded a date of 3339–3205 calBC (4450 ± 45 BP, Ox A-9130) (Roberts 2009: 36), putting them into the middle of the Neolithic period. In an effort to date the footprints in beds sediment samples taken by Roberts from Blundell Path were sent for dating analysis using optically stimulated luminescence (OSL). Two samples were analysed: the first taken from a depth of −10 cm gave a date of 5978–3371 calBC (5750 ± 600 BP, OxA 1528a), and the second, taken from a depth of −30 cm, gave a date of 7311–4169 calBC (6650 ± 700 BP, OxA 1528b), (Roberts et al. 1996; Roberts 2009). The exact location of these sample sites is not recorded, and the dates obtained from the sediment give a very broad time span for the mudflat formation but indicate that terrestrial and marine sediments were steadily accumulating from the late Mesolithic period. However, the coastal palaeoenvironment at these locations had changed substantially over time as the dates of the oak and alder roots indicate. Eventually, by the Bronze Age, trees had become established over the former saltmarshes as the coastline moved significantly further to the west as local sea levels regressed (Huddart et al. 1999; Tooley 1978).

The rarity and significance of the archaeological record at Formby Point was established by Gordon Roberts, a local resident, who was primarily interested in the footprints which he noticed in the mud when walking his dog. His careful recording – photography, casting and cataloguing of many footprints enabled him to identify most of the faunal species and to identify and make estimations on the sex, age and stature of the human population (Roberts et al. 1996; Roberts 2009). Represented in the faunal population, he identified red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), aurochs (*Bos primigenius*), crane (*Grus Grus*) oystercatcher (*Haematopus ostralegus*), dog/wolf (*Canis lupus/familiaris*), small seabirds, wild boar (S*us scrofa*), unshod horses (*Equus)* and possibly beaver (*Castor fiber*) (Huddart et al. 1999; Roberts 2009).

Footprint Formation and Preservation Process

As the extensive saltmarsh formed intertidal reed beds and mudflats accumulated at the fluctuating fringes of the coast. These were cut by muddy channels filled with brackish water. This area attracted a variety of fauna drawn by the richness of the reed beds and the openness of the mudflats in contrast to the tangled fenn-carr inland. During the late spring and summer months, the mudflats were exposed for some hours when the tide was out, enabling the footprints of all those moving over them to be captured in the damp sandy mud. During the warmth of the day, the mud hardened and the footprint was retained, baked into the silt. The hardened impressions would have been first filled with aeolian and tidal sand and then covered and sealed by the next water-borne sediment deposition (Allen 1997, 2007; Bennett et al. 2010; Roberts 2009). This fresh layer of silt also had the potential to retain a further array of footprints. However, as can be appreciated, a particular suite of circumstances was needed to enable preservation to take place. Most footprints would have been destroyed by the returning tide within hours of their formation. Over time though, a consolidated bed of sediment formed with the preserved footprints retained in the stratigraphy – offering a snapshot of activity which had taken place over a few hours but which was buried by silt and sand for millennia.

In an experimental research project regarding footprint formation and retention, Marty et al. (2009) described the best conditions for footprint preservation as occurring when the substrate was moist but not waterlogged. In these circumstances the fine details in the footprint would be retained so long as the impression was not immediately covered by water (Marty et al. 2009: 134). Allen described this as stiff mud with a moderate moisture content (1997: 500). The pristine footprints revealed in some of the contexts in the beds at Blundell Path suggest that these conditions were present when these footprints were formed, indicating activity when the tide had been out for a considerable period. Others with less detail suggest a much wetter substrate existed when they were formed and that animals and people also accessed the mudflats shortly after the turn of the tide.

The sedimentary bed which will be discussed in this chapter was only visible for approximately two weeks during June of 2016 and has been named Blundell Path C as it lies in close proximity to two other beds of similar colour and consistency which were previously recorded. This bed measured roughly 4 m by 1.5 m. It was composed of two large exposed layers of approximately 4 m by 0.5 m and one small third layer running under the upper two. Each of these layers contained distinctive trails of footprints. Due to the rapid exposure of the bed in June 2016, most of the footprints were clear, retaining the finer footprint detail and some were in pristine condition. They were recorded over a period of days. At the end of this time, a large quantity of sand once again buried the whole bed to a depth of at least 45 cm.

Blundell Path C

Many beds are intermittently exposed along the foreshore but, during the seven years of recording, Blundell Path C was only visible once for a period of approximately two weeks. However, during this time, it was dated and the exposed parts of the bed fully recorded. Located at Grid reference SD27105 07795, it lies approximately in the middle of the span of beds which extend for 4 km around Formby Point. The mixed stratigraphy of this bed indicates the existence of a dynamic intertidal environment which experienced both periods of flooding, resulting in the deposition of sand, and periods of reduction in relative sea level, which enabled the sediment of the bed to gradually accumulate in three distinct layers of hardened silt (Fig. 16.1). The bed was finally buried beneath the sand where it remained intact until its recent exposure. Each layer, described as a context in this chapter due to the separate episodes of formation, contained footprints.

In order to date the footprints, plant macrofossils were extracted from bulk samples recovered from contexts 1 and 3 and were radiocarbon dated. From context 1 (at the top of the bed), a date of 4331–4050 calBC (5363 ± 59 BP, UBA-32242) was obtained. Context 3 returned a date of 4659–4489 calBC (5749 ± 59 BP, UBA-33959), indicating that the bed accumulated over a period of approximately 400 years. This chapter, therefore, represents an analysis of the humans and animals present within the intertidal muds in Formby at the end of the Mesolithic period in Britain.

The Footprints in the Bed

The lack of clarity of some of the footprint impressions in context 1, which appear eroded, reflects the extended duration of the exposure of this layer of silt to the elements before it was sealed. However, during its formation, this bed had not been subjected to intense drying as no desiccation cracks had occurred. The transient visibility of the bed in 2016 meant that most of the footprints were well preserved and were not exposed to taphonomic processes after exposure. The visible stratigraphy formed two main contexts (Fig. 16.1). A third lower context appeared as a small layer of silt for two days only, before it was partially eroded and reburied. However, these footprints (forming context 3) were photographed and measured. During the recording of the bed, which took place over 4 days, parts of the seaward edge of the bed were eroded at a rate of approximately 45 cm a day. This affected the continuity of some footprint trails in context 2 which had fortuitously been previously recorded. However, it illustrated the ephemeral nature of the bed and the footprints once exposed.

Of the six species recorded here (human, red deer, roe deer, wild boar, oystercatcher and crane), human footprints dominate, accounting for 22 individuals ranging from toddlers to robust adults. Of the animals represented, a small flock of cranes at the most southern end of the bed (Fig. 16.4) accounts for their increased representation in context 1. Of the other species, red deer accounted for three trails of prints and roe deer seven. Unusually, roe deer outnumber red deer in this bed, in contrast with the other Mesolithic beds, where red deer dominate. A single wild boar

Table 16.1 The species and their numbers represented by the footprints in the bed at Blundell Path C

Species	Human	Red deer	Roe deer	Wild boar	Oystercatcher	Crane
Context 1	3	1	4	1	2	8
Context 2	14	2	3		1	1
Context 3	5					
Total	22	3	7	1	3	8

Table 16.2 The dimensions of the footprints, the estimated heights of the children and the direction of travel in context 3 (cm)

Feature number	FL	FW	FD	H	Age	Direction
F.0054	14	5	5	90	≤3	S
F.0055	22	8.5	2	146.5	14+/A	NE
F.0056	10.6	4	1	68	<3	SE
F.0069	12.7	6.5	0.6	81.5	<3	W
F.0070	8.5	5	0.7	54.5	<3	NE

FL foot length, *FW* foot width, *FD* foot depth, *H* height

trail and three widely spaced oystercatcher prints account for the other species. Table 16.1 shows the number of species present within each context.

The footprints will now be discussed in each context starting from the earliest dated context (3) to the newest (1), to highlight the activity taking place during the accumulation of the bed.

Context 3, the Lowest Layer

The footprints in this 1 × 0.5 m exposure of mud were made by four young children and one person over 14 (Table 16.2). No overall trend in the direction of travel could be seen due to the lack of full footprint trails. Only single footprints left by individuals were discernible (Fig. 16.3d). However, they were all within the same area. The grouping of the footprints suggests a number of infants moving around in the mudflats when the tide was out, probably under the supervision of a teenager (F.0055 in Table 16.2).

It is interesting to note that the prints left by the four very young children conform to groupings of children's footprints which are repeated in several of the beds along the foreshore of Formby Point. It would appear that children frequently ventured out onto the mudflats together and that an older youth or young adult was close to them. However, occasionally children moved around together without an accompanying elder. Their presence at the edge of the mudflat indicates the level of familiarity that even very young people had with this intertidal environment. The footprints show their movement directly to and from the sea and at an oblique angle to the tidal edge. At a very young age, habitus, which Ingold (2010, 2011, 2018) defined as the development of skilled knowledge through repeated engagement in a particular setting, was developing. In later life, habitus can be interpreted in the trails of adult footprints progressing with ease through the intertidal muds.

Context 2, the Middle Layer

In this context, the footprints were left by five species; roe deer, red deer, crane, oystercatchers and humans. The footprints were made by 14 humans dominate, although these are frequently only single footprints lying amongst the animal footprints. Only two trails composed of several human footprints were preserved. The measurements of the single human footprints indicate that each age group is represented in this context. Adults are represented by half of the 14 sets of prints. There were three sets of footprints belonging to children under three years of age, two children around ten years of age and two sets belonging to sub-adults aged 14 and above. The assignation of sex was problematic due to the lack of detail in most of these footprints. However, the largest footprint lengths indicate that the adults ranged in height from 155 to 175 cm. This suggests that both sexes were represented by the tracks. The three sets of footprints belonging to children indicate that one child was 112 cm tall and the two smallest sets indicate a toddler and a slightly older child under three years of age. Table 16.3 is a summary of the human footprint dimensions in this context.

Table 16.3 The dimensions of the human footprints in context 2 (cm)

Feature	FL	FW	FD	H	Age	Sex	Trail/ Single	Direction	Interpretation
F.0040	25.5	9.5	2.9	171	Adult	Male?	Single	NW	
F.0041	25	8		166.5	Adult		Single	N	F.0042, F.0043, same person
F.0042	23.5	9	3	156.5	14+		T	W	
F.0043	23.5	9	3	156.5		Female?	T	W	
F.0044	partial	9	3				T	SW	
F.0046	21	7.5	3	134	14+/ adult		T	SW	F.0044, F.0046, F.0047, F.0048, F.0049, F.0052 same person
F.0047	22	9	3	146.5			T	SW	
F.0048	25	9.5	2.7	166.5	Adult		T	SW	
F.0049	24.5	9.5		162	Adult	Male?	T	SW	
F.0053	7	7	3.7	49	≤3		Single	NE	
F.0052	24.5	9.7	2.7	162	Adult		T	SW	
F.0057	24	13	0.5	160	Adult	Male?	Single	S	
F.0058	14	8	2	90	≤3		Single	S	
F.0059	22	8	1.5	146.5	14+/ adult		Single	S	
F.0060	18	7.5	1.5	116	10+		Single	S	
F.0061	15.5	8	0.5	99.5	≤10		Single	S	
F.0022	10	4	3	64	≤3		Single	E	
F.0023	27	6	3	179	Adult		Single	N	

FL foot length, *FW* foot width, *FD* foot depth, *H* height

Although the human and faunal prints (red deer and crane) lay in close proximity within this context, there are no obvious connections between them. The direction of travel by the three roe deer shows a preference to travel along the mudflat to the northeast and the southwest. This contrasts with the red deer who moved east or west. The crane and oystercatcher prints show their random movement over the bed. Although these prints lie near to the human footprints and show the presence of several species over a short space of time, the animals would not have been present at the same time as the humans, rather shortly before or shortly after.

That the humans did not step into faunal footprints is noteable and provides us with a sense of their awareness of others. Despite no recognisable trends apparent in human travel over these mudflats, there was a slight preference to move towards the south along them, parallel to the inland vegetation. However, some human footprint trails clearly show particular patterns of movement. For instance, the clearest set of footprints were left by a person 165 cm tall (probably male) who walked along the mud before stopping (Fig. 16.2, features F.0044, F.0045, F.0046, F.0047, F.0048, F.0049 and F.0052). This person then carried on walking southwest, oblique to the sea. This trail was crossed by another – also an adult – who stood 155 cm high and headed west directly to the seaward edge of the mudflat (features F.0042 and F.0043). These two sets were joined by a third person (171 cm) who walked northwest to join the others (feature F.0040). A slightly different orientation shows a fourth person (also 165 cm tall) who walked north (feature F.0041). However, at least three of the group of people were converging on one area at the seaward edge of the mudflat (Fig. 16.2). It suggests, therefore, that they may have been engaged in activity at the edge of the sea.

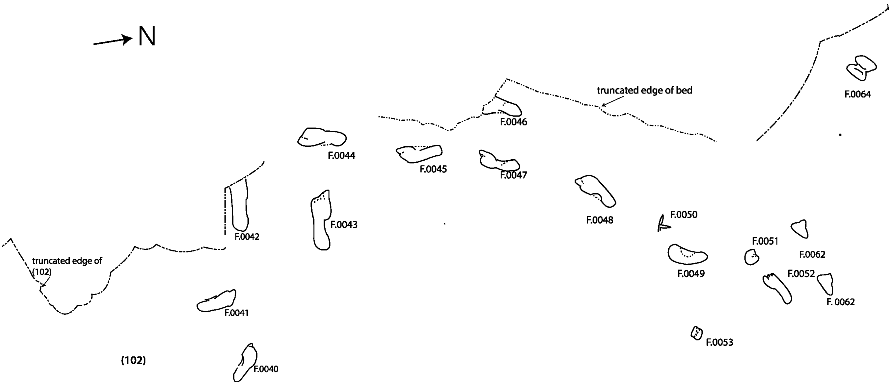

Fig. 16.2 A group of human tracks in context 2 Blundell Path C recorded in June 2016. The plan covers an area of approximately 5 × 3 m

Figure 16.3 shows three of the sets of footprints from this group which could indicate two males and possibly one female. However, this footprint F.0043 could also represent a youth due to the width of the forefoot. Of note is the division between the

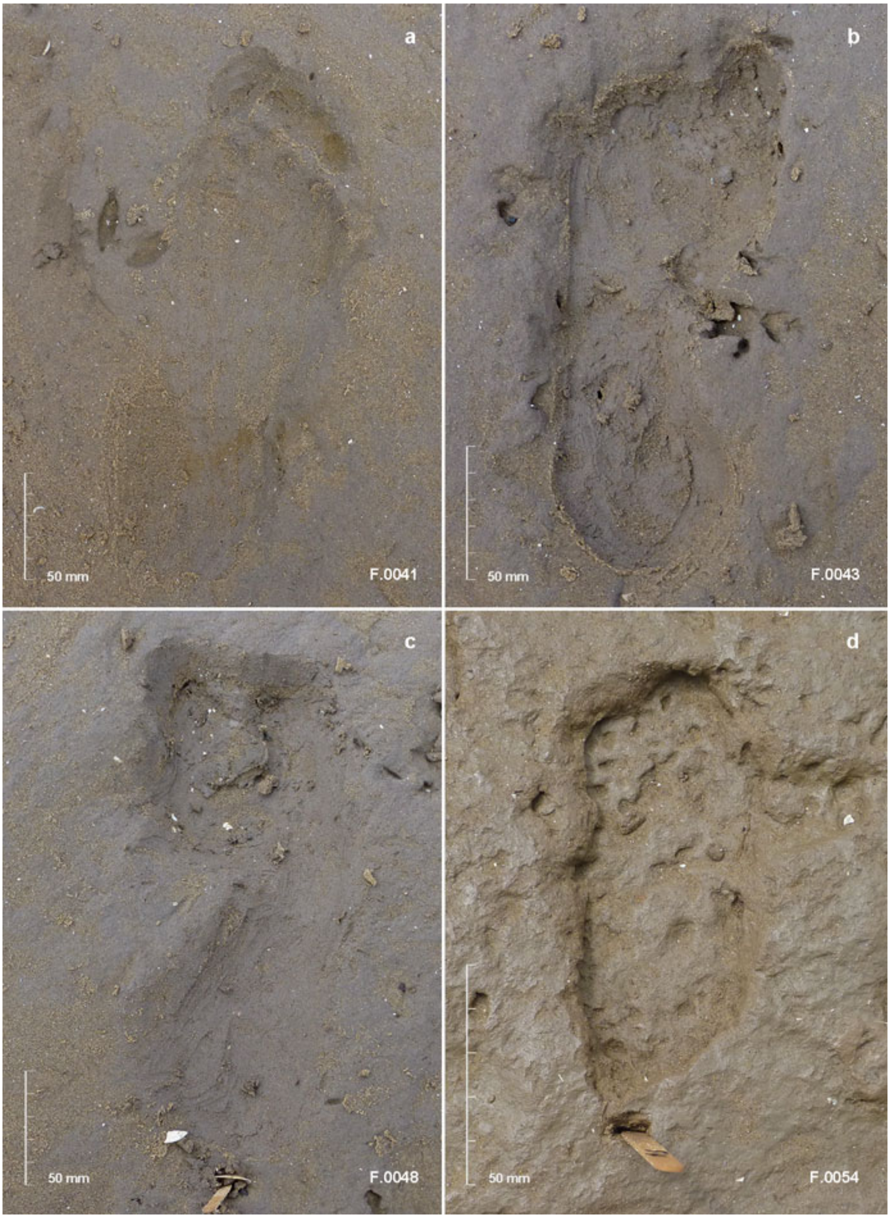

Fig. 16.3 Footprints from three adults shown in Fig. 16.2; (**a–c**) features F.0041, F.0043, F.0048 in context 2; (**d**) a child's print in context 3 shows the wide foot of an infant (F.0054). (Photos June 2016)

big toe and the other toes in feature F.0048, left by the first (165 cm tall) individual described. This print anomaly was not caused by the substrate but represents some form of foot deformity or a missing toe. This is confirmed by the same impression left in each right footprint. This abnormality is not seen on the left side.

Context 1, the Top Layer

Here the footprints were left by six species. A small flock of cranes represent the greatest number of prints left by any one species. The footprints in this context are widely dispersed, but the crane prints in the southern end of the bed shows their random movements as they foraged for food buried in the silt. Their bill probes left distinctive marks as small oval shapes in the mud amidst their footprints (Fig. 16.4). Bird species are also represented by the oystercatcher, the most common seabird recorded at Formby Point.

Roe deer are well represented in this context, accounting for four sets of prints, indicating that this location was quiet enough at times to enable the wary roe deer to feel safe in the open landscape. This interpretation of composure is accentuated by the footprints of two adult roe deer that travelled across the bed towards the sea at a steady walking pace. One roe deer was slightly larger than the other (Table 16.4). Both had hooves larger than adults of the extant breed (which have hoof prints which average 4–5 cm long and 3–4 cm wide). Of the four sets of roe deer prints, two indicate movement towards the northwest and two towards the southwest, indicating travel towards and back from the seaward edge of the bed where they may have been drinking the backish water flowing through the channels at the edge of the mudflat. Of the animal species present on the beds at Blundell Path, roe deer and red deer represent the greatest numbers and were clearly prolific in this wetland area during the Mesolithic period.

Fig. 16.4 A photogrammetric plate of the crane prints and their bill scrapes at the southern end of Blundell Path C. The scale rod shows 1 m. (Photos June 2016)

Table 16.4 The size of the hoof prints made by two roe deer in context 1 at Blundell Path C (cm)

Roe deer	Feature	FL	FW	FD
Context 1	F.0024	9	7.5	2
	F.0025	9	7.5	2.5
	F.0026	8	7	2.4
	F.0027	8	6	3
	F.0028	8	7	3.2
Context 1	F.0009	8	8	2
	F.0010	7.5	6.5	2.5
	F.0011	6.7	6	2
	F.0012	7	8	2
	F.0013	7	6	3
	F.0014	8	6.5	4.5
	F.0015	8	5	4

FL foot length, *FW* foot width, *FD* foot depth

The lone red deer trail showed a small animal moving northeast (Fig. 16.2, feature F.0051). The single wild boar trail is the only confirmed recording of this species at Formby, although other scholars have reported the possibility of its presence (pers. comm. Roberts). Apart from the group of crane prints, there were no visible connections between the individual sets of footprints between the various species. All the hoof and footprints show movement at a steady walking pace in an undisturbed environment.

The two sets of human footprints in this context were eroded to the extent that the impressions were shallow and the foot shape indistinct with no fine internal footprint details remaining. One set showed a track of five footprints, the clearest of which measured 25.5 cm in length suggesting a person 171 cm tall (F.0031, F.0034). This person travelled north along the mudflat. The other track (F.0036) was made by an adult of approximately 186 cm tall, and this broad footprint at the level of the metatarsal heads suggests a male (Fig. 16.5). This person travelled east back to dry land. Due to the amount of erosion of these footprints, the footprint lengths used to calculate height of each individual are variable (Table 16.5) and therefore give a range of possibilities. Some footprints also show slippage of the foot which further complicates estimates of height using these indistinct impressions. Therefore, although the clearest footprints have been taken as the approximate height of the individual, these calculations can only be estimates at best.

The difference in detail between the human and faunal prints in this context (compare the impressions in Figs. 16.4 and 16.5) could be due to humans being present when the mud was hardening so that the footprint was not captured in detail. Erosion by the incoming tide could have further erased the detail.

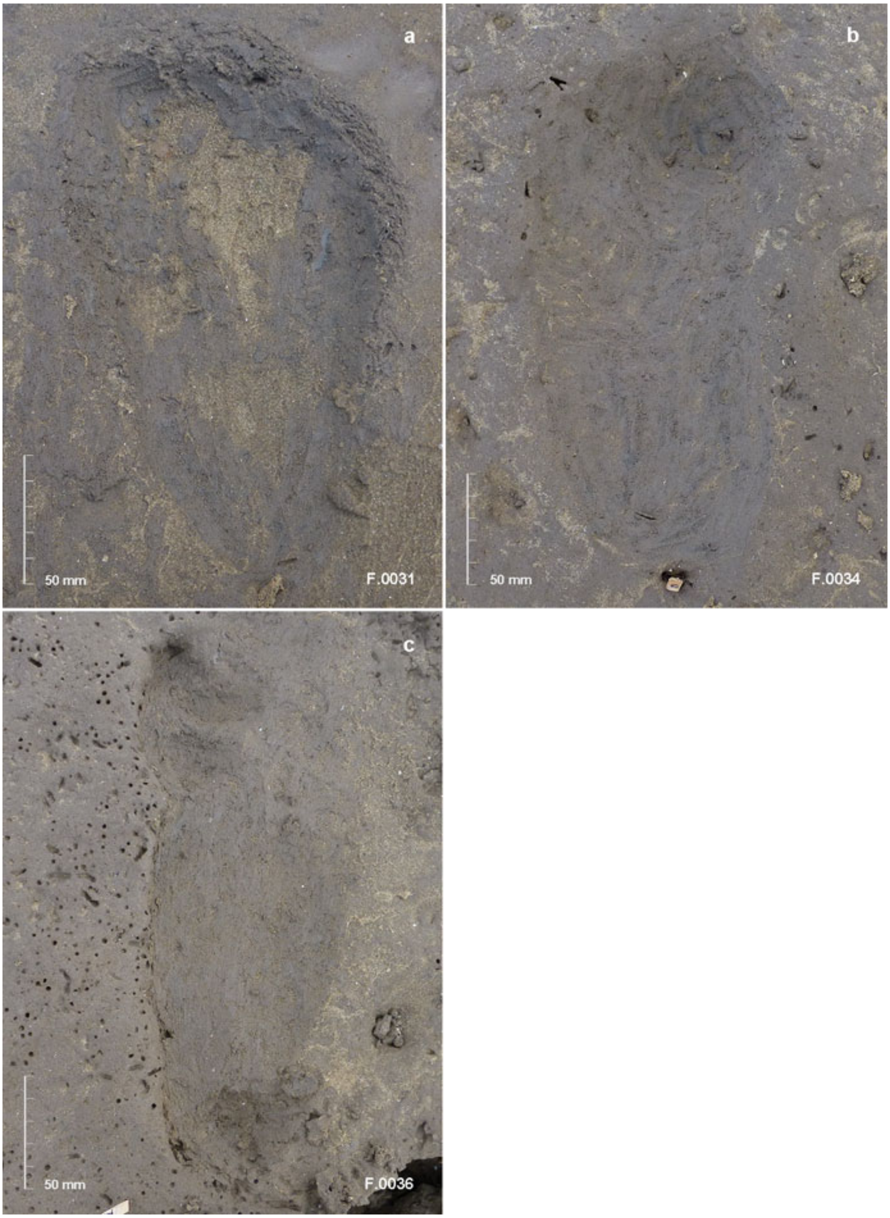

Fig. 16.5 The two sets of footprints left in context 1 Blundell Path C; (**a**) and (**b**) the two clearest footprints left by person 1 (F.0031, F.0034); (**c**) the clearest footprint left by person 2 (F.0036). (Photos June 2016)

Table 16.5 Measurements from the human footprints in context 1 (cm)

Context	Feature	FL	FW	FD	H
Human 1	F.0031	32	13	2	153
	F.0032	21	10	1	134
	F.0033	20	11	1.3	128
	F.0034*	25.5	11	3	171
Human 2	F.0035	23	8	3	153
	F.0036*	28	10	2.5	186

FL foot length, *FW* foot width, *FD* foot depth, *H* height, * clearest print

Activity on the Mudflats

Faunal Behaviour in the Intertidal Zone

The faunal imprints contained within each context offer a snapshot of activity which occurred during the drying process of the silt. However, some knowledge of the habits of the different species present at different states of the tide enables us to make a number of interpretations about the activity which occurred in this bed. For instance, the red deer and roe deer would only have been visible on the bed at dawn and dusk unless a particularly quiet interlude during the day could have enabled them to feel safe when exposed on the mudflats. The wild boar would not have been on the saltmarshes at the same time, preferring instead to be active during the night, foraging from dusk until dawn in the undergrowth nearby and only venturing onto the saltmarshes to wallow in the mud during the day (Overton and Hamilakis 2013). Humans, however, could have been present at a similar time to the deer but were most likely to have been most active during the middle hours of the day, at the same time as the cranes and oystercatchers. The cranes are present in some numbers and may have nested in the alder trees fronting onto the saltmarsh coming down on them to forage for food. They are found in each Mesolithic bed, showing their presence throughout this time but not later during the Neolithic. Although not recorded in this bed, the aurochs was present at Formby and would have been active during the day. Known as a wetland specialist (Hall 2008: 190), the aurochs would have fed on young reed shoots and wallowed in the mud (Aurochs footprints have been recorded in the other Mesolithic beds at Blundell Path).

In this Blundell Path C bed, in context 1, it can be hypothesised from an interpretation of the depth of the footprints, that the roe and red deer and possibly also the cranes were present very early in the day at dawn when the mud was still saturated shortly after the turn of the tide. This enabled clear, deep, sharply cut impressions of each hoof and claw to be captured in the mud. The humans, however, were present some time later when the mud had had time to dry. This reduced the depth and details of their footprints which were also then rapidly further eroded by the incoming tide, before being capped with further sediment and sealed as the bed accumulated. When the footprints are interpreted using a range of information regarding the habits of differnt species and the appearance of the footprints themselves, a picture of movement in the intertidal mudflats is gained and the changing nature of activity on the mudflats better understood.

Many of the trails of footprints left by different fauna suggest a familiarity with this environment that enabled them to take advantage of the intertidal muds and marginal vegetation. Here, animals moved obliquely to the edge of the sea, thus using the terrain to travel through. This may have been because it was easier walk along a mudflat than travel further inland where the wetland fen carr would have offered many obstacles. The openness of the saltmarshes would also have afforded an awareness of the presence of other species and, at times, would have provided an early warning of potential danger. At Blundell Path C, the very alert roe deer travelled at a walking pace, but in other beds they frequently travelled at some speed as if escaping from a threat. Apart from humans though, predator species are not noted at Blundell path C. However, the presence of wolf/dog and lynx has been noted in the other Mesolithic beds at Blundell Path, so they were almost certainly, in the proximity of the mudflats.

In summary, the intertidal environment was in a constant state of flux. Here we have a sense of continual movement on and off the marshes at different times depending on the state of the tide and the habits of the animals. Overall though, an impression of familiarity and comfort in this intertidal area is gained, where there was minimal perception of threat despite the possibility of predators being nearby. A return to the area by the same species over many generations also shows patterns of activity which remained consistent over a long duration, despite the ever present challenges of an existence within such a dynamic environment.

Humans in the Intertidal Zone

The human footprints in each of the three contexts in this exposed area of the bed discussed, demonstrate a human presence on the marshes over the several hundred years of its existence. People of all ages are represented, although not recorded in each context. For instance, in context 3, four young children and a 14 +/adult are represented. In context 2, adult footprints dominate (14 people are represented here). In context 1 there are only two adult trails. However, these footprints all show persistent activity focussed on this area in the intertidal zone for over at least 400 years at the end of the Mesolithic period.

As previously mentioned, one notable feature in each context is the lack of overlap of any of the footprint impressions despite their close proximity. This is particularly apparent in context 2 (Fig. 16.2). Here also, adults travelled both along the mudflats and directly out towards the sea. However, in this particualr area, people appear to have been progressing from several directions to converge at the seaward edge of the mudflat. In context 1, adults still walked along the mudflats often progressing notrhwards, in reverse of context 2. They also walked east towards land

and away from the edge of the sea. However, despite these differences in orientation, they still may have been engaged in the same activities, like the fauna, generations later.

Experience in the Intertidal Zone

The depth and uniformity of the base of the footprint impressions showed that these people moved through the mud at a steady walking pace, fully aware of others around them and the semi-liquid environment in which they walked. This awareness would have been accentuated by the visibility of other footprint tracks left in the mud, read as clues to the whereabouts or intentions of other beings (Ingold 2010: 131) whose temporal and territorial rhythms would have been familiar and understood (Brittain and Overton 2013; Haraway 2003; Ingold 2010, 2018). Later return along the same pathways would have reinforced impressions of the location, both of the path and its setting in the saltmarsh (Ingold 2018). The dynamics of erosion would also have exhumed beds with ancient footprints and made them visible to all who walked in the mudflats. At these times, local knowledge, connections to the past and memories of the easiest paths and routes across the mudflats as well as past encounters with other humans and animals would have strengthened a feeling of co-habitation and a sense of bonding with others. This would have been particularly keen between the animal species and humans that shared the same rhythms (Brittain and Overton 2013; Ingold 2010; Sturt 2006; Wieckowska-Lüth et al. 2018).

The footprints which show adults travelling west towards the sea could indicate seafaring activity – fishing for young fish in the shallow waters along the edges of the saltmarsh, or possibly embarking on sailing trips along the coastline on the protected waters at its edge. Knowledge of the seasonal tides and currents, combined with periods of calm weather, would have enabled this to be a regular occupation (Robinson 2019: 150) and could have enabled regular contacts to be made with other communities of people living along the coast. From the shores of Formby, the North Welsh coast can be clearly seen, appearing easily accessible across the River Mersey, which during the late Mesolithic period would have been a small estuary (Fitch and Gaffney 2011). Although dugout log boats have been recovered from Mesolithic sites such as Tybrind Vig, Denmark (Anderson 2011; McCartan et al. 2009; Robinson 2019), and Lough Neagh Co. Tyrone (McCartan 2004: 280), seafaring using curricles made from wood and hide have been shown to be more seaworthy (Callaghan and Scarre 2009; Robinson 2019) with the potential to travel across the Irish Sea from many locations, particularly in the summer months (Cobb 2008; Robinson 2019).

Evidence of Coastal Occupation

Close to Formby, on the foreshore at Rhyl (in North Wales, 4 km from Prestatyn) (Fig. 16.1: site number 8), intertidal footprints and a submerged forest have been recorded. A red deer antler mattock embedded in the silt of the forest was dated to 5640–5360 calBC (6560 ± 80 BP, OxA-1009; Bell 2007: 298). At Prestatyn, ten shell middens have been excavated at Nant Hall Road, only 1 km from the current coastline. These shell middens were situated at the Mesolithic margins of the saltmarsh and wetland area. The oldest are contemporaneous with the Oronsay middens and date from the late Mesolithic 4470–4050 calBC (5470 ± 80 BP, CAR-1424). They were largely composed of mussel shells (*Mytilus edulis*) that were mixed, in some deposits, with charcoal, small numbers of periwinkles (*Littorina littorea*) cockles (*Cerastoderma edule*), fragments of flint, red deer bones and fractured beach pebbles (Thomas and Britnell 2007: 272). Here, small-scale, short-term activity rather than a year-round occupation took place (Bell 2007: 311) and the middens were the result of small fires and stone tool production necessary to process and cook shelfish and red deer. Although not present in the archaeological record at Formby, the activities indicated by the Prestatyn middens would also have applied to the contemporaneous population based around the coastline of North West England. However, along this coastline, only the footprints remain as evidence of Mesolithic lifeways.

Hunter-Gatherer-Foragers at Formby

The footprints manifest intimate traces of past actions, and their distribution in each context has provided a portrait of contemporaneous activity in the intertidal reaches. They are therefore a rich source of information on the human and animal behaviours that took place at a particular time, as described. However, to make some nuanced interpretations on particular aspects of human activity, it has been necessary to use ethnographic analogy to make comparisons between the footprints of the Mesolithic population and modern populations for whom footprints form an important source of information - extant hunter-gatherer groups. For them, information contained in the footprints can provide clues to who was in the vicinity, how long ago and whether alone or in the company of others (pers. comm. Thui Thao, /Ui Kxunta, Tsamgao Ciqae Jul'hoan tracker*)*. This information is pertinent to both animals and humans. Patterns of walking can be interpreted and individuals discerned through their gait after they have moved through an area, and the activity in which they were engaged read by their footprint trails some time later.

This type of enquiry has been invaluable to assist with the interpretations made regarding the Formby footprints and particular patterns of movement reflected in some individual tracks or groups of trails. For instance, two sets of human footprints, one in Blundell Path C and another in Blundell Path A, show adults walking and then stopping, standing with their feet apart firmly planted in the mud in order to look around. This type of movement replicates that of the Bartek tribe in Malaysia who are opportunistic hunters. Their method of pursuing quarry is to proceed with care for a few steps and then stop and silently observe what prey might be in the vicinity.

This relies on an awareness of the fauna that might potentially be present within the local environment and a skilled ability to walk carefully so as not to make noises that would disturb any targets in the surrounding area (Laws 2017).

Other footprint trails at Formby show large adults walking alone along the edge of the mudflats. Within the same context however, other footprints were made by younger people who appeared to have been moving parallel to the adult. Occasionally these human trails are associated with very large red deer prints and sometimes crane prints, which can be observed running both parallel and across the human footprints. It is possible in these scenarios that, as with the Juǀ'hoan, older experienced teenagers and adults were leading scouting expeditions across the mudflats in search of quarry. Ethnographically, in the Juǀ'hoan community, male youths accompany elders in order to learn hunting techniques. One explicit purpose of these expeditions is to learn to read the clues displayed by footprints and information contained in spoors (pers. comm. Juǀ'hoan hunter 2017).

In the constantly changing mudflat terrain at Formby, adults may also have been actively engaged in familiarising young children with the intertidal environment, the safe areas and the more dangerous ones nearer to the sea, the state of the tide and the preferred locations of particular species at particular times of the day. This would have enabled hunting expeditions to be more successful and people of different ages to be actively involved as part of a purposeful group. Ethnographically, these behaviours can be seen in the Yamana tribe who teach their young to imitate adult hunting activities. These are an important part of community life, where replication of adult behaviours by juveniles helps to bolster the social reputation of adults and assists with the formation and maintenance of social norms and cooperative behaviours (Santos et al. 2015: 2). In the Hadza tribe, children as young as three are taught to forage and contribute food to the immediate family, spending up to half the day away from their parents with their peer group (Lozoff and Brittenham 1979). At Formby, the footprints show that people of all ages and both sexes engaged in activities on the mudflats, but most were undertaken by small groups of people working co-operatively together with children under the watchful supervison of their elders.

In the bed at Blundell Path C, the footprints show a healthy population. However, one adult footprint trail shows a missing second toe (Fig. 16.3 F.0048). This is the most common foot abnormality seen in the Mesolithic population. However, in two cases, in the Mesolithic bed at Blundell Path A, the little toe (at the fifth metatarsal head) was fractured and was left to heal at an oblique angle to the other toes. Occasionally, disability has also been indicated by a lack of alignment of the toes which have left an odd impression in the mud (and could be due to club foot (*talipes equinovarus*). However, the vast majority of footprints show a population with healthy feet and no skeletal lower limb abnormalities.

Conclusion

This paper has discussed the transient exposure of a late Mesolithic sedimentary bed at Formby Point on the Sefton Coast of North West England which was formed over a period of approximately 400 years. During this time only three episodes of footprint preservation within its layered stratigraphy were identified. The particular atmospheric and tidal conditions necessary for footprint retention have been described as has their appearance in the bed at Blundell Path C after their recent exposure by the sea on the foreshore at Formby. The rapid capture of the footprints in antiquity has meant that daily activity on the saltmarshes can be seen and interpretations can be made of engagement in the intertidal zone at different times. For instance, it is notable that in contexts 1 and 2, despite a potential separation of several hundred years, the species present and the activities in which they were engaged remained very similar. Of note is the fact that several species used this mudflat to travel along the coast and not just to access the resources of the intertidal zone or the shallows of the sea. This may have been due to the ease of moving over the mudflats in contrast to the neighbouring wetland fen-carr landscape.

The patterning of the footprints suggests a shared environment in which daily activity varied with the temporal rhythms of the tides, weather and other species on the mudflats. The diurnal habits of ungulates, birds and wild boar would have been known to the humans who appear to have respected the footprints made by others. This has provided a unique insight into the relationships that operated between people and animals and has moved us away from the interpretation that people were simply accessing the intertidal area for food procurement. In an otherwise empty archaeological setting, these footprints illustrate the importance of the intertidal zone during the Mesolithic period in North West England. It presents an intimate and unique record of life not otherwise available through other forms of the archaeological record.

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Chapter 17
Prehistoric Human Tracks in Ojo Guareña Cave System (Burgos, Spain): The Sala and Galerías de las Huellas

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Abstract In 1969, members of Grupo Espeleológico Edelweiss discovered the Sala and Galerías de las Huellas in Ojo Guareña Cave system (Burgos, Spain). These contained hundreds of ancient human footprints, preserved in the soft sediment on the floor. These footprints represent the tracks of a small group of people who walked barefoot through these complex passages in the cave. Owing to the difficult compatibility of the documentation and preservation of these prints, it was not possible to study them before the development of new non-invasive remote sensing techniques. However, since 2012 optical laser scanning and digital photogrammetry have been used in Galerías de las Huellas, in combination with GIS techniques, to obtain a model of the cave floor, where the footprints and their internal morphology can be observed in detail. We have identified over 1000 prehistoric human footprints and at least 18 distinct trackways through the passages, which could have been left by around 8–10 individuals. Since 2016, an archaeological field study has been conducted in this sector, in order to determine and explore its surrounding area and find other archaeological evidence that may be directly associated with these tracks. Numerous remains of torches are preserved on the walls and floor in the immediate surroundings of the footprint sites. Some of them have been dated, which has

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revealed the intensive use of this underground landscape from the Upper Palaeolithic to the Mesolithic-Neolithic. However, the remains in Sala and Galerías de las Huellas date solely to the Chalcolithic, around 4300 calBP.

Keywords Human footprints · 3D laser scanner · Ojo Guareña Cave system · Exploration · ^{14}C data · Chalcolithic

Introduction

The Ojo Guareña Cave system, forming one of the most important underground systems in Spain, is located in the Cantabrian Mountains and the Upper Ebro Basin, in the north of the Province of Burgos (Spain) (Fig. 17.1a). This cave system developed in the northern flank of the Mesa-Pereda syncline (del Olmo et al. 1978), in the Coniacian (Late Cretaceous) limestone and dolomite unit. Ojo Guareña is an extensive multilevel cave system, formed by the connection of 14 caves and over 110 km of passages, distributed on 6 main interlinked levels, from a relative height of +70 m to the current level of the River Guareña (Grupo Espeleológico Edelweiss 1986; Ortega et al. 2013: 45–53).

The blind valley of San Bernabé ends at the Guareña sinkhole and contains a series of old fossil entrances perched at different heights above the River Guareña (at 692 m a.s.l.) that, together with the River Trema (karst discharge zone) and the Villamartín stream, has shaped this singular karst landscape listed as Natural and Cultural Heritage of Spain.

This karst complex contains an impressive record of human activities from at least the Upper Pleistocene. The archaeological sites were discovered at the same time as speleological explorations were taking place. The diversity and variety of archaeological remains, in more than 80 sites (Ortega and Martín 1986; Ortega et al. 2013: 164–236), include living areas in cave entrances, rock art, burials, human bones, grave goods or different archaeological objects, which demonstrate the use of this cave landscape from the Middle Palaeolithic to the Middle Ages.

The hundreds of human footprints in the soft sediment on the floor of Sala and Galerías de las Huellas I and II are among the most singular and vulnerable archaeological sites in the cave system. They were found in 1969 by members of the Grupo Espeleológico Edelweiss, during the survey of one of the most labyrinthine sectors of the system, called Dédalo Oeste (Uribarri 1969; Osaba 1969: 305–309; Rubio 2001), which is related to the geomorphologic evolution of the Guareña blind valley and San Bernabé cirque.

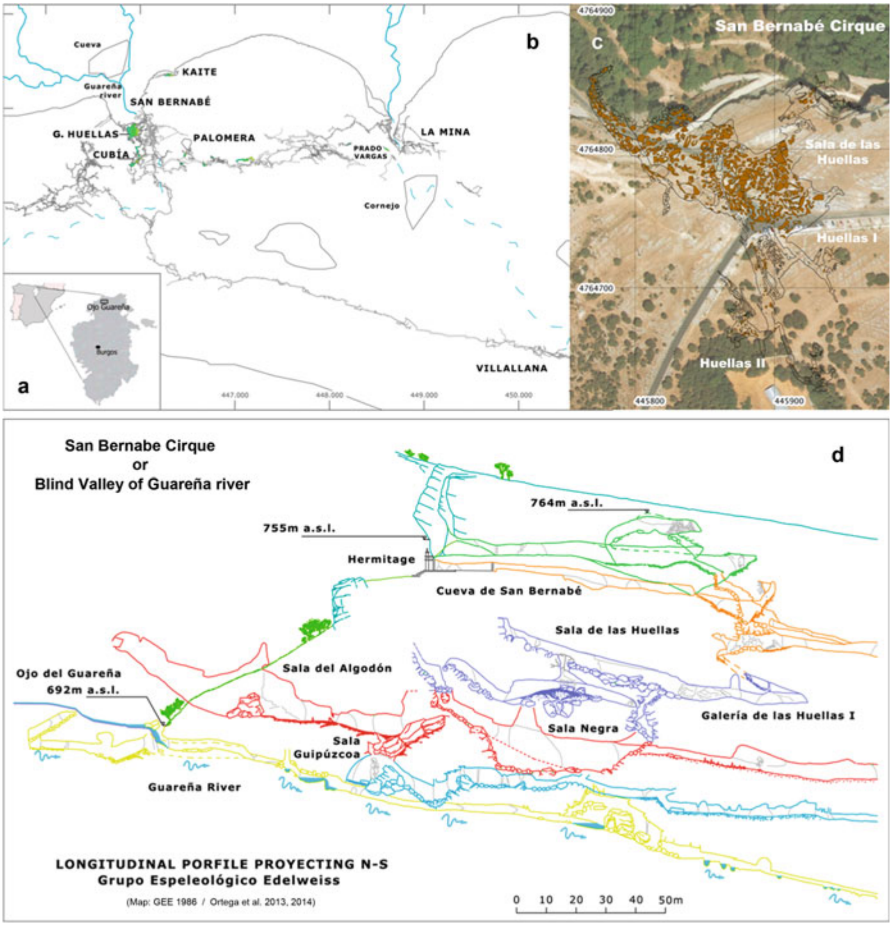

Fig. 17.1 (**a**) Situation of the Ojo Guareña karst in the Iberian Peninsula; (**b**) location of the Sala and Galería de las Huellas sites in the Ojo Guareña complex, with reference to the main caves; (**c**) map of Sala and Galería de las Huellas with an orthophoto of the PNOA (IGN, Spain); (**d**) longitudinal profile, projection N-S, of the Ojo Guareña Cave system in the blind valley of the Guareña River. (Modified from Grupo Espeleológico Edelweiss 1986; Ortega et al. 2013, 2014)

The Site

The Sala and Galerías de las Huellas formed in the third karst level known as Dédalo Oeste. It covers an area of 5652 m^2 and connects with Laberinto Otilio and Sala Negra in the fourth level. This third level is perched at 40 m above the Guareña River level and comes very close to San Tirso and Bernabé Cave, whose passages belong to the second karst level (Fig. 17.1c). Their western passages descend until they link topographically with the end of Galería de las Huellas I (GH I), although without a physical connection because of the collapse of the cave ceiling and the growth of a large speleothem (Grupo Espeleológico Edelweiss 1986, Annex mapping 153–3; Martín 1986: 141–147; Ortega and Martín 1986: 342–343). Additionally, sediment on the San Bernabé hillsides has completely silted up the old entrances in this sector, so current access is from Palomera Cave, 1250 m to the west.

Sala de las Huellas is an enormous chamber 80 m long, 50 m wide and more than 5 m high, with large boulders that have collapsed from the ceiling and obstruct transit (Figs. 17.1 and 17.2f). Galerías de las Huellas I and II (GH I and GH II) are located on the south side of this chamber (Figs. 17.1b, 17.2c, g and 17.9a). The first gallery (GH I) consists of a main passage, 60-m-long and a 25-m-long side passage (Figs. 17.2g and 17.3d). The main axis of the second gallery (GH II) is approximately 100 m long. Both galleries are about 5 m wide and 4–5 m high (Fig. 17.3f, g).

The floor of these galleries is characterized by interior cave sediments, with a loamy texture and composition mainly of calcite, quartz, feldspar and to a lesser extent phyllosilicates (Benito-Calvo et al. 2013: 220).

Small channels have incised the floors of both galleries, particularly in the final section of GH II. The entry sections have calcite crusts, which do not register any footprints. On the contrary, the deposition of fine calcite crystals makes it difficult to recognize many of the impressions, especially in the GH I gallery.

The human traces located in these passages are very well preserved in both galleries, thanks to the protection measures that were taken at the time of the discovery, limiting access to the sites and waymarking alternative routes (Fig. 17.3). But unfortunately the difficulty of transit in the large chamber (Sala de las Huellas) led to the destruction of many traces, and only a few footprints have been preserved on large boulders (Figs. 17.2f and 17.3a).

The cave survey in this sector was finished in 1970, and Almagro invited André Leroi-Gourhan to plan a project to study the footprints, including photogrammetric analysis. Unfortunately, it never materialized. Plaster casts of two footprints were made at that time, and a sediment sample from the first passage was sent to León Pales and Michel-Alain García (Ortega et al. 2013: 178–182; 2014: 43–44). In addition, charred wood remains were collected from Laberinto Otilio in the lower level, at the bottom of a shaft from GH I, and interpreted as thrown or fallen from that gallery. They were dated to 15,600 ± 230 BP (Delibrias et al. 1974: 53).

New surveying in 1981 (Grupo Espeleológico Edelweiss 1986) achieved an acoustic connection between GH I and the southwestern passage in San Bernabé Cave (Fig. 17.1b). This connection motivated the dating of the speleothem plug that separates the two caves. Rainer Grün, who was visiting Spain to sample caves for his PhD, dated the speleothem to about 175 ka (pers. comm. Adolfo Eraso). This age prompted a new study of the footprints and their superpositions, in order to determine the direction of the prints through photographic and photogrammetric analysis (Galaz et al. 2000). These studies showed that the prints followed an entry and exit route within Sala de las Huellas (Galaz et al. 2000; Ortega et al. 2013: 178–182) and that they were, therefore, not connected with the passage in San Bernabé Cave.

This new study also identified traces of small carnivores (mustelid-type) especially in the eastern gallery (GH I), in whose initial section bear claw scratches are also preserved on the walls. Some charred wood remains have also been observed on

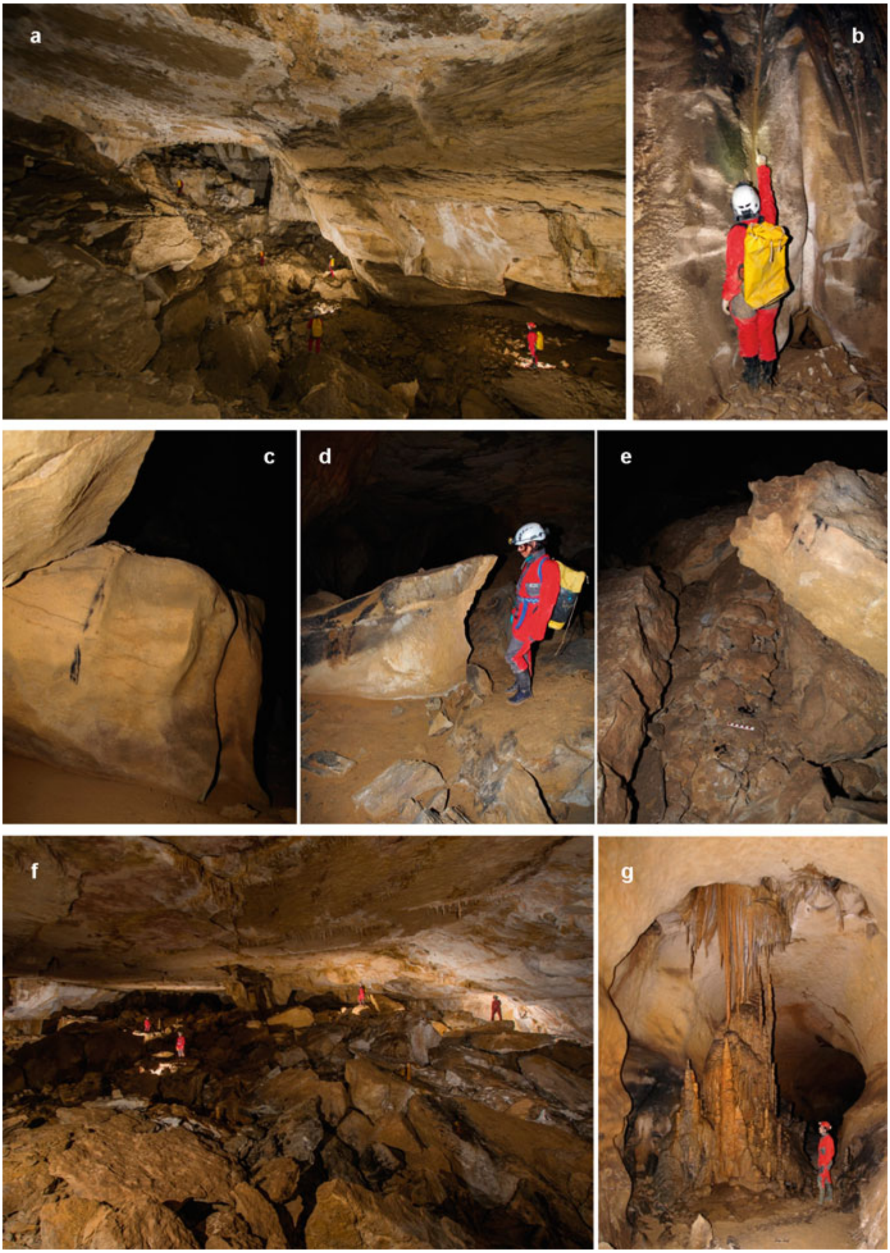

Fig. 17.2 (**a**) General overview of the Sala Negra; (**b**) charcoal samples (No 11 and 12) located in the connection shaft between Galería de las Huellas I and Laberinto Otilio; (**c**) charcoals in the block (No 10) of Laberinto Otilio; (**d**) block decorated with torch remains and charcoals in the ground (No 14, Laberinto Otilio); (**e**) torch remains on a block, with charcoals in the floor (No 4), of the Sala de las Huellas; (**f**) general view of Sala de las Huellas; (**g**) cross section view of the beginning of Galería de las Huellas II. (Photos (a) P. Carazo-Grupo Espeleológico Edelweiss; (**b**–**f**) M.A. Martín -Grupo Espeleológico Edelweiss)

Fig. 17.3 (**a**) Human footprints on a large block of the Sala de las Huellas; (**b**) remains of a torch under a block of Sala de las Huellas (No 1); (**c**) detail of a footprint of Galería de las Huellas II; (**d**) view of Galería de las Huellas I; (**e-g**) several views of the traces of the Galería de las Huellas II. (Photos M.A. Martín-Grupo Espeleológico Edelweiss)

the walls and floors of Galerías de las Huellas, although charcoal remains are more numerous in the lower passages (Laberinto Otilio and Sala Negra). In 1999, a charcoal sample from the western Galería de Las Huellas (GH II) provided a date of 3820 ± 50 BP (pers. comm. Juan Luis Arsuaga). This date was very different from the Palaeolithic date mentioned above and showed that the passages had been entered again in recent prehistory.

Access to a Complicated Sector

It was traditionally thought that the access to Galerías de las Huellas during prehistory was from the blind valley of the Guareña River or the San Bernabé cirque, given its obvious proximity (Ortega and Martín 1986: 342–343). Later, the possibility of access from San Bernabé Cave was discarded, because of the age of the collapse now blocking the cave, which is sealed by a thick speleothem (Ortega et al. 2013, 2014). Finally, direct access from outside to the Sala Negra has also been discarded, given that the current blockage of boulders, a consequence of the receding hillside, seems very stable and was already consolidated in the Neolithic, according to the dates obtained in the framework of this project (Table 17.3) (Ortega and Martín 2019).

In contrast, recent investigations into the archaeological evidence inside Palomera Cave, currently the main entrance to the Ojo Guareña Cave system, indicate that transit inside this large cave was much more frequent and intense than previously thought. This is evidenced by the succession of archaeological remains that extend up to almost a kilometre and a half from the current entrance, towards both the east and the west, belonging to different periods from prehistory to the Middle Ages.

On the route from Palomera Cave to the surroundings of Las Huellas (Fig. 17.4), several archaeological remains have been documented in the passages of Museo de Cera, Galería de la Escalada and Galería Macarroni, with confirmed prehistoric dates. The distance from the start of the latter gallery to the Sala del Cacique is barely 100 m; it is very comfortable to walk through and currently included in the tourist route. It is a further 100 m from this point to the first side passage in Galería del Cacique, which leads to Laberinto Otilio. This is the beginning of the sector studied here, where abundant charred wood marks on the walls and pieces of charcoal on the loamy floor and boulders have been identified.

There are several points of access to the Sala and Galerías de las Huellas in this area. One of them starts at the northeast end of Sala Negra, which finishes in an impressive boulder blockage (Figs. 17.2a and 17.9b), where the presence of charcoal confirms the transit, at least in the Early Neolithic (Fig. 17.9b, number 13 and Table 17.3). Another access point, which is a little more comfortable, is through a side passage that ascends gently towards Laberinto Otilio until Sala de las Huellas can be reached by climbing between boulders. As already stated, the entire route is full of charred wood marks and pieces of charcoal (Figs. 17.2b–g and 17.9).

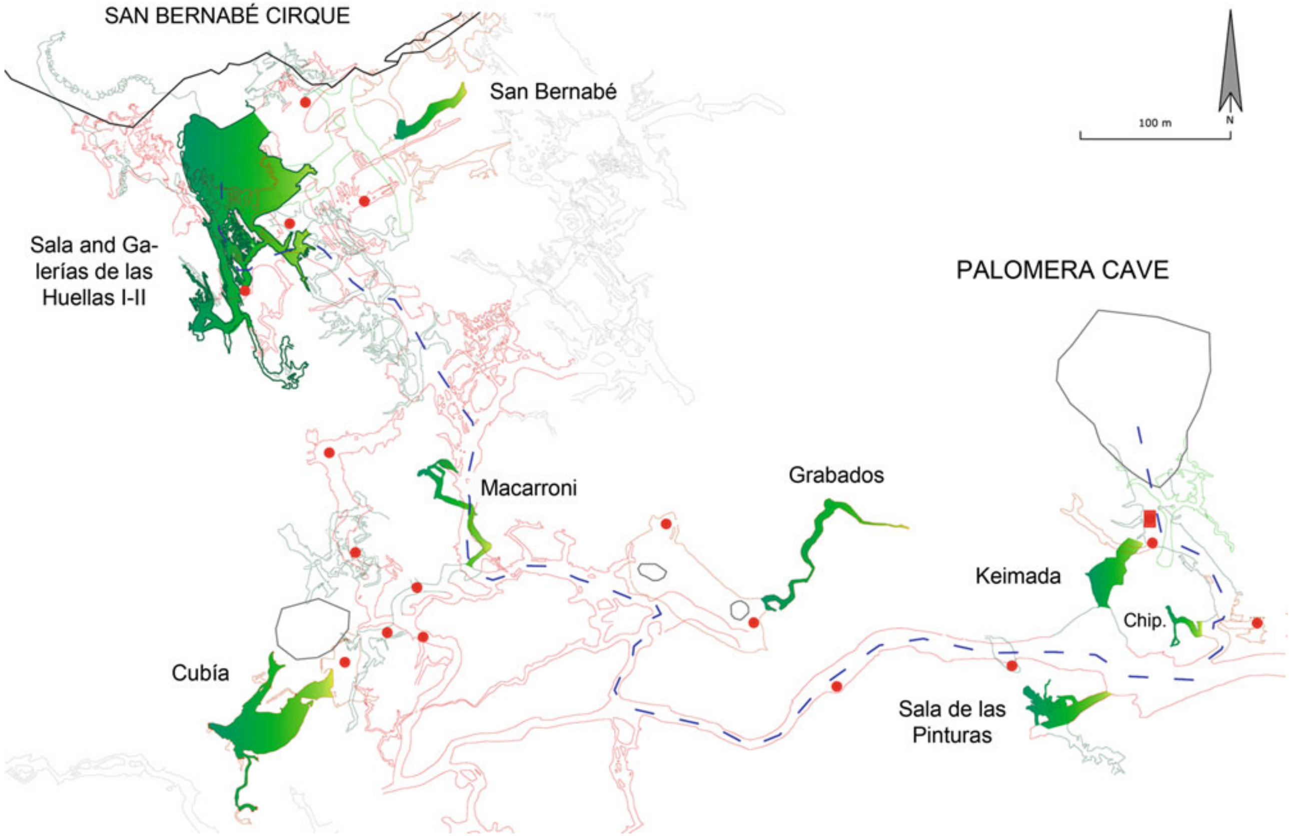

Fig. 17.4 Map of the possible access route to the human footprint site. The *dark green* passages represent the third level of Palomera Cave and the *dark red*, the passages of fourth level. The *greenish shadings* indicate the sites with rock art and the footprint site. The *red marks* refer to other archaeological evidences (habitats, burials, transit, etc.). The *blue dashed line* represents the route of access from Palomera Cave. (Modified from Grupo Espeleológico Edelweiss 1986; Ortega et al. 2013)

This evidence suggests that, after a 1200-m-long route of easy transit through large underground passages, prehistoric humans explored a sector of Palomera Cave that is more complex because of its large size (5652 m^2), intricate topography (mazes) and instability (with large embedded boulders that hinder transit). Despite this danger, at least one of the human groups that walked through this sector could have reached the upper level of the Sala and Galerías de las Huellas.

Materials and Methods

Footprint Documentation

Human footprint sites are not very common in the archaeological record because of the special requirements for their formation and preservation, although the number of cases has increased over time (Lockley et al. 2008; Bennett and Morse 2014a). These footprints provide information on human behaviour regarding the environment and on the nature of the sediments, where fine-grained substrates favour the formation and preservation of the prints (Bennett and Morse 2014b). The difficulty in balancing the documentation and conservation of these traces has conditioned their study for many years, and it only became possible with the development of non-invasive digital remote sensing technologies applied to archaeological research and heritage management (Bennett et al. 2013; Ashton et al. 2014; D. Webb et al. 2014; Citton et al. 2017).

The study of the human footprints in Ojo Guareña started in 2012. It focused on accurate three-dimensional reconstruction of Galería de las Huellas I and II, using 3D laser scanner technology and GIS methodologies (Benito-Calvo et al. 2013; Ortega et al. 2014). Sala de las Huellas was excluded from this work because of its topographic irregularity and the difficulty of transit in such a chaotic space.

The three-dimensional mapping of this site was achieved with a ScanStation C10 Leica laser scanner, with a maximum flight range of 300 m, 4 mm accuracy. Seventeen high-resolution scans were performed (5 mm at 10 m), seven in GH I and ten in GH II. The point clouds obtained were joined by a common reference system with reference targets, obtaining a mean error of 1 mm, with final point clouds that reached resolution means of 3 mm in GH I and 4 mm in GH II.

The models of the obtained surfaces were exported to GIS format, generating high-resolution digital elevation models (DEM) that show the topographic relief of the galleries with sufficient resolution to analyse the shape and distribution of the tracks (Benito-Calvo et al. 2013). The terrain roughness index (TRI) model (Riley et al. 1999) allows the irregularities of the floor to be differentiated (white colours) from the softer areas (black colours) by stressing the depressions of the best preserved footprints according to their internal morphology (sole, heel, toes, etc.).

Footprints and Trackways

This precise cartography allows the position of the tracks to be observed in relation to the morphology of the passages by identifying not only the human footprints but also the topographic elements (boulders, rocks, speleothems, crusts, channels, etc.) that form the surface and condition the presence of human footprints. This enables the reconstruction of some of the paths and movements made by these ancient visitors. All the measurements and most of the observations of the footprints have been made over the resulting three-dimensional and cartographic restitution with AutoCAD software, as it is not possible to measure them in situ, owing to the nonconsolidation of the sediment recording the traces.

Once the footprints were scanned, each of the prints was individualized.

The maximum length (FL) was measured parallel to the longitudinal axis of the footprint, while the width of the ball (FW) and the width of the heel (FHW) were measured perpendicular to the FL axis. The longitudinal axis was determined following the technique of D. Webb et al. (2006a).

From the FL and FW measurements, the footprint index (FI) was calculated, which consists of the ratio between foot width and foot length: $\mathrm{FI} = \mathrm{FW}/\mathrm{FL} \times 100$.

The arch index (AI) is a widely used measurement for the purpose of classifying the foot type according to a high ($\mathrm{AI} \leq 0.21$), normal ($\mathrm{AI} = 0.21$–0.26) and flat ($\mathrm{AI} > 0.26$) arch (Cavanagh and Rodgers 1987). AI was measured according to Cavanagh and Rodgers (1987), whereby a perpendicular line to the foot axis was used to divide the toeless area into equal thirds (Fig. 17.5a): rearfoot (A), midfoot (B) and forefoot (C) regions. Then, AI was calculated as the ratio of the area of the midfoot to entire toeless footprint area: $\mathrm{AI} = \mathrm{B}/(\mathrm{A} + \mathrm{B} + \mathrm{C})$.

Finally, arch angle (AA) or Clarke angle is defined as the angle between the medial border line of the footprint and the line connecting the most medial point of the metatarsal region of the footprint and the apex of the concavity of the arch of the footprint (Citton et al. 2017) (Fig. 17.5a). AA is a conventional measurement that classifies the internal longitudinal arch between tendency to flatness or pronation ($\mathrm{AA} \leq 31°$), normality range ($\mathrm{AA} = 31°$–$45°$) and tendency to cavus foot ($\mathrm{AA} > 45°$) (González-Martín et al. 2017).

Estimation of Height and Weight

Many studies support the use of foot length to obtain an individual's range of height, while body mass can be estimated by the correlation between foot width and body weight (D. Webb et al. 2006a; Ukoha et al. 2013; Atamtürk and Duyar 2008; Krishan 2008; Robbins 1986).

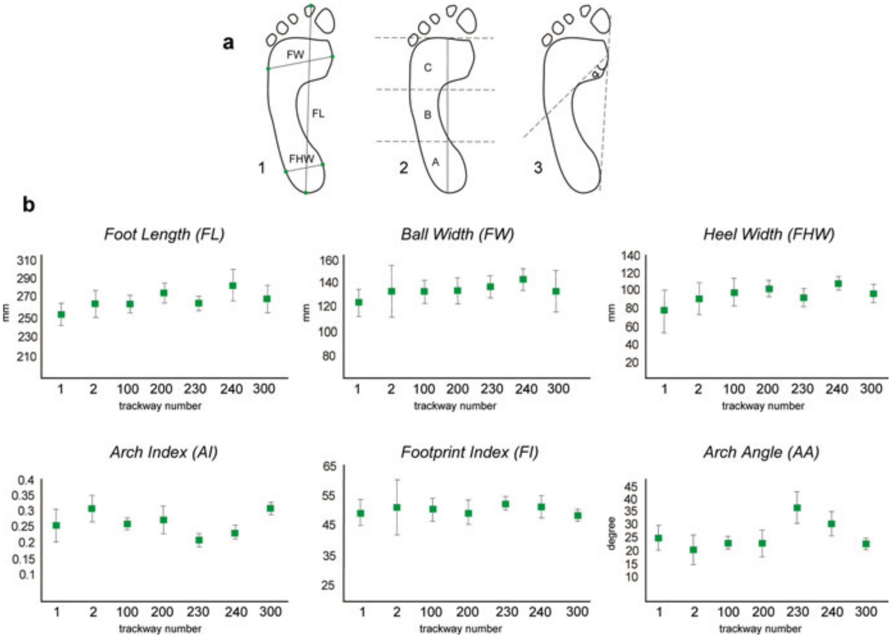

Fig. 17.5 (**a**) Morphological parameters used in the current study, (**1**) maximum foot length (FL), width of the ball (FW) and width of the heel (FHW), (**2**) arch index (AI = B/A + B + C), (**3**) arch angle; (**b**) average and standard deviation of all biometric variables used in the current study for each track

Chronology

Another objective of this project has been to specify the chronology of the tracks in order to contextualize the activities that took place in this sector of the cave, the deep zone over 1 kilometre from the current entrance of Palomera.

To study transit and use in this sector of the system in greater depth, since 2016 we have been conducting a project with the aim of surveying and dating the surroundings of the sector, including Sala and Galerías de las Huellas, on the third level of Ojo Guareña, and Galería del Cacique and its side passages, as well as Laberinto Otilio and Sala Negra, on the fourth level, i.e. lower than Huellas and the main level within the Ojo Guareña Cave system.

Sixteen organic samples were taken for radiocarbon dating. AMS dating of 15 samples was performed at BETA Analytic Inc., between 2017 and 2019. The Gif-1721 sample, dated at the ^{14}C Gif Radiocarbon Laboratory in 1974, completes Table 17.3.

Results

Footprints and Trackways

Although the study has not yet been completed, about 700 footprints have been identified and at least 8–9 entry trackways to GH I and about 10–11 exit trackways (Fig. 17.6). Many superimposed footprints follow an apparently chaotic pattern at the junction with a side passage. This may indicate that some people explored that passage, while the others waited in the main passage.

About 500 human footprints have been identified in GH II, as well as a minimum of 7 entry trackways and 11 exit trackways towards Sala de las Huellas. In addition, the new cartography shows that one of the visitors separated from the group to inspect one of the hidden corners of the gallery (Fig. 17.7).

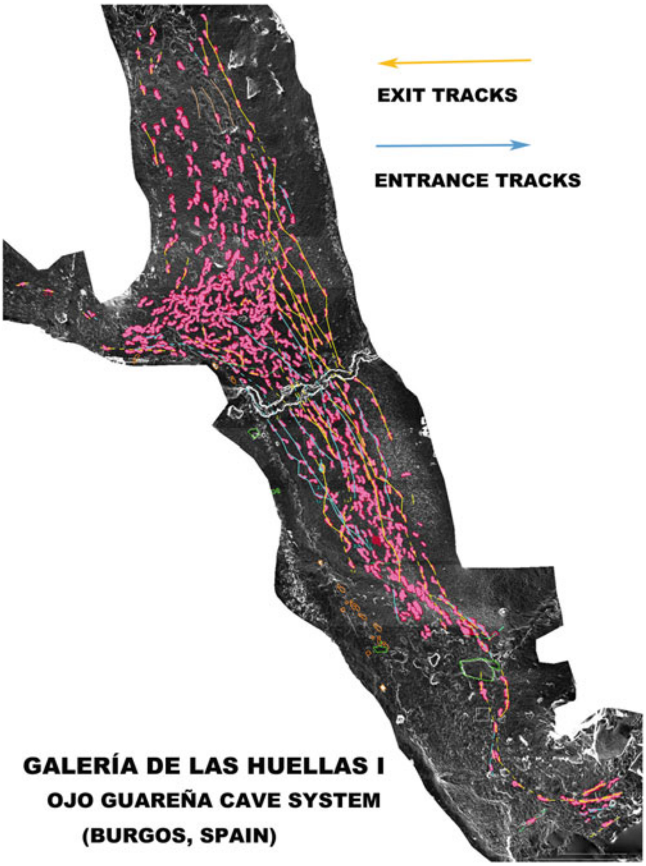

Fig. 17.6 Plan of the Galería de las Huellas I, from the scanner, with the identification of imprints and trackways

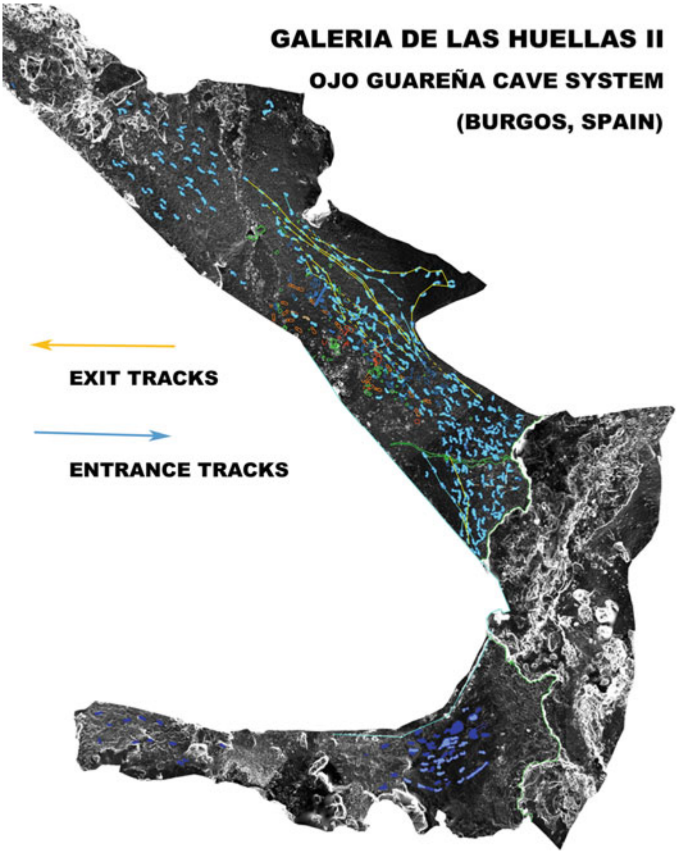

Fig. 17.7 Plan of the Galería de las Huellas II, from the scanner, with the identification of imprints and trackways

A preliminary study of 39 GH I footprints will be described. They are integrated in seven trackways in Galería de las Huellas I: two in an entry direction (trackways 1 and 2) and the remaining five in the exit direction towards Sala de las Huellas (Fig. 17.8 and Table 17.1). All these footprints are located on the sides of the passage and correspond to 22 right feet and 17 left feet. They are in an excellent state of preservation, with the identification of complete footprints with clear anatomical features (toes, balls, heels, etc.) in the form of a low relief in the soft loam sediment.

The measurements of the maximum lengths and widths of the footprints are given in Table 17.1.

The sample of footprints is characterized by a certain uniformity in foot length, with measurements ranging between 250 and 290 mm, resulting in average estimated heights of between 173 and 188 cm (Tables 17.1 and 17.2). This suggests that the footprints correspond to adult individuals, probably males. The foot width range shown in Table 17.2 varies from narrower traces, about 123 mm wide, to prints about

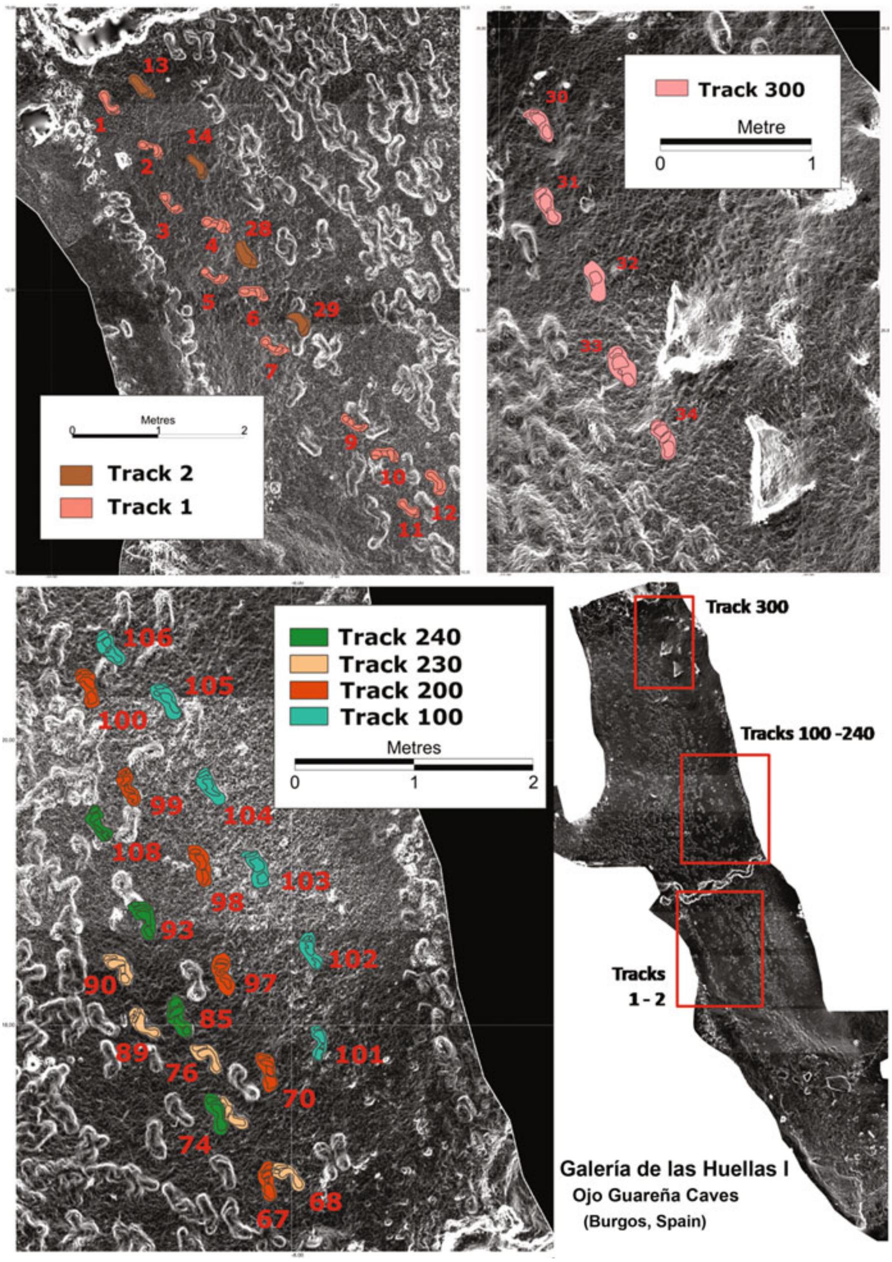

Fig. 17.8 Identification of the trackways and imprints analysed in this study. Galería de las Huellas I, Ojo Guareña Cave system

Table 17.1 Main measurements of the 39 footprints (grouped in 7 trackways) selected for this study, from Galería de las Huellas I (mm)

ID_Foot	L/R	FL	FW	FHW
1	R	251	112	79
2	L	247	129	84
3	R	247	111	81
4	L	263	128	76
5	R	259	118	88
6	L	256	134	76
7	R	266	122	80
9	R	247	106	77
10	R	257	139	109
11	R	226	121	84
12	L	255	138	11
13	R	273	112	100
14	L	258	119	82
28	R	272	155	113
29	L	245	147	72
101	R	249	117	75
102	L	264	131	100
103	R	258	134	123
104	L	272	129	92
105	R	272	139	105
106	L	256	145	97
67	L	269	124	97
70	R	274	126	104
97	L	267	148	118
98	R	292	137	90
99	L	266	123	102
100	R	271	143	106
68	R	254	124	94
76	R	271	143	82
89	L	259	136	88
90	R	267	144	106
74	R	288	132	120
85	L	290	150	108
93	R	287	150	104
108	L	257	140	103
30	R	249	116	91
31	L	264	125	108
33	L	281	156	86
34	R	273	135	105

L/R left or right, *FL* foot length, *FW* foot width, *FHW* foot heel width

Table 17.2 Estimated stature and body mass of seven trackways of Galería de las Huellas I, using different height calculation equations (mm)

Trackway	Direction	FL*	FW*	FHW*	Atamtürk (2003)	Ukoha (2013)	Krishan (2008)	Atamtürk (2003)[a]	Atamtürk (2003)[b]	Krishan (2008)[a]	Krishan (2008)[b]
1	Inlet	252 ± 10.9	123 ± 11.2	77 ± 23.9	173.34	172.627	175.63	91.95	82.18	72.92	69.85
2	Inlet	262 ± 13.2	133 ± 21.1	92 ± 18.3	178.46	175.769	179.21	99.25	89.84	75.67	75.62
100	Outlet	262 ± 8.8	132 ± 9.5	99 ± 15.6	178.26	175.646	179.07	98.79	93.52	75.50	78.40
200	Outlet	273 ± 9.5	133 ± 10.7	103 ± 9.2	183.87	179.095	183.00	99.48	95.77	75.75	80.09
230	Outlet	263 ± 7.4	137 ± 9.1	92 ± 10.3	178.76	175.954	179.42	102.06	90.29	76.73	75.96
240	Outlet	280 ± 15.6	143 ± 8.8	109 ± 7.5	187.63	181.405	185.63	106.62	98.75	78.44	82.34
300	Outlet	267 ± 13.6	133 ± 17.2	97 ± 10.7	180.81	177.216	180.86	99.25	92.79	75.67	77.85

FL foot length, *FW* foot width, *FHW* foot heel width, * median/standard deviation

[a] Body mass from footprint width

[b] Body mass from footprint heel width

133, 137 and 144 mm wide (Tables 17.1 and 17.2). These values stress the presence of strong individuals.

Despite the uniformity in foot size among the trackways analysed, the AI and the AA reveal some morphological differences. The AA shows a tendency to flatness or pronation in all trackways (AA $\leq 31°$), except in trackway 230, which corresponds to a normal range (Fig. 17.5b). Furthermore, the AI suggests a normal arch range for all trackways, except for trackway 230, which displays a slightly high arch, and for trackway 2 and trackway 300, which display a flat arch. These flat arches according to the AI are commonly a consequence of weight-bearing activities, so it may suggest that some individuals were carrying an additional weight.

The analysed footprints belong to seven trackways, which represent a minimum of five individuals according to the direction of the trackways (two entry trackways and five return trackways) (Fig. 17.8). The length and width measurements of trackways 2 and 100 are similar, which suggests that these may belong to the round-trip trackway of the same individual, whose estimated height is about 175–179 cm. The weight calculations are more disparate, however. Depending on the chosen equations and markers, the weight could be either about 76–78 kg or 90–99 kg (Table 17.2).

Chronology

The chronology of the trackways has been determined in order to contextualize the activities that took place in this part of the cave, over 1 kilometre from the current entrance of Palomera Cave.

Delibrias et al. (1974: 53) published four radiocarbon dates from Ojo Guareña, and Sample Gif-1720 (OG2), from the footprint site, provided an age of 15,600 ± 230 BP, in the Upper Palaeolithic. This sample, collected in 1970, was taken from the charred remains of a torch at the bottom of a pit that connects Laberinto Otilio (lower level) with Galerías de las Huellas (upper level). In 1999, a new date of charcoal on a footprint in Galería de las Huellas II was more recent, 3820 ± 50 BP (pers. comm. Juan Luis Arsuaga), which suggests that both Palaeolithic hunter-gatherers and Chalcolithic farmers transited this sector of the cave (Ortega et al. 2013: 182).

The new survey has identified a significant amount of evidence of visits, totalling 60 records: 6 remains in Sala Negra, 23 in Laberinto Otilio and side passages of Galería del Cacique, 22 in Sala de las Huellas and another 9 in Galerías de las Huellas I and II, different from the footprints (Fig. 17.9).

In all these passages we have documented scattered remains of charred wood as well as small concentrations of charcoal and charred wood marks on the walls and boulders, to mark the rock or rekindle the torches. Several panels of bear claw scratches on the walls and abundant mustelid imprints have been documented at the beginning of Galería de las Huellas I and also in the initial section of Laberinto Otilio.

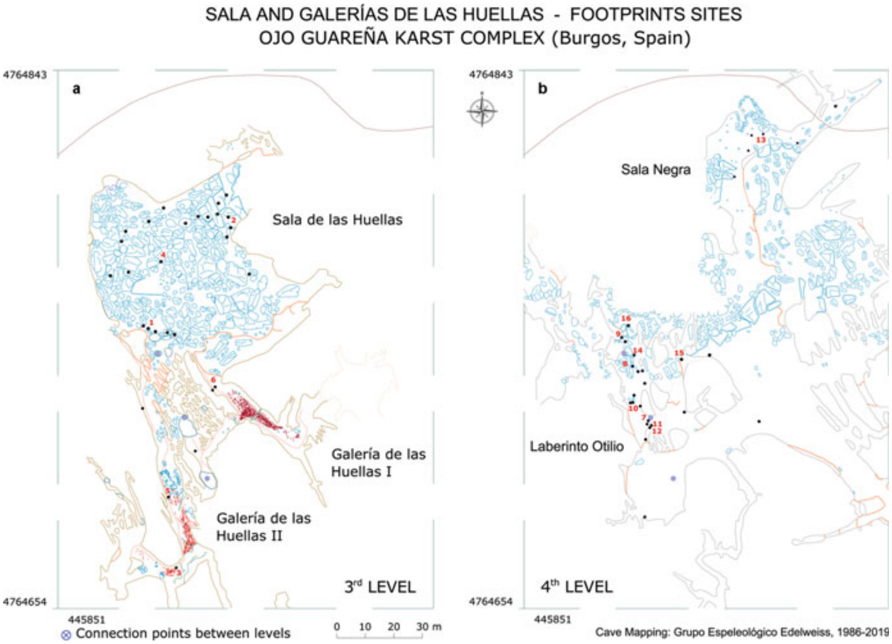

Fig. 17.9 Map of sector of the Sala and Galería de las Huellas site, separated in the different levels; (**a**) third level, Sala de las Huellas and Galería de las Huellas I–II; (**b**) fourth level, Laberinto Otilio and Sala Negra. The *black points* represent the archaeological evidences and the *red numbers* the dated samples, referred to in Table 17.3. (Modified from Grupo Espeleológico Edelweiss 1986; Ortega et al. 2014)

This survey has also documented the deterioration of the human footprints in Sala de las Huellas, in which only three areas with prints are preserved, all of them in the southern section of the great hall, on the irregular surface of the large inclined blocks covered with loam in which a few human footprints can be observed (Fig. 17.3a).

This study thus presents the results of 15 AMS radiocarbon determinations for samples from different pieces of charcoal and torches in the Otilio-Negra-Huellas sector (Figs. 17.2b–e, 17.3b and 17.9). They were selected from 55 points with charcoal identified in the archaeological surveying.

Table 17.3 reflects all the ages of the samples in the different sectors. The number refers to the identification of the sample on the maps in Fig. 17.9. The table has been divided into two groups, the upper one corresponds to the third level, with three dates from Sala de las Huellas, two from Galería de las Huellas II and one from Galería de las Huellas I. Additionally, it should be noted that we have been able to identify the 1999 sample in the field, which corresponds to sample 17.OG17.GH2.C2 (Fig. 17.9, number 3).

Regarding the fourth level of the karst, the survey of the northeast end of this sector could indicate a possible access from the San Bernabé blind valley (Figs. 17.1b, c and 17.2a), and one sample of the five identified in the blockage in

Sala Negra has been dated (Fig. 17.9b, number 13). Eight samples from Laberinto Otilio have been dated, to add to Sample GIF-1721 OG2 published in Delibrias et al. (1974: 33) (Fig. 17.9b, numbers 7–12 and 14–16).

The distribution map and chronological table of the remains (Fig. 17.9 and Table 17.3) reveal the wide chronological range from the Upper Palaeolithic to the Chalcolithic in the Laberinto Otilio-Sala Negra sector and the concentration of dates in the third level.

The Palaeolithic sample (GIF-1721 OG2) was collected by members of the Grupo Espeleológico Edelweiss at the base of the pit that separates the two Galerías de las Huellas and connects with Laberinto Otilio (Figs. 17.2b and 17.9b, number 7). The new dates from this section of the maze are concentrated in the Late Mesolithic and Initial Neolithic (Fig. 17.9b and Table 17.3). A third period corresponds to the Chalcolithic, with two dates from the upper part of Laberinto Otilio, in areas with difficult access to Sala de las Huellas.

The spatial layout of archaeological evidence in Sala de las Huellas displays a clear perimeter distribution towards Galerías de las Huellas II and I. This southern part of the hall is next to a connection between boulders with the lower Otilio maze, and several charcoal fragments are observed in both levels. The charcoal identified as number 1 from Sala de las Huellas was dated to 4080 ± 30 BP, and the charcoal from the upper part of Laberinto Otilio, number 16, was dated to 3850 ± 30 BP (Fig. 17.9 and Table 17.3).

In turn, the six samples from the Huellas Sector in the third level have ages between those two dates (Fig. 17.9a and Table 17.3). This suggests that the Huellas sector was explored in approximately 4300 calBP.

In contrast, visits in the immediately lower Otilio Sector took place in a wide chronological range from the Upper Palaeolithic to the Chalcolithic.

Table 17.3 Summary of the human footprint site ^{14}C data from charcoal, all unpublished and AMS except Gif-1721 (Delibrias et al. 1974)

No	Site	Lab-no	Sample	^{14}C BP	calBP*	calBP* (m)	Period
1	SH (floor, under block	Beta-518405	141.OG18.SH14	4080 ± 30	4648-4514 (68%) 4806-4760 (15.8%) 4481-4445 (7.9%)	4606	CH
2	SH (floor)	Beta-518404	124.OG18.SH3.2	3910 ± 30	4422-4248 (95.4%)	4335	CH
3	GH-II (floor)	Beta-463838	6.GH1	3870 ± 30	4414-4227 (89.7%) 4200-4178 (4.3%)	4314	CH
4	SH (floor)	Beta-518406	144.OG18.SH21	3860 ± 30	4410-4225 (84.0%) 4203-4158 (11.4%)	4301	CH

(continued)

Table 17.3 (continued)

No	Site	Lab-no	Sample	^{14}C BP	calBP*	calBP* (m)	Period
5	GH-II (floor)	Beta-473662	17.OG17.GH2.C2	3820 ± 30	4299-4142 (84.9%) 4126-4093 (5.3%)	4214	CH
6	GH-I (floor)	Beta-473661	16.OG17.GH1.C4	3780 ± 30	4245-4081 (82.9%) 4031-4009 (2.5%)	4159	CH
7	LO (shaft area, connection with GH I)	Gif-1721	GOG2	15,600 ± 230	19,392-18,446 (95.4%)	18,919	UP
8	LO (floor)	Beta-463837	5.LO1	6940 ± 30	7839-7689 (95.4%)	7764	ME
9	LO (hearth)	Beta-473663	18.OG17.LO1	6920 ± 30	7826-7680 (95.4%)	7753	ME
10	LO (floor, close to torch)	Beta-498596	104.OG18.LO9	6840 ± 30	7732-7610 (95.4%)	7671	ME
11	LO (wall, shaft, connection with GH I)	Beta-463836	4.LO2	5800 ± 30	6670-6503 (95.4%)	6587	EN
12	LO (wall, shaft, connection with GH I)	Beta-473664	19.OG17.LO2	5780 ± 30	6656-6499 (95.4%)	6578	EN
13	SN (floor)	Beta-518403	119.OG18.SN4	5760 ± 30	6650-6484 (95.4%)	6567	EN
14	LO (torch)	Beta-498597	105.OG18.LO15	5410 ± 30	6289-6181 (94.0%) 6139-6129 (1.4%)	6234	EN
15	LO (upper level)	Beta-518402	145.OG18.LO20	3860 ± 30	4410-4225 (84%) 4203-4158 (11.4%)	4301	CH
16	LO (upper level)	Beta-498598	106.OG18.LO19	3850 ± 30	4407-4218 (75.7%) 4209-4156 (19.7%)	4286	CH

SH Sala de las Huellas, *GH* Galería de las Huellas, *LO* Laberinto Otilio, *SN* Sala Negra, *CH* Chalcolithic, *UP* Upper Palaeolithic, *ME* Mesolithic, *EN* Early Neolithic, * calibrated with OxCal 4.2 using Intcal 13 (Bronk Ramsey 2009), *m* median

Discussion

An increasing number of sites with prehistoric human footprints are becoming known (Aldhouse-Green et al. 1992; Bell and Neuman 1997, 1999; Ambert et al. 2000; Facorellis et al. 2001; Onac et al. 2005; Bennett et al. 2010; Bennett and Morse 2014b; Citton et al. 2017; Ashton et al. 2014; S. Webb et al. 2006b; D. Webb et al. 2014; Atamtürk et al. 2018; Roach et al. 2016). Recent research approaching this type of site through different disciplines is contributing new knowledge of interaction between humans, the land and the environment in painted caves as special places (Pastoors et al. 2015, 2017).

The Sala and Galería de las Huellas can be framed within those sites that provide information on the use and transit of the dark zone of caves, where the tracks of old paths are preserved, but whose specific relationship with the concept of the natural, social and cultural environment is unknown (Mlekuž 2012; Moyes 2012).

In the case of the tracks in Ojo Guareña, their singularity lies in the fact that they are a long way from the possible entrance point sand without a direct relationship with symbolic spaces (rock art, burials, etc.), although these exist in other parts of the cave system. The large number of traces is unique, with over 1200 footprints of a minimum of 6 individuals but probably of between 9 and 11, according to the trackways that have been counted.

The superimposition of the footprints, in opposite directions, is indicative of round-trips, which suggests a single inspection of these passages, during which some members approached the recesses of the walls or entered the side passage in GH I. These preliminary observations are visible in both of the Galerías de las Huellas passages.

It can therefore be proposed that the human footprints in the Sala and Galerías de las Huellas correspond to a single visit, possibly to explore this deep sector of the cave.

However, the human visits or tours that have been documented at different times in the Laberinto Otilio-Sala Negra sector are more difficult to comprehend. This sector is characterized by the absence of archaeological record and the isolation of the sector from places of symbolic activity. Nevertheless, this space was visited on at least four occasions in prehistory: the first about 19,000 calBP, the second moment around 7700 calBP, the third about 6500 calBP and the last time in relation with the exploration of the Huellas sector about 4300 calBP.

The results of this project show that the first significant explorations in Laberinto Otilio, a relatively comfortable maze in its initial section, took place in the Mesolithic and Early Neolithic, the times of which the first remains are preserved in Sala Negra. During more intense explorations in the Chalcolithic, the unstable final ramp of large boulders was first accessed in order to reach the upper level where their footprints have been preserved in the Sala and Galerías de las Huellas. The challenges involved in access to this sector, combined with the spaciousness of its passages and the chaotic boulders on the floor, do not facilitate an understanding of the specific activities that took place, although they must be linked with the exploration and knowledge of the underground world.

The characteristics of this site mean that it cannot be compared with most human footprint sites, which are generally linked with the zones of habitats, or sacred or rock art sites, both in the open air and in caves (Bennett and Morse 2014b; Ashton et al. 2014; Westaway et al. 2013; Atamtürk et al. 2018). Ciur-Izbuc Cave, Romania (D. Webb et al. 2014); Bàsura Cave, Italy (Citton et al. 2017); Aldène Cave (Ambert et al. 2000); and Foissac Cave, France (García and Duday 1983), dated in the Middle Palaeolithic, Upper Palaeolithic, Mesolithic and Chalcolithic, respectively, are not associated with symbolic elements. Foissac Cave was quarried for clay in the Chalcolithic. The deep zone of Mammoth Cave (United States) was also used for mining activities (Kennedy and Watson 1997; Willey et al. 2009). However, the prehistoric traces in Jaguar Cave (Tennessee, USA) are more interesting for our case study. Watson et al. (2005) documented a single visit by a group of nine individuals about 4500 BP. The cave was never used for any specific purpose, so the tracks represent an isolated event.

The footprint site in Sala and Galerías de las Huellas similarly represents a single event, a simple exploration, but its surroundings, Laberinto Otilio, Sala Negra and Galería del Cacique, were explored earlier several times. They are in the eastern part of Palomera Cave, where different types of evidence and human activities have been identified over a distance of more than a kilometre in length. They show that during prehistory, the inhabitants of this karst transited and explored the cave until they met the sediment plug in the San Bernabé cirque, leaving marks in the underground landscape, small hearths, torches, stones or rock art, graves, etc.

This indicates that the exploration of the interior of this cave system was an activity that was carried out with certain normality. This exploration must have represented an initial contact of the underground world that they wanted to conquer and then select at a later time the different symbolic places that have contributed to the singularity of this site, which has been designated as Spanish Cultural Heritage since 1972.

Conclusion

The human footprint site of Sala and Galerías de las Huellas is one of the most important sites in the Ojo Guareña Cave system, located about 1200 m from Palomera Cave. It is dated in about 4600–4200 calBP, a range that suggests a use of the dark area of the cave in the Chalcolithic, although intensive human traffic in the immediate environment (Laberinto Otilio-Sala Negra-Sala del Cacique) is documented during the Upper Palaeolithic, Mesolithic and Neolithic.

The analyses suggest that a group of between 8 and 10 adults explored several passages in the Dédalo Oeste sector of this large cave, leaving more than 1200 footprints in the soft sediment on the floor of Galería de las Huellas. The exceptionality of this incursion is due to the complexity of access. This survey of the route taken by the explorers and their trackways is improving our knowledge of the use of the underground world in prehistory. The analyses of the numerous evidences of transit in this big cave are helping us to understand the intensity of cave use in prehistory and especially the use of the dark zone as a symbolic and social landscape.

The research also proves the value of optical laser scanning and photogrammetry in the collection of data, analysis and preservation of the fragile footprints.

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Part III
Experiences with Indigenous Experts

Chapter 18
Tracking with Batek Hunter-Gatherers of Malaysia

Tuck-Po Lye

Abstract Tropical hunting studies that focus on tracking – how signs are interpreted – are rarely done if at all. This paper provides a preliminary sketch of the tracking strategies and knowledge of Batek of Malaysia. Studies of hunter-gatherer tracking rely heavily on Liebenberg's carefully observed documentation of San tracking, enriched by his own scientific expertise in faunal behavior. Of the three levels of tracking he mentions, simple tracking is unreliable for the Batek, simply because of the nature of tropical forests. The default mode is systematic tracking, carefully gathering information, and piecing together a multisensorial picture of where prey is to be found. Their visual, auditory, and olfactory acuity is exceptional and so is their vocabulary for expressing these states. Tracking for Batek is not limited to the interpretation of tracks, or, rather, the notion of tracks needs to be broadened, to include tracks that cannot be seen, but can be heard and smelt. Tracking is about multisensory engagement in the needs of the moment and deploying the skills to decide what is and is not relevant information. It is about performance.

Keywords Tracking · Tropical forests · Hunter-gatherers · Batek

Introduction

This paper sets out, in a preliminary way, how tracking is done in the tropical forest, specifically by Batek hunter-gatherers in Pahang, Malaysia. While it is reasonable to assume that successful hunters are expert trackers of prey, tropical hunting studies that focus on tracking – how signs are interpreted – are rarely done if at all. Hunting ethnographies do give some attention to how various game animals are tracked or the spoors characteristic of particular animals (e.g., Puri 1997, 2005; Sillitoe 2003), but do not generally take tracking as their primary interest. For example, Gardner

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(2006: 39–41) provides an excellent account of a wild boar hunt, which includes some vivid imagery of how Paliyan men tracked, but does not elaborate on the subject. Anthropological attention has been towards hunting strategies and the products of the hunt rather than how the animals are found (e.g., Bulmer 1968; Dwyer 1974; Griffin 1984; Hayashi 2008). The purpose of this paper is to fill this lacuna.

Tracking has been described as the origin of science (Liebenberg 1990). It creatively combines empirical knowledge with imaginative hypothesis-building. Expert trackers have the spatial orientation to navigate along paths and are always on the lookout for signs of where to go next. They are also ready to be surprised: to respond to new and unpredictable situations and change plans as information changes. They do not just follow obvious tracks and traces but draw from prior knowledge to plan and anticipate directions. This knowledge is also based on that of other group members, which is often shared through storytelling (see Biesele Chap. 20). The skill to interpret comes therefore from shared experience, as discoveries and encounters are discussed and odd conjunctures of space, time, and sign are debated. As anthropologists argue, much of this knowledge is not solely the product of individual skill and experience, but must be interpreted through shared cultural idioms (Hutchins 1995; Widlok 1997; see Biesele Chap. 20).

Anthropologists have either been experienced hunters or become apprentice hunters in the field (Aporta 2009; Biesele and Barclay 2001; Estioko-Griffin and Griffin 1981; Puri 2005). Much of this paper is based on conversations about hunting, animals, and tracking, especially with ʔeyDukec and ʔeyHagap, who are both expert trackers in middle age (the former is more often quoted in this paper, but the latter, who is older and more experienced, was present on many conversations; both are old friends of mine). Personally, I mainly experienced tracking incidentally while doing something else (over an observation period of 27 years). I have documented animal trails and tracks but not systematically inventoried them thus far. As I will show below, Batek tracking is less about reading tracks than about connecting the marks on the ground with perceptual data, and making associations between this evidence and what is known more generally about the landscape. As such, tracks are not "read" in the way that, say, one might pursue words on a page, one after another in linear fashion. I will return to this point below. Although it is relatively easy to write about Batek perceptual knowledge (Lye 2004: 150–156), the challenge is to examine how sensory data – sounds, scents, and sights – plays a part in activities like tracking. In this paper, I will attempt to sketch out some broad parameters of tracking knowledge.

Ethnographic Background

The Batek call themselves *batɛk həp* (people of the forest). Numbering some 1500–1600, they are among the score or so indigenous ethnic minorities of Peninsular Malaysia, the Orang Asli ("Original People" in Malay). Before large-scale logging and land transformation began in the early 1970s, the Batek territory was contiguously forested; Endicott (2000: 110) estimated that roughly two-thirds of that area is lost beyond regeneration. Taman Negara, the 4343-square-kilometre national park, mostly sits astride Batek territory (Lye 2011), which covers a sizeable area where the states of Pahang (where I have done all my work), Kelantan, and Terengganu meet (Fig. 18.1). The park is mostly covered in lowland tropical

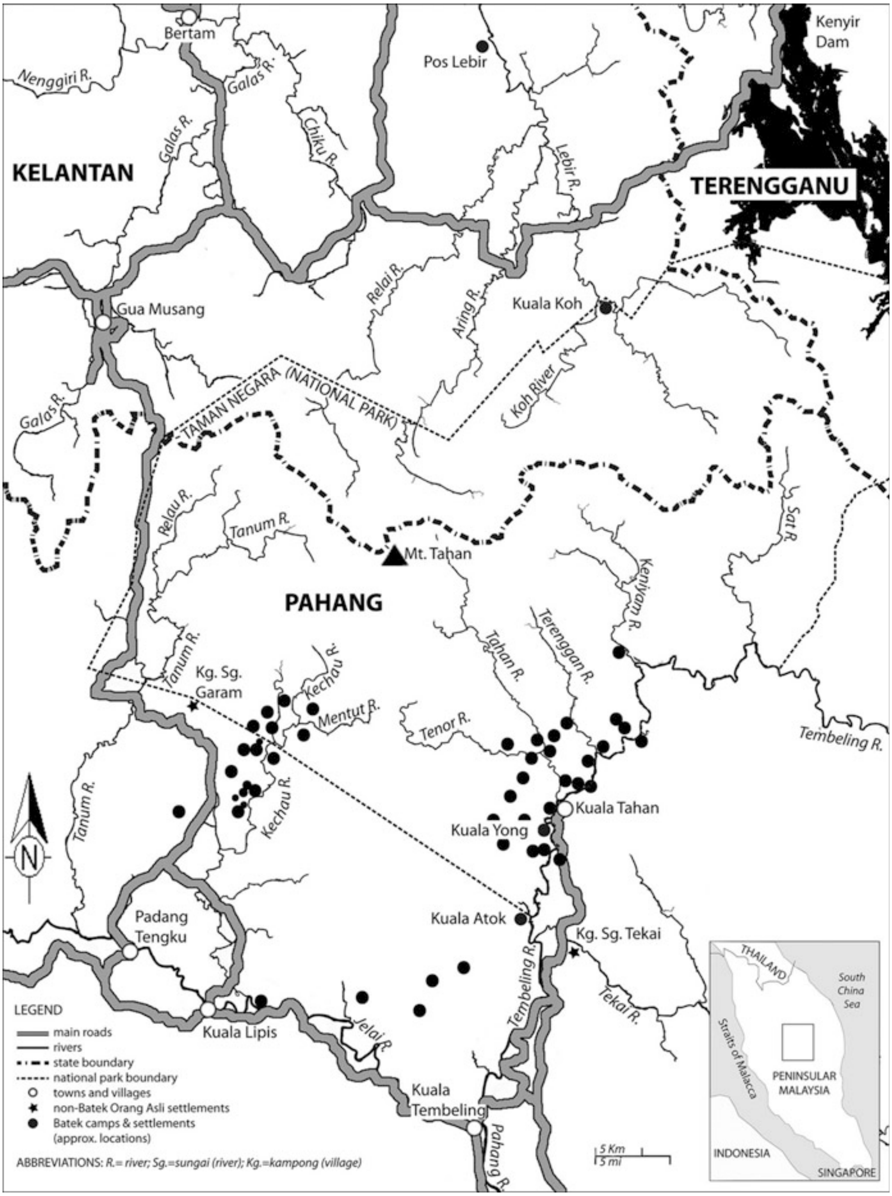

Fig. 18.1 Map of the Batek territory

evergreen rainforest. In Pahang, where the population numbers 650–800, just over half spend the majority of their time in Taman Negara. Taman Negara remains the largest unbroken tract of forest available to all Batek, who are permitted to live there and travel in and out of the park at their will, but not to collect forest products, including fauna, for sale. They are regarded as the original inhabitants of the park but do not have an administrative role and are not consulted on management issues (Lye 2002). Conditions outside the park are variable due to logging and land conversion from the 1980s onwards. The most extreme effects are the irreversible conversion of previously intact forest into oil palm and rubber plantations and, in Terengganu, total obliteration of forestland for the Kenyir Dam reservoir.

Most of Batek everyday movement occurs in an undulating lowland forest environment, with forested foothills being their preferred ecological niche. GPS-derived data show that they conventionally place camps and settlements at around 100 m a.s.l. (but see below on hunting tracks). The traditional mode of dwelling in the forest is to live in a camp (*hayʔ*); these camps are connected by an extensive series of pathways (*halbəw*) that traverses over walking trails, rivers, and logging roads, in a topography marked by the alternation of land and water.

In 1990s Pahang, Batek moved from camp to camp (*jok*) on average every 2 weeks or so. Two or so settlements had already emerged, partially due to external influence or pressure, but most sub-groups were forest-bound and mobile. Settlement composition was much like the big camps that periodically appeared whenever prominent shamans called people to them, usually for ritual-making purposes. The largest group I documented had just over a hundred people passing through at various points, large by Batek standards, where the average group population was 36.2 (around 40–45 was the preferred size). Traditionally the pattern was for each group to travel within the bounds of a tributary system over the course of several months. After 3 or 4 months, roughly corresponding to the end of a season, camp groups would disband, and splinter groups moved to other river valleys, joining and forming groups anew. Now they alternate between mobility and sedentariness, i.e. between settlement and camp life. The number of settlements has increased since the 1990s, but the essential character of communities has not changed. Populations in camps and settlements still fluctuate sharply, and settlements continue to be like base camps in which to rest or store belongings before moving on to other pursuits (Lye 1997: 390–428).

Batek are highly egalitarian and strongly value personal autonomy. There is no political hierarchy, although there are nominal headmen (*penghulu* or *batin*) appointed by the Department of Orang Asli Development (JAKOA) to mediate between groups of Batek and the government.

The Batek's economy seemingly encompasses a broad variety of options. It is characterized by flexible and opportunistic shifting from one suite of activities to another as conditions change (Endicott 1984). The main source of cash income, and the economic activity that seems to occupy the most time, is commercial extraction of forest products: primarily rattan (mainly *Calamus* sp.). Other products are collected according to demand. When opportunities arise, men may do some day labouring, and there is some casual agriculture (Lye 1997: 69–76), now increasing in importance. Full-blown agriculture was traditionally the least favoured of these activities. Those living close to the headquarters of Taman Negara are also heavily involved in tourism, both in hosting the visits of tour groups to their camps and settlements and in guiding and driving tourist boats.

Throughout the daily, seasonal, and annual changes in production activities, hunting and gathering of forest foods remain important, both as a preferred alternative to buying store-bought foods and as valued activities in their own right. These subsistence activities are also central symbols of cultural and gender identity. They have high cultural value. The Batek's staple diet, when nothing else is available, is *takop* (wild yams, *Dioscorea* sp.): "the most important and reliable source of carbohydrates" (Endicott 1984: 33). Fruits (available seasonally) are probably the Batek's favourite foods and can temporarily replace game in the diet. The forest also provides them with vegetables such as palm cabbage, honey which is available in abundance during the flowering season, and, of course, game animals (*ʔay*), of which more below.

Tracking Habitats

The habitat in which tracking occurs is a key variable. The lowland tropical forest is notorious for its low visibility. Not only is a high percentage of ambient light cut off before reaching the forest floor, views may be obscured by trees and other vegetation (Gell 1999: 239). Walking in the rainforest involves negotiating intimate spaces and an ever-changing mosaic of plant and animal communities. In foraging, one has to pick out tracks and traces of prey and plant foods in rather dim light. Of moving targets (e.g. birds in flight, squirrels darting along a tree limb, feeding creatures), all that is visible may be a quick flash of moving colour, the tip of a tail, an indistinct part of body, or, worse, the flutter of leaves or swaying of branches. Size, shape, and distinctive markings often cannot be reliably determined from the ground (Diamond 1991: 84; Ichikawa 1998: 109, 112), although animals may be identified from afar by their modes of locomotion, postures, and other characteristics (for example, whether they move in groups). An added complication is that animal sightings are relatively rare. In the daytime, little of the famed faunal diversity, other than inedible insects, bloodsucking leeches, and other invertebrates, as well as birds and other arboreal fauna, can be seen (Puri 1997: 150; Whitmore 1997: 58). Tracks on the ground are accordingly not plentiful. Having the skill to pick out salient details from the mass of wood and green matter is essential. Contrast this with tracking spoors in the arid environment of the Kalahari, where: "a tracker does not need exceptional eyesight. It is more important to know what to look for and where to look for it" (Liebenberg 1990: 71). Although knowing the what and the where is equally important to Batek, having good eyesight is critical to them (as demonstrated by a profusion of terms in their language for various kinds of seeing postures). The most fundamental is knowing how to look, what I call skillful looking. This was demonstrated by ʔeyDukec, who wore a head-mounted action camera as he walked a trail. Reviewing the video later, he pointed out: "This is how Batek search (*kədap*). We don't look down at our feet. We stare left, right, upwards (*diʔʔr ba-kiriʔ, ba-kanan,* *ba-ʔates*). We take a quick look (*tɔt*), we look to the side (*kihley*). If we're only looking for spoors, then we search the ground." The Batek's perspective is global, their eyes sweeping grandly around them, rarely resting on their feet. Furthermore, they must search knowledgeably. For example, they often trace animals' *pənyir* (animal paths in the canopy; this word also refers to the flight paths of birds and other flying creatures) and know the trees that certain animals favor for their *pənjɛs* (sleeping trees), all of which presuppose a broad knowledge of the botanical environment too. On countless occasions, a walk will be brought to a sudden halt when someone in the group (men or women) casually espies something useful off-trail and goes off to harvest it. By far the bulk of environmental information comes from sounds (*kəlɨŋ*). The rainforest can be a noisy place, its cadences punctuated by distinct noises like the *wəswas* (great call) of female lar gibbons, the *ramiŋ* and *cantum* of siamangs, the *pərikah* of banded langurs, the *bəbəp* (ribbit) of giant Malaysian frogs, the *gərliŋ* (drumming) of woodpeckers, and so on. Obviously, sounds travel farther than visual images and can convey a lot more information. For hunters, the first indication that prey is nearby comes with sound emissions (*kəŋlɨŋ* "to emit sounds"). ʔeyDukec explained this: "When we hear the sounds (of game animals) stationary in a place[1], we go there, go towards the sounds. If the sounds have died down, we circle around. Walk round and round looking for the animal [see Fig. 18.2]. If we're close and the sounds have died and the animal isn't coming, that's it."

This reliance on sounds has been described for other forest peoples. For Mbuti of the Ituri Forest, Ichikawa (1998: 109) found that they "often could not identify the captured birds by their figure alone, but immediately identified them when the birds emitted their peculiar calls." Gell's comment that Umeda of New Guinea on their forest treks tended to use their "ever-receptive ears" to survey the far-off while keeping their eyes focused on the nearby is—with modification—a fitting description of Batek habits too (Gell 1999:239).

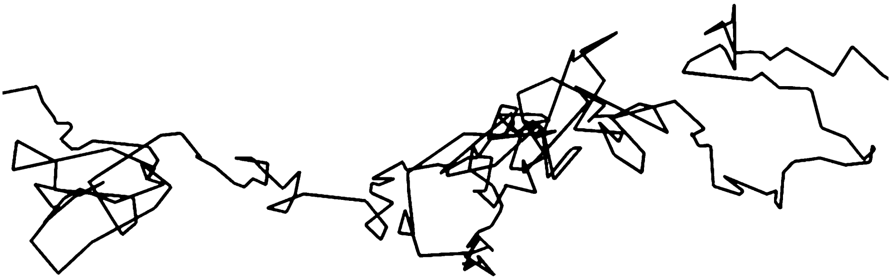

Fig. 18.2 Walking round and round looking for the animal: excerpt from a GPS track showing a hunter in mid-hunt in 2017. (Google Earth)

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[1] The original in Batek was kəjiŋ kəlɨŋ ŋok kə-tun (hear the sounds sitting over there).

In like vein, I found that Batek were distinctly less interested (and more likely to make mistakes) in identifying birds from images, but became very alert and discriminating when they listened to audio recordings of the same species. Gell's comment that Umeda of New Guinea on their forest treks tended to use their "ever-receptive ears" to survey the far-off while keeping their eyes focused on the nearby is – with modification – a fitting description of Batek habits too (Gell 1999: 239).

Hunting, Animals, Tracks

Animals have an honoured place in Batek imagination; they are, like many hunters (e.g. see, Nelson 1983), enraptured by animals, first-rate observers of and intellectually stimulated by animal appearances, habits, and behavior. They talk about animals often, telling stories, sharing observations, and asking questions of each other. The sounds of fauna are a constant hum in the background, and most Batek have phenomenally sharp ears. Invariably Batek will hear faint sounds (sounds that are *bəʔabey-ʔabey* or so faint that one cannot tell what they are) long before I am aware of them. Recordings of animal sounds are popular. Once in 1996, I recorded the calls of a lar gibbon moving close to camp; the Batek repeatedly asked to listen to it. One young man said the recording made him *haʔip* (yearn). When listening to playbacks of recorded sounds (of, say, the songs of gibbons), Batek will point out the sounds of other creatures captured in the recording and even how the animals were positioned relative to each other. For hunters, hearing the sounds of game provokes desire: as I was told, *mɨʔ haran mɨʔm haluh mɨʔm jit mɨʔm rɛɲ* (we feel the desire to shoot, to capture, and to eat). However, Batek interest in animals goes beyond satisfying gastronomical needs.

The general Batek term for hunting is *sam*. Under this broad category, the prototypical hunting method is to shoot (*haluh*) with the blowpipe (*bəlaw*), which is used to target arboreal game (Endicott 1974: 64–65; see Fig. 18.3).[2] Among Batek in 1970s Kelantan, Endicott estimated that blowpipe-hunting accounted for 68% of the time spent hunting and 71% of the game brought in (1979: 9). Hunting tracks generally follow ridge paths; elevations are higher than normal, averaging from 113 m a.s.l. to 557 m a.s.l. (as recorded thus far with GPS receivers). Normally hunts last from 5 to 7 h, though successful hunters might be detained into the night hours cooking the meat in the forest before trekking home (to lighten their loads). The primary targets are langurs (kaldus "banded langur, *Presbytis femoralis*" and *talok* "dusky langur, *Trachypithecus obscurus*"), and macaques (*bawac* "pigtailed

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[2] When a hunter goes out, he might say *yɛʔm sam* (I'm going to hunt), but the corresponding term *yɛʔm haluh* (I'm going to shoot with the blowpipe) sounds rather odd and is never announced except in jest. This may due to the avoidance practices which the Batek share with many hunters (e.g. Puri 1997: 256–258 on the Penan Benalui).

Fig. 18.3 Using the blowpipe

macaque, *Macaca nemestrina*" and jəlew "long-tailed macaque, *Macaca fascicularis*"). Gibbons (kəboη "lar gibbon, *Hylobates lar*" and *batẽw* "siamang, *Symphalangus syndactylus*") may also be hunted, but rarely. Other tree-dwellers like civet cats (viverrids), shrews, squirrels, and birds can also be captured in this way.

Blowpipe-hunting may be planned or fortuitous. When a hunter goes out, he will have the intention to hunt, but the choice of prey depends on what he finds there.[3] Once game is sighted but still elusive, hunters may stand still, head raised (*bilay*) far up (*jɨlkok*), studying the treetops (*pratiʔ*, Malay *perhati* "to look in detail"). Sometimes a place will be *jaʔɛl*, where animals are wary of humans and will flee on sight.[4] Under ideal conditions, the hunters must learn to stalk or creep (*pədep*) in such a way that they don't reveal themselves. These stopovers (Guèze and Napitupulu 2017), when hunters stalk, can last from 10 min to just beyond an hour (as recorded by GPS receivers). Stopovers are defined as "areas where the density of track points is higher" (Guèze and Napitupulu 2017: 46), when hunters are detained by sight or sound of game. If they do sight game, and release the dart, the quarry does not die immediately and may escape successfully. If game is high beyond the range of the blowpipe, hunters may lure the animals (sensu Bulmer 1968) by making decoy calls through sound mimicry, drumming on the quiver, whistling with leaves, etc. If the animal has moved on, so do they. Hunters do not habitually chase the animals, though they may linger, waiting for wounded game to fall.

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[3] Hunts may also be stimulated by reports from other people. For example, to *pənton* is to tell others where one had recently encountered game. Obviously, anyone, hunters and non-hunters alike, can *pənton.* If the animal has been sighted, to *pəltɔt* ("to cause to see") is to direct another person's attention to it.

[4] This description is from ʔeyDuket and ʔeyHagap, who provided an exegesis of a video that I had shot of another man, ʔeyAlɔr, stalking prey.

On other occasions, they may be lucky to capture an animal like *kaldus* when it descends from the treetop to drink or feed on snails and shrimps on side streams. ʔeyMantɔr remembered once:

> [The *kaldus*] went upstream, I was on walking on land. I saw it. Slowly I crept up on it. It was sitting on an old piece of wood; its hand left an impression, like this [gesturing]. It had come down for food. It moved to another piece of wood to feed then climbed back up. I shot it. The shot landed.

Such animals are always in motion, whether on the treetops or (for some species) darting from tree to ground and up again, and therefore are not ambushed. I imagine that good hunters know how to select their trails to maximize their chances of such encounters, though thus far they've been too modest to admit to it. Arboreal hunting primarily requires knowledge of animal habits and their sounds and odours (the Batek most often mention urine), while the impressions the animals leave on the ground are extremely faint. Failure to procure (*pawɛs*) has been variously attributed to poor eyesight, hunters not knowing how to stalk and revealing themselves to game too soon, the dart poison had been weakened by age or contamination, or some happenstance of luck.[5]

The precursor to blowpipe-hunting is catapult-shooting (Lye 1997: 367). All the hunters I've ever asked mentioned that they first learnt their skills playing with catapults as boys. Even today, the sight of boys and girls with catapults is pervasive everywhere. Their targets (often successful) are birds and, as they grow and begin practicing with blowpipes, squirrels. Catapults are an apt practice for the real thing: they learn to study the treetops, learn about the behavior of (avi)fauna, and practice eye-hand coordination, stealth, and how to stalk successfully.

Terrestrial hunting (primarily though not exclusively of deer) may be done with a spear (*juliw*), and some hunters are renowned for their success with it. The traditional Batek hunters would move camp with both a spear and a blowpipe, using either one depending on need. But while only the men use the blowpipe, women can use the spear too (I have listened to several enthusiastic accounts by women of how they plunged the spear into this or that animal). Other hunting methods (which women are also skilled at) include chasing and clubbing an animal with a machete or whatever else is available; digging up or luring from burrows, bamboos, or tree hollows with smoke or some other method; and, very rarely, setting traps and springes. Most of such hunts may be fortuitous encounters or planned when tracks of the animals are spotted (or their sounds heard). For swamp or riverine turtles and tortoises, they may head towards a likely spot, just to try their luck, and then look for the animal's tracks and traces. On one memorable (to me) occasion, we were passing a swamp when we saw a turtle; I scooped it up by hand and presented it to the camp as the product of my hard work and visual acuity. In general, Skeat's summary of Orang Asli hunting techniques continues to apply (with some modification) to Batek:

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[5] For both men and women, pawɛs is contrasted to *bərguh* (to be successful), while *malaŋ* and *siyal* are foraging failures attributed to some combination of ill-luck and human error.

> the catholicity of their tastes necessitates at once a most thorough and accurate knowledge of the habits of the varied denizens of the jungle, and a considerable amount of ingenuity and mechanical skill in the contrivance of traps, pitfalls, springes, and nooses for securing their quarry, and this knowledge, skill, and ingenuity the wild races certainly possess in a very marked degree. (Skeat and Blagden 1906: 11)

The one class of animals Batek don't hunt is the larger animals like seladang, rhinoceros, tigers, elephants, crocodiles, etc. (Endicott 1979; Rambo 1978). Wild pigs roughly belong in this category (in the sense that hunters don't normally launch an intentional hunt for pigs) but may be speared if the opportunity presents itself. However, even for this class of rarely-to-never hunted animals, Batek possess a great deal of intelligence and always stop to inspect footmarks and other signs of presence (like the farrowing nest of a wild pig).

Batek more rarely or outrightly did not use other hunting methods that might necessitate persistent track recognition, like ambushing (e.g., Bulmer 1968; Puri 1997), flushing out game with dogs (Puri 1997), besetting (Bulmer 1968: 310–311), shooting with guns (Puri 1997), and driving animals to a restricted or enclosed area (Bulmer 1968: 311–312). They do recognize the utility of the fire drive (Bulmer 1968: 312), but to chase animals *away* rather than to draw them in; for example, once they used fire to drive elephants away from a settlement. In 1970s Kelantan, Batek claimed to have practiced ambushing of wild pigs, but they were never observed to do so (Endicott 1974: 67–68).

Encountering Forest Tracks

Let us visualize what kind of tracks (*hal*) we might find in the tropical forest, specifically along an undulating lowland forest path in Taman Negara National Park, where most Batek live. There are one or two big clumps of vegetative matter on the ground – an elephant was here just days ago. Hoof marks going off-trail may show that seladang or deer were browsing or passing through. A fallen tree across the way, once seen fresh, has dropped more twigs and branches, with pointy sticks jutting up from beneath the leaves. Farther down the trail, another trunk obstructs, but it has lain here for many years and looks like a shadow of its former tree-self, becoming an integral part of ground dynamics and an ecosystem in its own right; the trail neatly winds around it. In a low part of the trail are deep, sloppy marks in a wet patch of mud where pigs have wallowed. A constant buzzing of ambient sounds betrays their makers' presence. Some bird- and cicada-sounds are recognizable; most sounds will remain obscure. Here and there is evidence of people walking ahead: footprints, skid marks, crushed leaves, holes dug deep, shallow, or wide, bent twigs, discarded palm leaves, cut sticks, blackened half-peels of fruit strewn along the ground, or the ashy remains of a wayside fire. Between these signs, there may be none at all, giving the illusion of walking along a remote and deserted jungle path.

I first composed this passage for a paper on landscape marking (Lye 2016). What's missing is what is above eye level. As discussed above, tracking (*tɔt hal* "to look at tracks" or *kədap hal* "to look for tracks") for Batek, as for San in the Kalahari (Akira Takada, personal communication), is as much about studying the treetops as it is about what the ground reveals. Foraging trails invariably take the form of a loop (as confirmed by GPS representations collected since 2010 of fishing, hunting, and yam-digging expeditions), beginning with a purposeful trek along the main trail to the farthest point of the exploration area and then moving in the direction of home along the course of the same river that they had followed out. Hunting patterns follow the standard method of meandering from patch to patch, looking for the intended resource while monitoring landscape conditions along the way. Walking in the forest, hunters keep their ears open for even the slightest of sounds, from nearby to far-off, from faint slithers in the brush to the distinctive calls of key animals. Most important, they keep their eyes peeled on the treetops, alert to the *jal* (indicators) of animals, which are the tell-tale movement of leaves and branches that indicates that something is concealed there. If the animals are not making distinct sounds, *jal* may be the first "track" available to hunters.[6] Hunters who are attracted to game this way will move slowly, in a movement Batek call *laŋkah laŋkah ɲan* (step-step-stand) – two steps forwards, stand quietly, three steps backwards – as they try to keep the animal in sight while themselves remaining concealed.

As noted earlier, botanical knowledge is a necessary complement. Bulmer points out:

> There is probably literally no limit to the knowledge of zoology and botany which is at least indirectly relevant or potentially useful to [a hunter]. To give but one example: a tree or plant may have no direct use for food or technology, but the ability to recognize it and the knowledge that its blossom, fruit, foliage, epiphytes or the insects which are found in it regularly provide food for certain kinds of birds or mammals, or that it regularly provides shelter from them, are highly relevant to the hunter. (1968: 316)

For example, the fruits of the fig trees *jəriʔ* (*Ficus* spp.; the name encompasses a number of species or sub-species) are favoured by hornbills, langurs, macaques, and gibbons alike, and occasionally these animals may congregate in the same tree, sometimes leading to interspecies fights. Another oft-mentioned feeding site is the *təmjum* tree (likely to be *Artocarpus rigida*): its resin is used as a binder for blowpipe darts as well as to darken the incised patterns on combs, while its fruits are favoured by animals. As animals feed, they may drop feces and fruits and other foliage on the ground, and it is these droppings that can point the way to a tracker. There are innumerable species of trees and palms that are useful in this way, which has not been comprehensively documented thus far. Beyond strictly utilitarian needs, Batek store an exemplary amount of information, which does not seem to have immediate uses. For example, they not only know about the ubiquitous fishtail palm *gaseʔ* (*Caryota mitis*; its fluff is used as tinder and it produces edible pith), they can distinguish it from the montane equivalent, *jɨk* (*Caryota* spp.), while admitting that

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[6] According to Alice Rudge, *jal* means both visual and sonic indicator; its meaning is multi-sensory (2017: 189).

they never see *jik* in their territory (it is ubiquitous in the hilltops of my territory, in Penang). Liebenberg provides an explanation for this “excess” of knowledge, what I’ve (Lye 2004: 62) earlier attributed to the Batek’s broad-spectrum foraging:

> Every animal, down to the smallest invertebrate that leaves a characteristic spoor is relevant to tracking. While hunters study animal behaviour far beyond their immediate utilitarian needs in hunting, even the most obscure detail may be used at some point in the future to interpret spoor. (1990: 88)

The odors (*məniʔ*) of animals is also important for tracking. In common with other Orang Asli cultures, olfaction is highly developed among Batek, and their language includes single-word terms to label the smells they encounter (more elaborated than in English). Like the Jahai, Batek have several basic odour terms, which “can be categorized along a pleasant-unpleasant dimension”, with the majority having unpleasant connotations (Burenhult and Majid 2011: 23). Importantly, the terms:

> abstract away from the actual sources typically associated with them. So although a verb like *ltpɨt* [for Jahai] is prototypically used to describe the fragrant odors of flowers (e.g. Globba, Lantana sp.) and perfumes, any source whose odor approximates such a quality can be described with the same verb. (Burenhult and Majid 2011: 23)

Batek odour terms and their prototypical sources uncovered so far include the following:

- *haʔãt* (to have a bad stench)[7]
- *pəlʔãt* (to have a smell like urine, dead leaves, and stale rice)
- *pəlʔɛŋ* (to have a blood/fish/meat-like smell [Burenhult and Majid 2011: 23])
- *səʔol* (to have a bad smell like *blauwɛn*, a species of wild mango)
- *cɨŋas* (to have a smell like curry or bones)
- *ŋãt* (to have a burnt smell) *traŋis* (to have the smell of burnt fur [but see Rudge 2017: 137 for an alternative definition])
- *hapak* (to have a musty smell, as of old clothes; a Malay loan)
- *mahũ* (to have a raw fragrance like bamboo leaves or cigarettes)[8]
- *ləʔɔm* (to have a fragrance like coffee, fresh leaves, and fragrant durians)
- *həraʔum* (to have the smell of food beginning to go bad)

Among these labels, *pəlʔãt* would seem most relevant to tracking, given the frequency that Batek mention the smell of animal urine, followed closely by *pəlʔɛŋ*, which is the olfactory quality associated with fish and the bearcat. However, it is not yet known how Batek conceptualize the smells of different animals, how the knowledge of smells assists in tracking and hunting, how odors are masked, and how hunters and animals manoeuvre around the reciprocity of odors. That the identification of smells is habitual was shown once. Some Batek men were walking outside

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[7] The prototypical source of *haʔãt* is shit. Once I asked what shit smells like. There was total (amused) agreement: *that just smells* haʔãt;

[8] This might be a loan of Malay maung. However, the meanings are completely different. *Maung* in Malay means a smell that induces vomit, whereas Batek *mahũŋ* has more pleasant connotations.

my home in Penang when they smelt the urine of long-tailed macaque. Though the information was irrelevant to that moment (they were not hunting and will not hunt town-adapted animals), they stopped walking, discussed where the scent came from, and reconstructed the macaque's movements down the hill: "it sleeps up there, and it's gone down there". One can imagine such reconstructions taking place on a real hunt, with the hunter not only placing the prey in relation to himself but entering into the perceptual world of the prey and its environmental affordances, including recognizing its likely pathways in the forest.

Simple, Systematic, and Speculative Tracking

If tracking is about the interpretation of signs, then those signs need to be defined differently. In a seminal study, Louis Liebenberg identifies three overlapping levels of tracking, simple, systematic, and speculative (see Lenssen-Erz and Pastoors Chap. 6).

Simple tracking involves:

> following footprints in ideal tracking conditions where the prints are clear and easy to follow. (Liebenberg 1990: 29)

As described earlier, the tropical forest rarely affords "ideal tracking conditions". Occasionally one may encounter distinct spoors in sand or hoof marks on a path after rainfall (see Fig. 18.4), but it's not very long before the tracks disappear into the woods where they become obscured by vegetation. More often, there will be single or dual footprints, left by an animal on a patch of mud. ʔeyHagap (among others) considers the scaly anteater (*man*) the most difficult animal to track; it can be followed through the forest, but it tends to escape over riverside rocks and then out of sight.

Systematic tracking is the next level up from simple tracking, which involves:

> the systematic gathering of information from signs, until a detailed indication is built up of what the animal was doing and where it was going" in conditions where "footprints are not obvious or easy to follow. (Liebenberg 1990: 29)

As the preceding discussion has shown, it seems that Batek are systematic trackers par excellence. In terrestrial tracking, tracking is less about interpreting what each print denotes, than using other evidence (such as impressions and discolorations) to identify the animal's path (*tənaŋoh*), like *cinroŋ* (a well-used animal path) and *wɛs* (a snaking trail made by fauna like snakes, deer, or millipedes) (for comparison with San classification of animal paths, see Takada 2016: 182–183). The Batek's skill at spotting such discontinuities in the landscape leaves their ethnographer shaking her head in disbelief. For example, we were tracking in the Penangx National Park once when ʔeyDukec and ʔeyHagap spotted a *tənaŋoh* on the side of the trail. It was a *cinroŋ*, confirmed when they brushed away the leaves to reveal the imprint of a pig's cloven hoofs (see Fig. 18.5). In retrospect, I could see

Fig. 18.4 Footprints in the mud (2013), attributed to a rhinoceros

Fig. 18.5 Uncovering the path of wild pigs in Penang National Park (screenshot from video, 2017)

discolorations in the soil which indicated that pigs had habitually passed through – once the tracks were pointed out to me. Most people, I suspect, would walk by without noticing anything. The signs are too subtle, and the forest is full of signs.

But most of their tracking, as discussed earlier, is arboreal. They not only have to attend to what's in the treetops; they have to connect that to the food that animals drop, to their characteristic smells and calls, to their knowledge of individual faunal behavior at different times, and to the wider forest milieu. Tracking is multisensorial for Batek, involving (at the very least) sight, sound, and smell and the knowledge that enables them to interpret what they encounter. It is not just a matter of seeing tracks and trying to figure out what Suzman (2017: 167) calls their “grammar”, “metre”, and “vocabulary”. Suzman was told by a Ju/’hoan man:

> [t]racks were there for everybody to see. . .but to read them you had to understand why they were made. (2017: 167)

The activity of interpretation itself is multisensorial, involving both visible and non-visible evidence, overlaid with countless observations of human and nonhuman behavior.

The third level of tracking is speculative tracking, which is complementary to systematic tracking; this:

> involves the creation of a working hypothesis on the basis of the initial interpretation of signs, a knowledge of animal behaviour and a knowledge of the terrain. . .With a hypothetical reconstruction of the animal’s activities in mind, trackers then look for signs where they expect to find them. The emphasis is primarily on speculation, looking for signs only to confirm or refute their expectations. (Liebenberg 1990: 29, 106)

The difference with systematic tracking is that in systematic tracking:

> Trackers do not go beyond the evidence of signs and they do not conjecture possibilities which they have not experienced before. (Liebenberg 1990: 106)

Liebenberg suggests that trackers vary between systematic and speculative tracking according to the conditions of the hunt; by taking the risk of (say) ambushing animals at a place where they are expected to appear, trackers might shorten the hunt. Reportedly, San trackers excel at speculative tracking, using “a combination of inductive and deductive reasoning outsiders have yet to understand”. (Biesele and Barclay 2001: 70).

As hinted earlier, the best Batek hunters probably do track speculatively, using their knowledge of landscape geography in their selection of hunting paths. For example, they may use botanical knowledge to explore likely feeding sites when they set out to hunt, thus increasing their chances of encountering game. ʔeyDukec remembers that it was in 1993 (when I was in camp) that he first brought down multiple animals on a single hunt (a combination of langurs and macaques). Up until then, he could only manage to capture at most one animal per hunt. He claims he doesn’t know what changed. I would suggest that that’s the point where he was able to incorporate speculative tracking skills into his repertoire. Certainly, there’s a lot of interindividual variation in hunting success. Speculative tracking provides one way of explaining this variation. However, this needs much more confirmation from the Batek.

Discussion

Studies of hunter-gatherer tracking rely heavily on Liebenberg’s carefully observed documentation of San tracking, enriched by his own scientific expertise in faunal behavior. But the environment he worked in is very different from the tropical forests of the Batek. Visual markers are clearer or more legible in the arid environments of the Kalahari. However, wind and rain play their part, and all marks eventually vanish whether in arid environments, in snow (Aporta 2009), or in the tropical forest. The effective difference is that simple tracking is unreliable for the Batek, except for extremely large animals (like the elephant), which leave unmistakable traces of passage through the forest. The default mode is systematic tracking, carefully gathering information, and piecing together a multisensorial picture of where prey is to be found. These tracks may be sequential (for example, when a scent trail is followed by sounds and then visual markers) or convergent (for example, when trackers sniff droppings to determine whether they were left by langurs or gibbons). Their visual, auditory, and olfactory acuity is exceptional and so is their vocabulary for expressing these states. Tracking for Batek is not limited to the interpretation of tracks, or, rather, the notion of tracks needs to be broadened, to include tracks that cannot be seen, but can be heard and smelt. It might be more productive to think instead of traces rather than tracks (Thomas Widlok, personal communication).

What then of the association between "reading" and tracks? When a tracker like ʔeyDukec draws on his expertise in seeing, hearing, and smelling the traces of an animal, he is not reading tracks. For one thing, reading suggests that the tracker is only looking at/for visual evidence. Rather, trackers draw on sensory input to figure out what is going on around them. Tracking is about multisensory engagement in the needs of the moment and deploying the skills to decide what is and is not relevant information. Tracking is about performance. The situational context of every track is different depending on the animals encountered and the particular suite of traces they leave behind them. Similarly, every tracker—every performer—will bring a different set of skills and aptitudes to the task at hand.

This paper has approached tracking as cultural activity. By this is meant that tracking is learned, not innate, knowledge. Although adaptation is a partial reason for the Batek's well-developed senses, expertise in tracking discernibly increases with age and experience, only to decline when faculties fail. In the case of the Batek, there is a broad stratum of knowledge about environmental signs and affordances, sightings, and events which all adults likely share, but there are subtleties, levels of expertise, which are more limited to those who regularly go to the forest and track. Only by following along on hunts (and other tracking-related activities) and being on hand when expert trackers are examining evidence does a novice learn how to do it, with secondary (derived) knowledge obtained verbally. This knowledge is visible in that it involves interpreting landscape traces, but much knowledge is tacit. Some kinds of knowledge are, if not esoteric, unlikely to be articulated out of context. For example, ʔeyDukec remembers that he was hunting with an older man when groups of gibbons sounded in the hillsides all around them, all at once; only then was he told that this was characteristic gibbon behavior for announcing rainfall (it did rain that afternoon). All this suggests that sedentarization and corresponding reluctance to hunt (both on the increase now) might pose a threat to Batek tracking knowledge.

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Chapter 19
Identify, Search and Monitor by Tracks: Elements of Analysis of Pastoral Know-How in Saharan-Sahelian Societies

Laurent Gagnol

Abstract This article deals with the knowledge and skills related to tracks in the sand among nomadic and semi-nomadic populations with a predominantly pastoral focus in the Sahara and Sahel. Identifying a sought-after individual, interpreting the associated clues, catching up with it by following the trail – all this is an essentially pastoral know-how. The punctual examination of the footprint aims at identifying the individual who produced it, and the search for clues associated with the footprint enables the tracker to discern other elements interpreting more generally the behaviour of this individual in movement. Through the understanding of the spatial and temporal context, linear tracking of footprints, by implementing a hodological strategy, makes it possible to catch up with the individual in question. Furthermore, this chapter discusses the power structures between the men who are in charge of tracking as well as the confirmation, assurance or subversion of the social order it implies. Finally, the permanence and transformation of this common and essential know-how in the process of becoming sedentary are analysed.

Keywords Track · Footprint · Path · Nomadism · Pastoralism · Hodology · Sahara

Introduction

> *Kel Awal a énnan: wa éshewayan tareyt wer gé élis* ("The people of the word say: he who follows the path is not a man.")

This proverb of the Tuareg Kel Ewey of Niger highlights the deeply rooted idea that an accomplished man never gets lost and should not passively follow a path: he makes his own way by examining the multiple traces on the ground. Unlike their sedentary neighbours, these nomads make it a point of honour not to depend on a route: depending on the objectives and circumstances, they examine ephemeral and

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discontinuous tracks that they follow or they choose to deviate from it. Consulting the tracks is not only about trying to orientate oneself and to find the way in the desert; it is also about interpreting the life that takes place there with all the movements, gestures, intentions, sensations, unexpected events that occur along the way as well as unexpected detours and subsequent narratives. Nomadic travel is not reducible to a journey between two points. It is to inscribe in the sand its passage within a network of itineraries of individuals who are also confronted with the desert environment and its traces.

This chapter presents the results of an empirical study on the knowledge and skills related to tracks in the sand among nomadic and semi-nomadic populations with a predominantly pastoral economy in the Sahara and Sahel. More precisely, they are the result of a thesis research among the Kel Ewey Tuaregs of Aïr in northern Niger (Gagnol 2009), exploratory surveys conducted in northern Chad (in January/February 2013) and especially in central Niger (in July/August 2012). While some additional observations are made, thanks to a short study carried out among the Tubus of Chad – more precisely the Daza and Bideyat of Borku and Ennedi – this study is essentially based on the analysis of about 15 in-depth interviews (individual and collective) with semi-nomadic agro-pastoralists of the Kel Agalal tribe (who belong to the Kel Gress Tuaregs) and who live part of the year in the community of Tajaé, south of the city of Tahoua in Niger. Most of the people interviewed are recognized as specialists, and most of them are elderly men, having lived as nomadic or semi-nomadic pastoralists, caravan guides and/or transhumant herders, providing them with a long experience in camel-dominated breeding. They have a high level of expertise in footprint inspection and tracking, and their wisdom is sometimes called upon to solve difficult cases.

This chapter follows a theoretical and epistemological construction on tracks that is relatively ancient – notably the evidential paradigm of Ginzburg (1980, 1989) and Ingold (2004, 2007) but lacks empirical study. Remaining as close as possible to its materiality – by an approach elsewhere qualified as geoichnological (Gagnol et al. 2018), a track is considered here as the material result of the passage of a moving body. It is ephemeral (being preserved and fossilized only on very rare occasions), specific (since it depends on the nature of the medium and many other circumstances) and individualized (since it identifies a single individual). Beyond the only specialists we were able to interview, the knowledge on the tracks is widely shared by all the Saharan and Sahelian rural populations and is part of a common and essential daily know-how (especially for pastoral and hunting activities). The similarity of the data collected between northern Niger and Chad attests to this. However, with a few exceptions (e.g. Liebenberg 1990; Therrien 1990; Aporta 2004), the lack of scientific literature on the subject does not allow this hypothesis to be confirmed and generalized to all pastoral and/or nomadic societies in the world. Other methods complementary to those presented here must be considered (see Lye Chap. 18) to deepen the knowledge (and their mode of transmission) that this know-how implies regarding tracks. This could involve investigating in situations through practices and not only through speech.

After having presented the unexpected richness of the know-how mobilized in the examination and tracking of spoor, the question of the power structures it implies will be raised and finally the question of the permanencies and current transformations it is experiencing under the effects of sedentarization.

Inspect, Interpret and Follow Tracks: A Common and Essential Activity in the Sahara and Sahel

Geographical Knowledge Relating to Sandy Soil

Pastoral societies such as the Tuaregs have a very rich geographical vocabulary to designate the diverse nature of the soils they travel and inhabit. Two generic terms are associated with the idea of soil: that of *akal* referring to the English notion of territory, country or region, without presuming any legal dimension (the territorial sovereignty) as a precise delimitation or scale, while the term *amadal* refers to the soil as a support and spatial extent (the terrestrial surface). It also refers to the soil in its materiality and depth (the earth, the underground world and the different aspects of the soil considered from the point of view of its composition). The Tuaregs distinguish precisely between different types of soil according to their texture but also according to whether or not they are suitable for footprints. For example, *taghardé* refers to a hard lateritic soil where it is impossible to follow the tracks. As for the word *ézizel*, it has a prototypal value. It is the noble sand of the minor bed of the wadis that offers the best qualities for the multiple practical and aesthetic functions that are attached to it. It is considered soft, white and pure because it is not dirty. Being sterile and mobile, it embodies positive values as opposed to the entrenchment of agrarian societies that identify with fertile humus.

The wadi bed arena is the most widely used material and has recently even become a small business. It is not necessary here to list the uses of sand in daily life or at specific events. Let us limit ourselves to noting its omnipresence: if it covers a large surface area of desert expanses and is thus attributed a wild character, it is also present within domestic spaces. *Ezizel* sand is brought and deposited inside abodes (tents, houses, mosques, etc.) and on the ground just in front of their entrances (the same applies among the Tubus). The interior walls are covered with it to make them smoother.[1] In general, sand is used almost daily: it is used as a writing medium (*tifinagh* alphabet, drawing, cartography, geomancy, etc.), as a mnemonic during an enumeration or simply to punctuate an argument or the salient features of a story. It is a mechanical gesture, and it is not uncommon to draw lines to pass the time while participating in a collective discussion, and which is immediately erased by sweeping it away with the hand. The games played in the Sahara are also based directly on

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[1] The rest of the houses are built with bricks made of a mixture of clay, sand and sometimes straw, all dried in the sun (adobe, known as *banco* in the Sahel).

the sand[2]; it is also used for culinary preparations (based on grilled meat or the famous breads baked in the sand and ashes, *togella*) and as a cache (provisions of food and water but also weapons). It is additionally used for dry ablutions and for therapeutic use (hot sand massage or heated *tégharghart* to treat cold diseases, or by using termite mound sand, considered to be sheltered from geniuses). However, sand can make you sick: direct contact with hot sand can cause a specific pathology *ézez*, same as damp and cold sand, *tessemdé*. There are also hunting and warfare techniques specific to the dune environments that the nomads master.

Finally, sand has a ritual value: while it is known as belonging to the wild world, that of the bush dominated by geniuses,[3] the floor of domestic spaces is covered with it at each rite that marks social life.[4] Sand is thus at the heart of the domestic world.[5] This is not without risk: for example, the tracks of newborns crawling on all fours on the sand would be erased for fear of being licked by geniuses, leaving them unable to walk. In some practices of black *éshaghaw* magic, sand is used to cast a curse on someone, preferably taken from the tracks left by the person's bare foot.[6] There are also sand-based prophylactic procedures to make rain and wadi flow and to stop an epidemic or a conflict (Gagnol 2009: 461–462).

Finally, drawing a line in the sand was of particular importance to the Tubus. One practice which seems to have disappeared today attests to this: it is a ground marking called *ortozze*.[7] At meetings of elders convened to settle a dispute, a line was drawn to separate the opposing sides: the fine was cancelled or doubled if one of the persons of the complaining party or the other crossed it. Other cases of *ortozze* imply a circle that was drawn around a date palm tree whose dates were beginning to ripen, which was how the owner was giving a warning signal to potential thieves. An even more serious warning is to draw a line on one's own trail when one knows one is being followed which is to indicate to one's pursuers that a weapon will be used if they continue beyond it, hence the trail becoming the path of war. Moreover, warning these enemies with this signal makes it possible to be absolved in the event of a deadly confrontation.

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[2] On the issue of sand in Tuareg games, see, for example, Bellin (1963) and Casajus (1988).

[3] The "song of the dunes" describes sand as an element of the geniuses, the whirlwinds being their caravans.

[4] In particular childbirth, appointment and wedding ceremonies, as well as religious holidays

[5] For example, the legendary account of the destruction of the Tuareg village of Takawat (Aïr, Niger) by a whirlwind of sand refers to the disorders created by a symbolic inversion between wild and domestic during a lavish wedding: to constitute the bridal tent, instead of sand, millet was placed on the ground; instead of leaflet mats of palm trees, fabrics were preferred to constitute the velum; instead of water, honey was poured into the jars; instead of a bull, it was a slave who was sacrificed (Gagnol 2009: 401–404). Among the Teda Tubus of Tibesti, the opening of the wild grass harvest in each valley gave rise to alms: a fragrant plant was thrown into the sandy bed of the wadi (Chapelle 1982: 382).

[6] This practice is very widespread: Lévy-Bruhl gave some examples on three continents (1927: 72–73).

[7] On this subject, see Le Cœur 1950: 160; Chapelle 1982: 320, 330, 334.

A Shared but Unevenly Distributed Pastoral Know-How

> A Tuareg riddle asks: “They are everywhere but you can’t grasp them. What is it?” Answer: “The tracks.”

The Tuareg language is very rich in vocabulary associated with spoor. There are more than a dozen terms to name the different types of trackways and paths. Concerning more precisely the tracks, there are about ten words: the generic term is *adériz*, while *tekkelt* refers to the human footprint, *asemmejannu* the footprint of a crouching animal, *azeggelleliz* a footprint in agitated sand, etc. At least seven verbs refer to the act of following a track and to subtle differences that are difficult to distinguish. The verb *agararas* means, for example, “to follow the tracks in the opposite direction”.

Tuareg and Tubu pastoralists recognize each of the animals they own by their footprints. The identification is thus individual. It applies to dromedaries, cows, donkeys and horses as well as to goats, but not to all sheep.[8] Frequently, they also know how to identify each head of cattle in the surrounding camps or concessions near the village. Finally, they recognize the footprints of the people of their camp and the surrounding camps and, among the sedentary groups, of some and sometimes all the people of the village. People know when they are dealing with foreign tracks, both for humans (they immediately recognize the arrival of a stranger) and for domestic animals (these are lost or stolen animals), or even for wild animals, as we will see later. The familiarity of the place and the intimacy with the people are thus lived through the tracks.

Footprint identification is an unevenly distributed capacity. It depends on the more or less great experience, the sense of observation and attention given, but also on the intelligence and memory of everyone: some people, it is said, recognize by the imprint the return to the village of a caravan or a migrant (called *exodants* in the Sahel) who left several months earlier. Specialists are sometimes called upon to solve difficult cases. They are mainly responsible for identifying the footprint and then indicating the track to follow, going up a few tens or hundreds of meters. They are not paid for it. Specialists can recognize the track of a lost animal that has crossed, or remained with, another herd (and animals are often lost because they follow another herd). In search of a dromedary, it is not uncommon to follow tracks over 2 or 3 days.[9] Some pastoralists who are unfit to identify their animals with their

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[8] Identifying ewe and ram by their footprints is less easy anatomically (their feet are very similar) and ethologically since, as gregarious animals with less marked individuality, it is more difficult to differentiate them by their behaviour: moreover, some individuals do not have an assigned name. Ewes are considered less intelligent and cunning than most animals, especially goats (on domestication among the Tuaregs, see S. Cabalion’s thesis 2013).

[9] Up to 1 week for exceptional cases. It is said in Tajaé that a man was able to follow the tracks of his guinea fowl for 5 km before finding them. Another found his lost sheep in the middle of a herd of about a hundred heads, etc.

footprints would tie wire under their hooves to facilitate their task. But this technique, rare and hidden, seems very uncommon because of the mockery it causes.

Footprint Identification Criteria

When examining the imprint, it is the anatomy of the foot that is analysed in the depression. Tracks enable to detect the anatomical characteristics of each individual's foot. In the case of the foot of dromedaries, Saharan pastoralists examine the sizes, volumes and wear of the constituent parts, namely, the sole, the heel, the two toes and their nails, the central slit, cracks and other features (Figs. 19.1 and 19.2). Each dromedary has a unique gait that the inspection of the print reveals: some project a little sand that settles next to the print; others press more uniformly without making a projection. For goats, sheep and cows (Fig. 19.3), it is mainly the shape of the hoof hooks and their possible crossing that distinguish them. The contact to the ground also differs: some only wear out that part of the hoof that touches the ground. It is also noted if the animal drags the hooves (Fig. 19.3). The same is true for humans: each has a characteristic foot shape and prop that are imprinted in the sand. The track depends on the anatomy of the foot but also on the gait. Part of the foot can touch the sand: some press more on the heel, others on the tip and others on the outer or inner edge. It also depends on the opening angle of the feet ("duck feet" or with an inward angle). Finally the pace is a distinctive criterion: the length of the step and the type of stride (trampling, shuffling, etc.). All this is observed through the

Fig. 19.1 Footprint of a dromedary's front and rear foot (Eghazer, Niger). This is a relatively recent imprint, but the wind has already blown in twigs. There are traces of urine droplets. The dromedary walks in an amble: this symmetrical, two-step pace means that the imprints of the anterior and posterior legs on each side are alternately brought closer together (here, they partially overlap). (Photo A. Afane 2013)

Fig. 19.2 Imprint of a dromedary (Eghazer, Niger). Recent footprint but tracks of nocturnal insects that intersect it indicate that it dates from the previous day. (Photo A. Afane 2012)

Fig. 19.3 Cow track (Eghazer, Niger) This heifer has the particularity of dragging its legs as shown by the small features that extend the footprints. (Photo A. Afane 2012)

differentiated wear of the sandals that are printed in the sand and allows individual identification.

Track inspection reveals certain particular characteristics that are specific to the individuals who left them. In the case of the dromedary, a herder can deduct from the print its approximate age. Moreover, the Tuaregs determine age according to the growth of teeth and the size of footprints rather than by size. It is easy to distinguish the first years according to the growth of the foot. But, from the seventh year onwards, when growth stops, it becomes more difficult. The appearance of the tracks (and what it indicates about behaviour) also reveals the animal's age: the juveniles are turbulent and jostle each other, while the older ones are quiet. For cows and goats, age determination is more approximate: the older they are, the more they drag their feet, and the hooks/nails are longer. The sex of the dromedary is revealed by the size of the sole as well as by the length of the step (and therefore the distance between the prints). In addition, the female dromedary's footprint is deeper (especially when dealing with a fully grown female), and the urine traces are different. The examination of the prints also reveals the unusual depth associated with a load (for a donkey, a bottle filled with water; for a dromedary, luggage such as that of caravan guides, etc.). Another indication is that when an animal carries a weight, the step length is shorter. When an animal is mounted, it can be recognized by the depth of the track but also by the more linear direction of travel. Trackers can distinguish certain diseases of the animal (the dromedary scratches its back with its legs or rubs against a tree for example), and they also see the degree of fatigue and injuries (limping, bleeding, etc.). The length of the steps and the degree of sinking of the feet increase with the speed of the animal: they allow detecting a slow or fast walk, a trot or a gallop, which is useful if one tries to evaluate the time it will take to reach the individual being followed by its tracks. Because we can, as we will see later on, determine quite precisely when the passage of the individual who left his track had been.

Hodological Strategy and Temporalities of Tracks

Footprint inspection allows to identify the animal and to know its path, i.e. the direction it has taken. But if someone wants to track spoor and track the individual who produced it, a one-time examination alone is not enough. Because following tracks is sometimes counterproductive, it wastes valuable time when looking for a lost animal that makes detours (or a thief who tries to make the tracks disappear or blur them). Besides, a track is not just a series of rectilinear imprints. The path it forms is very sinuous, and the line is often broken (by the temporary absence of tracks). That is why in order to follow an animal or a human Saharans, apply what could be called a hodological strategy.

The neologism hodology (or odology, from the Greek *hodos*, the path, the way) is a term used in psychology at the beginning of the twentieth century, referring to the notion of subjective space (Besse 2004). We refer to the work of the historian of ancient geography P. Janni (1984). Through the geographical narratives he analyses, Janni sees an opposition at work between a cartographic vision of the world (two-dimensional according to the axes of geographical coordinates) and a linear and multi-dimensional perception of the world, within which the time of travel, but also the movement and direction taken by journeying (real or fictional), takes precedence over the orientation according to the cardinal points. In some ancient texts, places or regions are described one after the other according to an itinerary, and everything happens as if the story shows a perception in situation and in movement. The surfaces and boundaries that prevail in the cartographic representation of the world are secondary in the hodological understanding of space, which is above all linear and mobile.[10]

The hodological strategy in spoor tracking consists in disregarding at least temporarily the punctual footprints by cutting the supposed itinerary formed by them, in order to meet the individual by a more direct and linear path. This is what the Tuareg verb *elked* means. The objective is then to join the trackway further forward where to find newer prints, while the challenge is to reach the individual without going beyond it. In practice, therefore, following punctual footprints is not all and everything. A tracker imagines the general path, the supposed purpose of the animal or human and the means or stratagems he or she will use to achieve it (so he must adopt their point of view and put himself in the perspective of others). This implies knowing not only the behaviour of the individual in question and even his or her character but also the places where he or she resides. It is all these skills that will allow to do less distance and therefore save time in order to catch up as quickly as possible (e.g. by going directly to a well). Following the tracks is a spatial game, a hodological one precisely speaking, because it is linear and in motion, but it is also a temporal game. To be effective, a tracker must project himself simultaneously in space and time. Doing it as quickly and directly as possible thus amounts to project oneself into the future and not only to follow the footprints, the traces of the past.[11]

The tracks suggest a passage, a movement: this implies for the tracker a distance to be covered, a speed and a time to complete it. In order to evaluate the distance remaining to reach the desired person, the tracker must calculate approximately that person's speed (the pace of walking) and thus the duration of his journey (the time between them). Then, by choosing a more direct route to retrieve the tracks, he must follow a particular course. After covering the estimated distance in a straight line, the route he has followed will become an area to inspect for fresh tracks.

Following a trackway is thus paradoxical from a temporal point of view: it is necessary to interpret past actions by what remains of them while being prospective. For the present of the tracker is the past of the being he seeks; the present of the latter being the future of the former. Following tracks is both going back in time and starting a countdown. Because time is precious, it is important to avoid that the animal goes too far and that the tracks are erased. It is crucial to know how to locate the footprint over time. Here again, the know-how is precise. New tracks are characterized by the fact that they have not been disturbed by the wind and that they have not been crossed by nocturnal insects. Saharan pastoralists distinguish

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[10] These two visions are most often intertwined, and it is not a question of systematically opposing them. In the spatial practice of Saharan nomads, a hodological vision coexists with a cartographic dimension and an orientation according to the four cardinal points. On this subject among the Tuaregs, see the analyses of Bernus (1981 and 1995), D. Casajus (2010) and those of my thesis (Gagnol 2009).

[11] We disagree here with Ginzburg's (1980) analysis which opposes the hunting "deciphering" turned towards the past to the divination, turned towards the future. As we have indicated, the intellectual operations involved in the tracking of traces (pastoral as well as hunting) also have a prospective aim.

Table 19.1 Objectives and means of know-how on tracks

Objectives	Means
Identify the individual	Imprint inspection: ad hoc review
Tracking to catch the individual	Tracking the trackway with a hodological strategy: linear examination
Discern its behaviour and the spatial and temporal context (of its passage and path since then)	Search and interpretation of associated clues: ethological and territorial examination

between the footprint that has a few hours (half-day), the one that has a day and the one that has spent a night. They can estimate the number of nights up to ten sometimes. Beyond that, the tracks are completely erased even if their disappearance depends on the substrate and especially on the meteorology (wind, rain, etc.).

The Clues Associated with the Tracks

The punctual and linear examination of the track is associated with the observation and interpretation of other clues that could facilitate the identification or search for the individual (Table 19.1).

An animal is identified by its imprint but also visually by its coat, by its branding mark[12] and even by its appearance when observed from a distance. Among the sensory qualities that are used, visual perception dominates. However, hearing is essential: people recognize, it is said, each species but also each individual by its call (cf. Lye Chap. 18). Smell and touch play less a role except, for example, in the examination of droppings. Complementary to the footprints, the latter are analysed in detail because they provide information on the time elapsed since the animal passed through due to their degree of humidity, crumbling, etc. Clues left punctually such as a trace of urine, a blood stain, a remnant of hair hanging on a thorny bush or lying in the print, a broken or browsed branch, a lair or a wallow – they all provide additional information. Dromedaries, for example, like to wallow in the sand and make a bedding by which one can see if they have spent the night there.

In addition to specific clues, a good knowledge of the territory is essential: it is necessary to know the water points and the good pastures to anticipate the direction taken by the animal. This familiarity with the territory is complementary to an intimate knowledge of animal behaviour. The ethological knowledge of pastoralists is based on ecological knowledge at the species level, but also on the habits specific to each animal on the scale of individual preferences. For example, herders know the

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[12] Some branding marks of cattle among the Tuaregs and Tubus are animal tracks (raven, bustard, gazelle, snake, etc.). These property marks are not individual but represent clans or fractions of tribes. They are not necessary for the identification of the animal but above all make it possible to prove the possible theft for vis-à-vis a third party. On this issue, see Landais (2000).

preferred places for dromedaries[13] which get lost by rushing towards or lingering near salt springs, or for some individuals which favour specific feeding areas (such an animal likes to enter millet fields and causes damage). Knowledge of individual habits makes it easier to find animals. For example, some breeding animals tend to chase females, so it is sufficient to identify the camel mares herd. Moreover, from the animal's imprint, one can infer its behaviour: it is discernible that a goat likes caprioles and that a camel is lazy, while another camel is irresolute.

If the track is lost and there are not enough clues, one can still be put on the trail by asking people who are met on the way for information. Because pastoralists know if there are any tracks of foreign animals on their rangelands. To increase the chance of finding an animal, one can also use divinatory procedures, votive offerings and religious alms (*takoté* among the Tuaregs, *sadaga* among the Tubus).

Confirm, Secure or Subvert the Social Order

Tracks as a Reflection of the Social Hierarchy

Through footprints, pastoralists recognize the different animal species but also intraspecific "races". The Kel Gress Tuaregs distinguish two main races of camels: the bicoloured ones, whose sole is rounder with a more pronounced slit (the *azelghaf* race considered more intelligent and robust, but less aesthetic and with poor eyesight), and the preferred saddle race (*ejiwi* more slender with a cream-colored plain coat), whose footprint is smaller with a smoother and longer sole. The Isherrifan Tuaregs, considered as specialists in tracks in the Aïr, go so far as to differentiate two races of sheep from their footprints. The origin of animals is also known according to the terrain they frequent: the dromedaries of the Aïr or Tibesti have a rougher sole, being adapted to rough and rocky soils, unlike the softer and more elastic sole of camels in the depressions and valleys of the Azawagh, Bourkou or Ounianga, which are used to sandy soils.

Contrary to the know-how on the tracks, linked to experience and personal intelligence, the gait and thus the imprint may be transmitted in a hereditary way. For Saharan pastoralists, anatomical features and the way of walking are transmitted from parents to children, and this can be seen in the tracks. As a father walks, so walks the son; or among the matrilineal Tuareg of the Aïr, rather like a maternal uncle so walks the nephew. But also a young dromedary walks like its mother. For

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[13] If not, there are other possibilities to detect them: at least that is what most stories of the discovery of springs, ponds, palm groves and salt marshes tell us which were found by following the tracks of a lost animal. For example, in Ennedi, it is claimed that it is by noticing the wet goatee of one of their goats and following its tracks that the Sara (Bideyat clan) discovered the Fada pond (*guelta*) and made it their home territory. In the same way, the Kel Ewey Tuaregs explain that it is by following the tracks of a lost camel that they became aware of Bilma's salt and palm groves, which they have since travelled in their caravan cycle.

example, it is told in Tajaé that a caravan guide had lost his dromedary more than a year ago. When he examined the tracks of a young dromedary, he knew that they were those of the offspring his female camel had had in the meantime. He followed the young dromedary's tracks that led him directly to the mother.

Similarly, in human beings, internal differentiations can be recognized – but more difficultly – through footprints. Ethnic groups have few detectable anatomical features. Rather, it is the cultural habits of each ethnic group that are revealed through the tracks. The Peuls Wodaabe of Niger, e.g. walk a lot and as a result, it is said, have toes spread apart. In addition they often use a stick which is clearly visible on the ground. In the same way, the Tubus say that people in Ouaddaï or southern Chad have different footprints from their own even if with today's intermarriages the differences are less clear-cut.

The hierarchical organization internal to pastoral societies is said to be more clearly identifiable by the tracks: each social category has a particular imprint. According to the noble Tuareg interlocutors, this is due to the fact that a man from this *amajagh* provenance has a haughty appearance (called *takama*) that can be observed in the imprint. He walks with a slow and steady pace, pressing firmly on the ground with the head held high, his back straight and his arms coordinated with the walk. This makes the feet stand out clearly in the imprint which is well marked and harmonious. There is no sand projection or dust raised. In contrast, the despised caste of the *inadan* artisans/smiths would, according to these same interlocutors, have an uneven gait made up of small quick steps and a disordered pace: the chest is advanced and the arms swing negligently behind the body. The prints are uneven and poorly formed. This appearance, considered as a buffoon by the higher categories, is called *taweligwelig*. It also corresponds to the appearance of former slaves who would trot in a disordered way. The track translates the body techniques and social order they reflect.

For dromedaries, trackers find this hierarchy in the gait and in the imprint: those with a saddle walk calmly, harmoniously and orderly, while those named *azelghaf* which are used for the gear of caravans sting the ground and hop. The look is more unattractive which is reflected in the appearance of the tracks.

How Can You Steal Without Signing Your Crime in the Sand?

After the search for lost animals or animals left unattended on pasture (dromedaries in particular), one of the first functions of the know-how on the tracks consists in finding a stolen animal by identifying and tracking it and then finding its thief by the signs he leaves on the sand.[14] Thieves are often strangers, so they are very easy to be

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[14] It also happens that someone goes in search of an individual which has got lost or has gone "crazy" and is lost in the bush. It is also possible to catch up with a travelling companion or a caravan that left early, etc.

recognized by their footprints in a nearby camp. Moreover, if theft is not considered to be committed by relatives or allies, it can take on a more rewarding aspect if it is committed by tribes towards whom a relationship of rivalry or even hostility persists. Among the Tubus in particular, cattle theft was once a mandatory step in proving one's bravery and ability to be an accomplished man. But today pastoral tribes are mainly victims of theft by sedentary populations when they are on transhumance during the dry season in the southern Sahelian regions. Caravan guides in particular are therefore very attentive to the footprints of their animals but also to those of neighbouring camps in order to react quickly in the event of loss or theft, the former often turning into the latter in these more populated regions that they know less well.

There are reliable clues to identify that an animal is stolen: the direction it takes is straight, and its footprint is deeper as it is mounted. If the thief walks, one can see his footprints next to the animal: either in front, and in this case he pulls it by the lanyard, or behind to move the animal forward which can be hobbled (in this case, pursuers can locate the place where the trammel was removed). Once a robbery has been detected, the victims try to find the thief by his tracks. The flight can be confirmed during the chase by observing the traces of camps where they stopped or loaded the animal into a vehicle. The pursuit may extend over tens or even hundreds of kilometres and cross international borders. It is not uncommon for Chadian Ennedi pastoralists to pick up their dromedaries from livestock markets in Darfur, Sudan, or for Tuaregs from Nigér to travel as far as Nigeria or Chad.

The thieves obviously know that the victims will be on their trail. They have schemes to scare them off and cover their tracks. They make detours, pass over hard soils (dry clay, rocks) or high grass and avoid sandy areas. If they cannot outpace those who are after them, they can waste their time. The objective for them is not to discreetly slaughter the animal which would delay and block them, but rather to bring it to the market to sell it alive. Some thieves even attach a small piece of cloth to the hoof (or a blanket on the rump) to sweep away the tracks. But, of course, this does not erase the traces of the sweeping which are even clearer and easier to follow (this tactic would be used by Hausa thieves, but it does not seem widespread and especially provides the Tuaregs with an opportunity to make fun of them[15]).

Cattle thieves are not the only ones being pursued by their tracks. All thieves are, even those who commit petty theft in village shops. Any marauder who seeks to thwart these future pursuers must be patient. He can spend a day observing the life of the village. He then notices the most worn model of sandals (Fig. 19.4), buys them discreetly and puts them on just before committing his crime. This will make it more difficult to find him afterwards. Others go so far as to change pairs of sandals several times during their escape. In the past, rudimentary sandals were specially made to

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[15] This practice is nevertheless attested elsewhere in the Sahara, notably in Algeria in the Tabelbala oasis studied by Champault (1969). It is also mentioned that one manifests one's identity by leaving a clearly visible footprint, for example, near luggage that one must leave unattended for a while. It is also possible to place things within a circle drawn with the foot, which reminds us of the Tubus *ortozze*.

Fig. 19.4 Trackways formed by two dromedaries and a dromedary driver (erg Chebbi, Merzouga, Morocco). The dromedary driver walks forward by pulling on the lead animal's lanyard. (Photo L. Gagnol 2014)

commit a crime,[16] or even, in Hermès' style, were made in such a way that the heel was at the front and inversely the tip at the back, to reverse the direction of the track: this stratagem making it possible to deceive pursuers who were misled and followed the trackway in the wrong direction.[17]

Nevertheless, there are counter-strategies to overcome the tricks of thieves. There is the anecdote of the commercial marauder whose victims had to walk around the village to recognize the path the thief took after his theft and compare these tracks with those that entered the village to be sure that they corresponded to the same individual. Tracking specialists know how to identify a footprint even if the person has changed shoes several times during the escape. The simplest way to fault the thieves' trickery is not to follow the tracks from where the theft was committed or to try to follow the tracks which he may have blurred. The trick is to find the route by which the thief came and which therefore indicates his way to the outward journey and not the return. Indeed, in general, thieves are less attentive to their tracks when they enter the village. The objective is then to follow the trail back to the thief's home – or starting point – but make sure he or she has not been to another village. If he was able to get rid of or resell the object of his crime, his footprint has the value of legal evidence, and he has no other means than to confess. This was also observed by C. Battalion (1963: 38) at Souf in the Algerian Sahara. In Fada, a small

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[16] On this subject, see the observations at Tabelbala de Champault (1969: 210–211).

[17] It is by no means a ploy specific to the Greek gods and Saharans: poachers of the French forests of yesteryear made inverted hooves for the same reasons.

administrative and military town in the Ennedi, no theft from a business is said to have taken place that could not be solved, thanks to the tracks.

Monitor by Tracks

The examination of tracks makes it possible to search for an animal or a thief, but also to carry out internal surveillance of the social group within the camp or the village. This question is more difficult to investigate than theft which is often attributed to foreigners.

The Arab geographer Al-Bakri (1975: 81) tells about how in his time in the sixteenth century the inhabitants of Zawila, in present-day Libya, monitored their city. Before nightfall, one of the guards was in charge of walking around the city walls, mounted on a beast of burden to which date palm branches had been attached, dragging partly over the ground. The next morning, the footprints left overnight on the previously swept floor were carefully examined by the guard and some other people on racing camels. If they noticed suspicious footprints leaving the city, they immediately went after the thief or fugitive slave (since the city was a large slave market). This allowed the city authorities to know who was entering (and where they came from) and who was leaving the city (and the direction taken by a possible runaway). Nowadays, in the south and west of the island of Madagascar, there is

> a customary system of village alliances and territorial surveillance to combat theft by detecting animal movements. Each village is responsible for its own territory which is based on the control of tracks left on the ground by zebus in strategic places of passage that are daily monitored and swept. (Saint-Sauveur, cited in Landais 2000: 458, translation TLE)

Nothing like this seems to be happening in the Sahara today. There are no local collective bodies responsible for carrying out such monitoring, and there is no mention of sweeping the sand to control access to a place. Although it is difficult to obtain information on this issue of internal monitoring, the attention paid to tracks seems trivial, if not almost instinctive for some people. On a daily basis, pastoralism requires sustained attention to the tracks of one's animals. Going in search of his dromedaries is an integral part of the life of a herder: they are left to wander, and it is sometimes necessary to follow their tracks for tens of kilometres to find them (often at a well or on good pastures). In villages and oases, it is also a daily exercise. A part of local life is found on the sand, and it contains many short stories for those who can read. For example, people know if a particular owner has entered his garden or left his house. One wonders what the two people who met said to each other because their tracks converged, etc. When the tracks are singular, reflecting an intriguing situation, they are examined more carefully: for example, why such a person ran, why he rested here, etc.

When a stranger enters a village, identification is carried out in three ways: by his name and genealogy when talking about him, by his face when seeing him and also by his imprints. Some people, before greeting a newcomer, look at the track even before they look at the face. In the village, only tracking specialists know everyone's footprints thoroughly. They then very quickly know the arrival of a stranger because new tracks appear. Foreigners are easily spotted[18], and one can know each of their movements.

Near the village of Tajaé in Niger, there is a hamlet of freed *ighawellan* slaves who looked after their former master's cattle. They are recognized as specialists, so they are often called upon in difficult cases, such as theft. Since they know the tracks of everyone in the surrounding villages and when a robbery cannot be solved, there is a high probability, it is said, that it is one of their own and that they refuse to unveil it so as not to betray anyone.

However, there is a practice among Saharans that may require more attention. It is a commonly accepted but hidden activity of a nightly gallant visit by a young man to a young girl. To avoid being spotted, he dresses in clothes and especially sandals that he has borrowed or reserved for this purpose. He enters, preferably on cool, moonless nights, camps or premises, slipping into the tent where the girl is lying, taking care not to wake anyone and leave before the first light of day. Despite all these precautions, the footprints easily betray the night incursion.[19] People in the camp/village can see tracks in the morning and go back to their source. But except in rare cases this is not done. There is a tacit tolerance of this practice, especially when people are acquainted with the person and their family and know their good intentions.

The Effects of Sedentarization: Tracks in a World That Closes, Freezes and Fixes Itself

Tracks in Hunting Practice

As we have seen, among inhabitants of the Sahara, the reading of tracks is above all a pastoral skill rather than being related to hunting. The difference between the two is

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[18] The first European observations on the "sagacity to recognize the tracks" of desert inhabitants seem to have been made by the Swiss explorer Burckhardt (1829) who travelled to the Arabian Peninsula in the early nineteenth century. Burckhardt delivers several pages in his account of what he considers to be "prodigious" knowledge that is almost "supernatural". He mentions specific examples: the Bedouins, Burckhardt tells us, forbid foreigners who sometimes accompany them in their caravans to walk beside their horses, because their boots, shoes or sandals, unusual in these countries, would risk betraying them and attracting the curiosity of looters.

[19] A ploy of the Tubu girls is indicated by Chapelle (1982: 295): joining the middle of the company where the man is whom she will wait for at night, she pretends to burn her feet on the hot sand and returns to her tent, having taken care to borrow his sandals and to make several comings and goings. She thus creates "a whole path of traces. This procedure will hardly deceive anyone but it will allow her to defend herself if she is accused: 'These traces, I made them, everyone has seen it'" [translation TLE].

essentially in that the hunter does not know the game he is hunting intimately, unlike the herder who is looking for his animal. The latter knows the particularities of each animal he owns: its anatomy, its character and its tastes. Even if long stalks make it possible to understand the animal's personality, the hunter interprets more a generic behaviour of the species than an individual one. In order to locate a track, he then uses much more of the species' territorialized habits as well as the specific clues it leaves behind to follow it (a game path, a broken branch, a lair, etc.).

If we take the case of Tajaé, there are no more large game animals in the region. The wooded steppe has been cleared to make way for millet fields, and today pastoralists are finding it increasingly difficult to find grazing areas for their herds. Gazelles and antelopes have been decimated by the use of guns and motorcycles to hunt them. The Tuaregs no longer hunt, since they do not consume small game such as lizards (varanidae), hares, hedgehogs, partridges, jerboas, etc. Only the Hausa continue to track these animals, and for some they are specialists in tracking. For example, they know the direction a snake takes with its traces: it suffices to look at the side where the sand is deposited to know its direction. When it passes over a twig, it moves up by lateral undulation on the opposite side of the direction it is moving.

Tracks of wild animals are also observed to get rid of harmful and especially poisonous species. Some people are familiar with the tracks of wild animals that frequent the surrounding areas mainly at night. In the morning, the herders recognize the snakes or jackals (Fig. 19.5) of which they are used to crossing the track, to such an extent that they know when a foreign snake or jackal has just arrived for the first time in the area. Dangerous snakes, especially horned vipers, are pursued into their

Fig. 19.5 Footprints of a jackal (Ennedi, Tchad). This probably nocturnal track was blunted by the action of the wind on the sandy soil. (Photo. L. Gagnol 2013)

holes to kill them. It is said that a marabout (a Muslim leader and teacher) from the village of Tajaé saw tracks of vipers around him when he woke up: he followed the trail for several kilometres before flushing it out. But he didn't kill it because it didn't bite him in his sleep. He bewitched it to send it to other places. Wild animals are thus considered as the livestock of geniuses. In the Aïr, a hunter tracking a sheep in a place without water points was surprised to find traces of water drops in its prints. This was confirmed when it was flushed out: its whole chest was wet because it carried water bags for geniuses, like donkeys do for men.

The Increased Difficulties of "Trace" Tracking in a Sedentary World

The presence of roads, villages and motor vehicles makes it increasingly difficult to follow tracks, and its effectiveness tends to decrease (Fig. 19.6). But despite the sedentarization, the know-how on tracks is perpetuated, even if the knowledge seems to be declining among the younger generations, or at least moving towards those of other frame tracks. Thus young people can read the track of a motorcycle (or a 4×4 vehicle): they can identify the direction it has taken and even distinguish it from other vehicles, thanks to its tire track, its wear and tear, its inflation level and assembling marks (patch, tape). They can also recognize a biker by ear. Not by the noise as such, but by what the noise reflects of the way of driving and in particular

Fig. 19.6 Tracks of a human, an insect, a donkey and a vehicle on a track (Tajaé, Niger). The superposition of tracks allows to locate in time the various circulations that took place here. (Photo L. Gagnol 2012)

the way of accelerating. The material and auditory traces reflect the driver's actions and the way he uses his vehicle.

Auditory traces are therefore also part of people's identification: if we recognize someone by their behaviour, people also identify a woman by the way she pounds, the rhythm and sound of the pestle in the mortar. An anecdote is revealing on this subject: a man walking down a street in the city of Agadez recognized a tailor friend without even seeing him – since he was sitting in a hallway – just by the sound of his scissors, in his particular way of cutting the fabric.

Today, it is the gravel roads and even more so the paved roads that make it even more difficult to apply know-how on the tracks. It obviously seems impossible to track a thief walking on tar with a stolen animal. However, some have managed to do so by observing the sand on the roadside. Knowing the direction, it is then advisable to walk along the road, paying attention to where the thieves left it. If they are in a vehicle, it gets more complicated. It is then necessary to visit the villages and especially the markets in the surrounding area to make sure that they have not sold the animals. When their tracks enter a village, it is essential to look around to make sure they have not left. Victims of theft then seek to negotiate with them through customary and/or administrative authorities. The surroundings of the village are guarded, especially at night, in order to prohibit any discreet departure with animals (on foot or in vehicles). It happened that this kind of siege lasted for more than a week, before the negotiations were successful and the pastoralists recovered their stolen animals. But in Chad and Nigeria in particular, the use of violence is widespread, and pastoralists are often armed to protect themselves against theft.

In the Sahara, people, domestic and wild animals and the landscape itself are particularly mobile. Sand in particular, by its soft nature, has the particularity of moving and constituting a moving morphology that temporarily records the movement of humans and animals by freezing it.

This work focused on the tracks as an object of knowledge and power particularly developed among Saharo-Sahelian pastoralists. Combining inspection of footprints to identify an individual in question, tracking and interpretation of the itinerary to track and find him, all this know-how on footprints is part of a hodological conception of space which, above all, is linear and in movement. To this sense of space that has often struck sedentary observers, the search for other associated clues is combined to better discern the context and understand the individual's actions. The interpretation of these clues concerns not only behaviour but also the stratagems it denotes: the reading of tracks requires anatomical and ethological knowledge but also a certain ability to take the point of view of others (of the animal, the thief, etc.).

The identification and tracking of spoor requires a thorough and proven knowledge of the desert environment. It testifies both to the relationship of humans to their territory and to domestic or wild animals, as well as to the power structures of people among themselves. The deciphering of what lies in the sand represents an unsuspected potential for knowledge and monitoring. This shows apparent links between the nomadic reading of tracks and the traceability procedures for bodies and objects, which also include monitoring their movement. However, there is an important difference: if the digital traces of computerized networks are achievable and therefore stable, fixed, even immutable, the tracks in the sand are only fleeting and fragile.

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Chapter 20
Trackers' Consensual Talk: Precise Data for Archaeology

Megan Biesele

Abstract This paper is based on ethnographic research with Ju|'hoan San in Botswana starting in 1970 and on translation and transcription work with Ju|'hoan San trackers from Namibia who travelled to the Caves du Volp in the French Pyrenees in 2013 to do archaeological work. The Tracking in Caves project, headed by German archaeologists Andreas Pastoors and Tilman Lenssen-Erz, was investigating fossilized human footprints in the caves dating back to around 17,000 calBP. The paper discusses three main verbal formats that can provide useful information to the archaeology of tracking: (1) narrative in the form of folktales and other oral forms referring to animal behaviour, (2) talk in the form of accounts of actual hunts, and (3) consensual discussion in the form of deliberations among trackers as they seek to gain many types of information from tracks. The paper outlines how the trackers and the archaeologists, after an initial period of misunderstanding and miscommunication, mutually learned from each other and eventually bonded on the basis of the scientific method. It does so by drawing on evidence from narrative, talk, and consensual discussion. By investigating verbal data provided by People's Science, the Tracking in Caves project shows us that skill in tracking, using the tools of egalitarian communication and based on extensive environmental knowledge, has been an enabling feature of the long human story.

Keywords San · Kalahari · Hunter-gatherers · Tracking · People's Science · Narrative · Consensus

Introduction: Tracking and Talking

> We should not speak of what we have been told, but only of what we ourselves see…What we don't see well, we can't speak of: only the things we see well. (Tsamkxao|Ai!ae [Tsamgao Ciqae], Pech Merle Cave, France, July 2013)

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In writing the introduction to this paper, I saw that it was best told as a story. I wanted it to graphically illustrate the power of narrative to bring alive a tale of learning and discovery. Thus I follow a roughly chronological path in telling how I learned what I have learned about the science of tracking and its importance for archaeology and other social sciences. Woven into the story are insights gained along the way from the study of the oral folklore, mythology, and social ideologies of hunting and gathering peoples.

In 1971 I was in the midst of fieldwork with the Ju|'hoan San of Ngamiland, Botswana (Fig. 20.1). At that time those Ju|'hoansi were obtaining much more of their subsistence from hunting and gathering than they are, due to land appropriation and other changes, today. I was learning their language, studying their folklore and religion, and observing how the environmental information necessary to their survival was codified, stored, and shared. I was particularly interested in the relationships between western science and what anthropologists later came to call People's Science, including tracking.

After my fellow graduate students in the Harvard Kalahari Research Group left our long-established camp at Dobe, Botswana, I set up my own camp at Kauri, nearer to the towns of Tsau and Maun. There were several groups of Ju|'hoansi living at Kauri, some of them working for Tswana cattle-herders. But much of their food still came from hunting and gathering, like that of the people at Dobe. I had brought with me several Ju|'hoan assistants from Dobe and was now on my own with no one to speak English to – a good formula for hastening language acquisition.

After a few months at Kauri, we needed to make a trip back to Dobe. We were intending to deliver Di//xao, my assistant = Oma!Oma's wife, and their toddler, to her people. Di//xao had become too homesick to stay at Kauri, but = Oma!Oma said he would continue to work for me. So we drove our Land Rover to one of the villages near Dobe where Di//xao's family had been living several months before. We learned that her people were not currently in residence and that they were living even further north, near Cherocheroha, in the direction of the mongongo groves, gathering the wild fruits and vegetables of that abundant 1971 rainy season and hunting.

I was quite taken aback. How would we find them? There were no roads – not even tracks – through the heavy sands of !Xu, the region of transverse dunes between Dobe and the groves. We were carrying a drum of petrol lashed snugly behind the back seat, and its contents were measured to suffice for only the kilometre distance we had planned to travel, with very little for contingencies. A stick poked down through the drum cap revealed only 6 inches of petrol left – and we still had many heavy sand kilometres to drive back from Dobe to Tsau, which had the nearest petrol pump. Yet we couldn't ask a young woman alone, carrying a small child, to make a dangerous walk like the one between Dobe and Cherocheroha, nor did the village people know when her family would return to the Dobe area. So the next morning, we began bush-crashing the Land Rover northwards. I was in utter trepidation, worrying about, among other things, running out of fuel and potentially losing precious weeks of assembling the materials for my dissertation. But as everyone

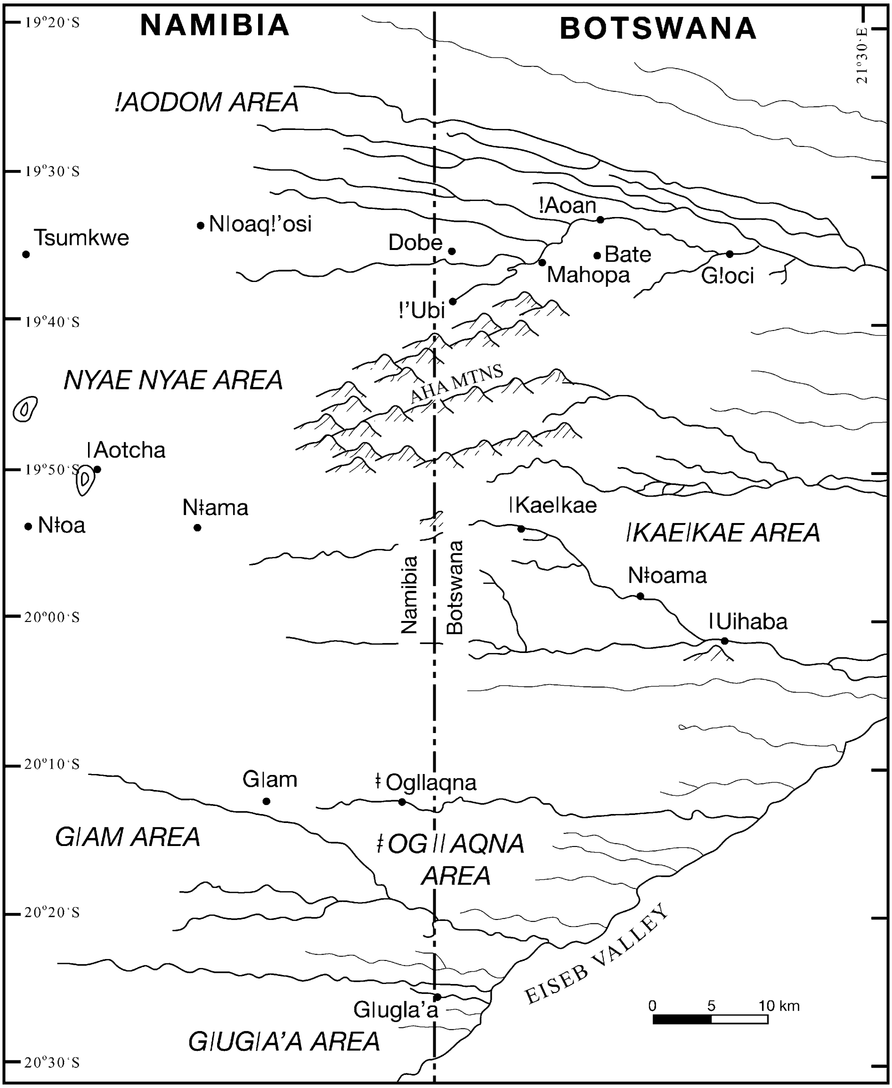

Fig. 20.1 Map of Dobe and Nyae Nyae areas in the northwestern Kalahari Region of Botswana and Namibia (Biesele and Hitchcock 2011)

else seemed relaxed and cheery, I decided I would just have to trust in their confidence.

After hours of banging into stumps, though, falling into aardvark holes, and cutting our truck out of thorn bushes, the afternoon sun began to wane, and we had not found Di//xao's family. I began to feel quite desperate. Every thicket, every clearing, started to look the same to me, and I worried that we might be going around in circles. My hands on the steering wheel were so hot I thought they might actually be getting burned. I was so weary and anxious that I felt we should go no further. “Stop!” said Di//xao suddenly. Gratefully, I stopped the Land Rover. She was sitting behind me on the back seat and pointing out her window. “Mba!u,” she murmured, “there’s my father’s footprint.”

In minutes we had located the people we were looking for. I was marvelling, but glad as they were to be suddenly reunited; everyone else concerned treated the whole episode quite routinely. The contrast between my amazement and their matter-of-fact certainty that the people would be found, using a combination of tracks known to all with geographic and social information about their likely whereabouts, could not have been starker. It whetted my appetite for learning about tracking knowledge: not a magical skill but an element of People’s Science on which Ju|’hoansi and their ancestors had clearly relied for millennia.

This experience was one of many pivotal moments leading to my eventual focus (in my dissertation and indeed in the rest of my life) not only on tracking but on the knowledge and communication systems – in general – of the Ju|’hoansi and other hunter-gatherers. I was thoroughly galvanized by the idea that there were close relationships between the ways information was communicated and remembered (including the stories I was recording that were rife with information about how animals behave and how humans ought to behave) and the people’s achievement of daily subsistence.

From the start of my graduate work in anthropology, I have been interested in the communication systems of hunter-gatherers. One of the first things I wrote after my initial fieldwork was a paper for the first CHAGS (Conference on Hunting and Gathering Societies) held in Paris in 1978 (Biesele 1978). Called sapience and scarce resources, it suggested the importance of studying sapiential paradigms of hunter-gatherer societies, defined as:

1. The repertoire of dominant images, image relationships, symbols, and metaphors used as constitutive elements in the prevailing world view of a society
2. The array of structures of description, inference, and persuasion used by a society to make decisions, solve problems, and generate consensus

I drew attention to what some at that time regarded as hunter-gatherers’ recondite systems of thought as actually embodying an essential and generalizable practicality. I referred to the famous 1976 paper of Blurton Jones and Konner “!Kung Knowledge of Animal Behaviour” (or, “The proper study of mankind is animals”) as laying the groundwork for the understanding that !Kung (Ju|’hoan) ethnoscience is in essence no different from western science. It has good predictive capacity for their subsistence situation and reflects a probabilistic view of the universe we would do well to understand and make available for comparative study in other hunter-gatherer societies.

Making the data of ethnoscience available demands, of course, not only precise understanding of language but a significant number of examples of its actual use. With regard to understanding the science of Ju|’hoan tracking, one can identify at least three spoken formats providing relevant verbal data. In ascending order of precision, it seems to me, these three are:

1. Folktales and other traditional oral forms dealing with animal behaviour
2. Accounts of actual hunts told by the hunter or hunters who were present
3. Spoken deliberations among trackers as they cooperatively assess tracks to determine which ones to follow as well as how to follow them

I started my fieldwork at the first level, recording many versions of the same story so as to make them available for the information they contained regarding, among other things, animal behaviour. This animal behaviour information is embedded in traditional stories in a way that is inseparable from not only environmental but also social and moral information (see Biesele 2009).

Later I became aware of the immense language richness in the accounts of actual hunts, the format I am calling my second level. Sometimes these accounts are told in tandem by two speakers in a form called by the Ju|'hoansi *hante*. One or both of the speakers would typically be actually present on the hunt. *Hante* is a dramatic and exciting, call-and-response, and/or repetitive type of narration that clearly enhances memorability.

John Marshall made a number of films of hunting stories told by the late = Oma Tsamkxao, the grandfather of Tsamkxao/Ai!ae who is part of the Tracking in Caves project (Cologne). During the 1980s I had the privilege of translating the Ju|'hoan parts of some of John Marshall's soundtracks into English.[1]

The third level format of spoken tracking information I identified, routine consultations made by trackers with each other while following spoor, required a level of athleticism that was beyond me even back in the 1970s. But in 1995 a happy accident of fate brought me into a tracking situation I could handle. Some months after breaking my ankle during a scholarly visit to Japan, I was scheduled for fieldwork in Nyae Nyae, Namibia, just across the border from Dobe, Botswana. I was to be accompanied by my late husband Steve Barclay, a former hunter knowledgeable about tracking in South Texas, who planned to make a study of Ju|'hoan tracking (Biesele and Barclay 2001). There, Di||xao = Oma came along with her late husband N!ani to walk back to camp with me should my newly healed ankle give out. Di||xao's presence gave us the chance to discover that Ju|'hoan women as well as men often have advanced tracking skills and that they sometimes use well-honed communication patterns long established with their husbands to participate closely in tracking animals. I presented these findings at the CHAGS conference in Osaka, Japan: Louis Liebenberg was there too, and I had the chance to learn more about his work with the CyberTracker system.

In another rich experience that took place on my level 3, in 2013 I had the chance to participate in the Tracking in Caves project with my Kalahari colleagues as well as a team of French and German archaeologists, the latter the same ones (Pastoors and

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[1] Many of these hunting story films can be seen in South Africa at !Khwa ttu San Educational and Cultural Centre, at its newly opened Heritage Centre, which has begun building an archive of San materials. Marshall's films have also been deposited at the Smithsonian Institution in Washington, D.C. These films are a rich resource on tracking skills and knowledge of animal behaviour. I hope it may someday be possible, through the Smithsonian's Recovering Voices Program, for the Ju|'hoan Transcription Group to transcribe and translate spoken materials from these hunting story films.

Lenssen-Erz) who have organized the Tracking Conference and this publication from it. The language data made possible by the setting and the technology then available seemed to me to be at the pinnacle of possible precision for outsiders like myself to begin to understand Jul’hoan tracking science.

Trackers’ Knowledge as Precise Data for Archaeology

Indigenous trackers routinely consult with each other while hunting: they sift and share evidence until consensus is reached. The three Jul’hoan San trackers who are still with the Tracking in Caves project today, Tsamkxao /Ai!ae, |Ui /Kunta, and /Ui G/aq’o, have been part of it since before it started in southwestern France in 2013. Joining them there as anthropological consultant/auxiliary translator, I facilitated collaboration between the Jul’hoan trackers and the French and German scientists in reading human tracks in four painted caves. Native language translation was provided by one of the trackers, Tsamkxao, as the three deliberated on evidence left 17,000 years ago by human feet.

Professional sound film was made of each verbal interaction. A most exciting aspect of the collaboration was this: lengthy conversations among the trackers were precisely time-coded to relevant visual signs of human presence within the caves. This produced a twinning of two rich sources of data in one medium.

Sound from the film can now be transcribed and translated for minute analysis of action verbs, body postures, and physical characteristics of trackmakers at each site. This work has been started by the Jul’hoan Transcription Group (JTG) in Namibia mentioned above, a long-term community-based project using ELAN transcription software (Fig. 20.2).

The JTG as an organization is committed to creative preservation of Jul’hoan language-based skills, knowledge, and social understanding. The JTG project makes it possible to use the social sharing of Jul’hoan men’s (and women’s) tracking knowledge to explore a precise new tool for the enrichment of archaeological data.

Fig. 20.2 Transcribers Charlie |Ui and Fridrik |Ai!ae, Tsumkwe 2007. (Photo R. B. Lee. for Kalahari Peoples Fund)

It also suggests a rich new dimension of collaboration between archaeology and anthropology: just for starters, understanding the social sharing of knowledge illuminates the relationships among people and how they share both resources and power.

Because elsewhere the background and new results of the Tracking in Caves projects are reported (see Lenssen-Erz and Pastoors, Chap. 6, and Pastoors et al. Chap. 13), I focus here only on outcomes of the particular roles I found myself playing in the project, those of supplementary translator, facilitator, and, as it turned out, temporary ethnographer of the project itself.

Tracking the Tracking in Caves Project

I start with the first few days of Tracking in Caves project (2013), which were spent in the Parc de la Préhistoire near Tarascon, France, and in the Niaux Cave. The experiences and communications of those days were critical to the eventual establishment of a good collaboration among archaeologists, trackers, and filmmakers. They were also the days on which the most dramatic realizations were made by each of the parties regarding what it would take to forge a meaningful collaboration. As in the introduction to this paper, I find it effective to present a narrative account of these critical experiences.

Lesson 1

The Parc de la Préhistoire was chosen for our orientation. This gem of French archaeology and tourism provides a stunning introduction to the caves, the paintings, and the methods and technologies once used by prehistoric hunter-gatherers of southern France. In the park building, we focused especially on the reconstructed subterranean mud hill known as Réseau Clastres. The hard-to-access Réseau features a bewildering array of dozens of fossilized human tracks and appears to have been frequently used as a pathway area for people travelling through the vast cave system. The archaeologists hoped that by looking at a reconstruction of the Réseau that is easy to view, the Juǀ'hoan trackers could shed light on how many sets of tracks were present and perhaps on the sexes and ages of those who made them 10,000 years ago.

In a dark hall in the park building, the Réseau model runs adjacent to a smooth walkway, with a metal barrier between visitors and the reconstruction, providing an unobstructed view of the masses of tracks covering the model, of what is now a fossilized, underground dune. Tsamkxao, /Ui, and /Ui stood together at several different points along the barrier, examining the tracks silently and intently with flashlights and pointers and from time to time conferring quietly with each other. The rest of us – the German archaeologists now joined by French colleagues notably including Jean Clottes the now-retired *doyen* of French rock art research, the film crew, and myself – kept absolute silence until they had completed their analysis. The trackers' discussion was captured faithfully with fine sound and visual equipment, after which the conversation was opened up to other participants. Tsamkxao gave us the summary of the trackers' observations. One of the first things he said was that all of the many tracks on the sand dune were made by the same person.

Audible gasps came from nearly everyone else in the darkened hall. There was a sudden sense that the entire project was imperilled. Running through many of the archaeologists' heads, I later found out, was a concern that perhaps these trackers who had been brought at great expense and fanfare all the way from southern Africa would not, after all, be able to corroborate the findings of Clottes and others in the original Réseau, dating to some 40 years before, that a number of different individuals had left their footprints on the dune. The silence continued for long, uncomfortable moments. Then Clottes himself cried out that he understood what had happened.

Using his hands to show the form of a plaster foot cast with a wooden dowel sticking out of the top of it for a handle, Clottes said that when the exhibit was made, the same cast must have been used to make all the footprints. Another audible gasp from all, this time one of relief – face was saved by the French researchers who had worked so long and earnestly at Réseau Clastres – and an immense respect for the honesty of the Juǀ'hoan trackers was born. Jean Clottes commented on camera on his regard for their abilities. It seemed the hoped-for western/indigenous scientific collaboration was soundly launched. However, we soon found we had relaxed our guard too soon.

Lesson 2

The following day we were kitted out with the official gear we would need to spend many hours deep inside Niaux itself. We each were given tough blue overalls and rubber boots to wear and had reliable lanterns strapped to our foreheads or around our waists. We wore as many layers as we could beneath the overalls, to deflect the damp, bone-chilling cold we were told would set in about an hour after we entered the cave.

The modern entrance is at a different site from the prehistoric opening to Niaux, now collapsed. In 1949 a number of human footprints was discovered about 600 meters from the original entrance, in a side cave now known as the Diverticule des Empreintes. A researcher named Pales wrote in 1976 about these imprints, saying he could discern 38 of them in the now-fossilized clay in an area of about 6 square meters (Pales 1976). Pales felt that the footprints were placed both intentionally and anarchistically by two to three children between the ages of about 9 and 12. Pales' interpretation was that the randomly distributed prints were evidence of an initiatory ritual dance. Everyone was excited to see what the Juǀ'hoan trackers would say.

It took about 15 min of struggle with a skeleton key to open the wire grille closing off the Diverticule to the general public traversing Niaux. Guards said it had not been opened in about 10 years. Once inside, we had to crouch very low to the floor and inch along the passage to reach the imprints. There was viewing room near them for only a few people at a time, stretched out on their stomachs or their sides, to look at the footprints. The three trackers looked long and hard at the chaotic collection of tracks, while the rest of us crouched in a nearby passageway or sat precariously on rough, uncomfortable boulders. Finally Tsamkxao gave the summation: the three trackers agreed that these were the footprints of a single 12-year-old girl who left an unequal number of left and right footprints. They said the prints were made slowly and deliberately, not in a hurry or in any sort of abandon. They also said they could not imagine why the prints were executed by someone who was clearly in a standing position, since the ceiling was only 0.95 m above the floor. The only person who could make such prints in an upright position would be a very young child.

Again the challenge to published authority caused consternation among the researchers. There was a very definite feeling that, among the archaeologists, doubt of the trackers' abilities had once again flared. The trackers maintained that they were just telling what they could observe with certainty, not trying to resolve the puzzle of the conflicting interpretations posed by the height of the ceiling and the puzzling distribution of left and right prints. We left the Diverticule then and proceeded to other parts of the Niaux system. But the feeling of mistrust and upset persisted.

That night, as we discussed the day, the Ju|'hoansi were angry. They felt that the scientists were not accepting or valuing their knowledge:

> After all," said Tsamkxao, "they tried to trick us yesterday with the plaster cast of the same foot, and now they've shown us something we can't understand from our observations. But they don't believe us when we tell them what we genuinely know about the girl's footprints! If they're not going to take us seriously, we might as well just go on home.

I'm not an archaeologist and was accompanying this project as a translator, not a person necessarily tasked with helping to sort out interpretations. But at that moment, I realized that both I and the Ju|'hoansi might be missing some vital archaeological information that might fit with their observations to make a more understandable whole. I spoke with both the Ju|'hoansi and the archaeologists about the urgent need for a different kind of communication between the western and the indigenous scientists if we as a group were to forge a meaningful collaboration. We arranged to have a meeting the following day.

Effects of Lessons

The Ju|'hoansi were pleased by the amount of care taken by the archaeologists to explain these things to them, and the archaeologists in turn realized anew the commitment of the indigenous trackers to telling the truth as they saw it, despite interpretive or social conflicts it might bring up. At this meeting a bond began to be cemented, and from then on, it grew ever stronger with each passing day. There was a recognition on the part of the archaeologists that, from the start, the trackers were practicing the scientific method (in which observations are made first and comments/hypotheses only later when all known facts are in place). They saw that they themselves were in fact not practicing scientific method to the fullest until they received the consensual testimony of the trackers as fact. Ultimately the western and the indigenous researchers bonded on a base of the scientific method.

Science and Memory

Louis Liebenberg's excellent book (1990) relies on the seminal article I mentioned by Blurton Jones and Konner (1976). Here is a quote from Liebenberg (1990: 43) on storytelling:

> Hunter-gatherers share their knowledge and experience with each other in storytelling around the campfire. Although this seems to involve relatively little direct transmission of information or formal teaching, much knowledge is gained indirectly in a relaxed social context. . .Storytelling in this way acts as a medium for the shared group knowledge of a band.

Because both Liebenberg and I gained so much insight from Blurton Jones and Konner's discussion of Juǀ'hoan learning memory, and communication, I would like to quote the passage in their article that has informed my own work since the day I set eyes upon it (1976: 344-345):

> (. . .) knowledge may be acquired mainly 'out of context,' in the relaxed social setting of the early evening, but it is then available when needed. One wonders whether the trade-off for the rather patchy nature of the knowledge transmitted is a greater efficiency in the 'filing' and retrieval of information stored in a system of the subject's own construction. This system is put to use when the subject wants to listen and when the storyteller's art gives many pegs on which to hang the information, and is quite different from one where he would try to store in his head someone else's data filed on that person's system.
>
> The explanation for the fact that knowledge gained 'informally' is assimilated more easily and rapidly than knowledge gained under pressure or direct instruction lies somewhere common both to that psychological suggestion itself and to the fact that it usually is acquired this way in (Juǀ'hoan) society. We have to ask why knowledge is acquired this way, and the answer to that may be also the answer to 'why does memory work that way?' One suggestion, itself raising further questions, is in the adverse reaction many people have to direct instruction. Not only can they be intimidated and confused, but (Juǀ'hoansi) (. . .) can be irritated by and can disapprove of people who tell each other what to do or in any way set themselves above anyone else. This presumably (and the people think so too) relates to very basic features of their society and its ecology such as food sharing. Since it is highly probable that successful exploitation of the social hunting and gathering niche depends on extensive food sharing, this is a powerful force among the selection pressures on hunter-gatherer behaviour. It is not, perhaps, far-fetched to suggest that this force may have been strong enough for long enough to set constraints on the way that information was best transmitted from person to person and acquired by individuals (. . .) (We advocate) re-examining our

> ideas on the function of old people as teachers or libraries (we suggest they are not reference libraries but are dramatized documentary television) and (. . .) examining closely the ways that information about subsistence is acquired and transmitted in hunter-gatherer societies. (Blurton Jones and Konner 1976: 345)

Conclusion: Talk, Narrative, and Consensus as Data

Trackers’ consensual talk, like hunting stories, folklore, and myth, provides precise data for archaeology and other sciences. There is clearly much of environmental and anthropological importance, not to mention illumination of the processes in prehistory likely to be responsible for the origin and development of *Homo sapiens*, to be gained from analysis of verbal and video data from indigenous trackers of the present. In particular, a transcription and translation process for sound files can grasp immense information treasures using fine-grained linguistic analysis. This information can then be further augmented in subsequent discussion. Such processes can, using the well-honed practices of consultation and consensus common to known hunter-gatherer societies, link time-coded talk to visual signs of human presence in caves and other archaeological sites. The video format allows for the twinning of two rich sources of data in one medium. For a sample indication of the possibilities of this data, the kinds of information obtainable include not only words and their semantic meanings but body postures, demonstrated action verbs, and demographic/physical characteristics, among many other sources of understanding.

All of these signifiers are connected by narrative to the values and behaviours that have long supported human adaptation: democracy of information-sharing, tolerance, respect for others’ opinions and knowledge, reluctance to rely on the knowledge of just one person, and reluctance to fail to share with all. We see the value of egalitarianism emerging as an overarching theme in prehistory for humankind. That, along with the skill of tracking based on extensive environmental knowledge, has enabled the human story.

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Chapter 21
An Echo from a Footprint: A Step Too Far

Steve Webb

Abstract Rarely in archaeology do we see the flesh and blood of ancient people living their lives? In Australia, a unique archaeological site discovered in 2006 allowed us to do just that as people went about their daily lives during the last glacial maximum. The site is a palaeofilm of men, women and children, walking, running and meandering across a wet area that was obviously special to them. While hundreds of footprints displayed this unusual but moving life tapestry, details of their behaviour and other marks they left behind were difficult or impossible to interpret. Moreover, were some of the marks made by humans or just artefacts of nature? Perhaps we were not making the right interpretation and not picking up clues to the everyday life of these people as well as we might. We required interpretative skills we did not have. To help us we needed to partner with people who had such skills. Pintubi people from Central Australia were asked to help, and they were some of the last people contacted by White Australia in the early 1960s. They had the vital skills of tracking, skills that had kept them alive in the harsh Tanami and Gibson deserts of Central Australia. It was possible that they would be able to apply those skills in reaching out to their ancient Dreamtime ancestors. They also brought that Dreamtime to us.

Keywords Ancient Australians · Pintubi · Tracking · Ice Age

A New Footprint

The current geological epoch is the Anthropocene. It is so named because of the significant impact we have made on the planet's climate and environment. It's not a good impact, and it's nothing to be proud of, but we are arrogant enough to put up a banner naming this infamous epoch after us. Anthropocene really means a time

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when humans have made a measurable impact on the planet, although no one agrees on exactly when it started.

The human population has grown almost to the point where we need two planets to support us. We have over 7.5 billion now and will have 9.7 billion in 2050 and 11.2 billion by 2100. Such growth has already taken us through an equanimity with our environment and the other life forms with which we share the earth. We have moved into a time when our footprint has brought about a significant extinction event for its animals, so much so that it is ranked with the top six of the past nine major extinction events which the planet has undergone in its 4.5 billion-year history. We have eliminated earth's natural forests and poisoned its oceans, and humans are beginning to undergo a slow strangulation of themselves through that process and collective greed. That is a footprint!

We can see the effects of that footprint all around us via the many trackways we leave behind. They are presented to us incessantly by the media, social and otherwise, as well as our own eyes. One trackway is our ever-expanding cities, roads and other forms of built environments we are putting in place of the natural environment. Another is our warming world. Except for the oceans, there is little left of the world that hasn't been visited, influenced or damaged by our presence, actions and the overwhelming technological and mechanical know-how that enables us to exploit it. Once, we were as close to animals as family. We painted them, we carved them, we needed them, we worshipped them, and we revered them, so we might survive because we so depended upon them. We also killed only those we needed for food and skins. People are just now beginning to wake up to the fact we are a menace not only to the welfare of the planet but to ourselves. That is a footprint!

Why do we do it? Perhaps because we have become removed from nature and, in reality, far removed from our ancestors, almost as though we are unrelated strangers. We are now the hominin that will kill off the planet's animals for profit, rip out their environments, pollute the oceans with plastic and other modern dross, destroy ecosystems to graze one or two domestic livestock species and plant monocultures like palm oil and soy beans replacing natural ecosystems and the animal species that relied on and evolved in them. Some of the last indigenous people, like those of the Amazon, Australia the Arctic and Southeast Asia, know those things and try to stop the destruction, at present in vein. In the oceans we destroy the marine equivalent of rainforests, coral reefs, with dynamite to catch a few fish, with overfishing in waters of local peoples to feed billions elsewhere. And we have human-induced rising water temperatures changing oceanic ecosystems, changing fish habits and destroying trophic systems.

We are no longer the pioneering people who strode the earth, inhabiting all the continents in the Pleistocene. Perhaps we became too strong, and we produced too many of us for our own good, so that we could no longer see the consequences of our activities and because we have lost our affinities with our natural world. We are killing planetary life through anthropogenic climate change and consciously by stealth. We poach, kill and traffic horn, body parts and living creatures. We do it for greed and profit and to fund wars. Other reasons include the need for quack potions, false aphrodisiacs, meaningless medicines, artless carvings and pointless ornaments and to supply foreign currency for corruption and drug trafficking by all nationalities and creeds.

Animals belong to all of us as our natural heritage, and they are supposed to be in our care. They are under severe pressure, but we kill them for sport: one more death won't make any difference! We humans have become greedy and thoughtless about our fellow animal travellers and the earth on which we stand. Many of us are bereft of common decency, humility, humanity and the ethical and moral considerations that made us different from animals and arose from the Enlightenment.

Our archaeological footprint will be easily seen for all who visit this planet in future. It will not take painstaking work to piece together our lifestyle and legacy like it does for an archaeologist today to reconstruct the past. Unlike people in the Pleistocene, we have become separated from the earth. Most of us live in cities, suspicious of and cringing away from open spaces and fearing the wide outdoors like skulking cowards. Cities are places where it is easy to think we no longer need the earth and be close to it or need to know anything about its workings and interrelationships. Most humans are totally ignorant of how it works, nor do they care because food appears in the supermarket and when they have had enough to eat, they throw it away, unlike the old hunter-gatherer that would save surplus in case the hunting and gathering doesn't work for a few days or even weeks. That hunter-gatherer also knew all about the interconnectedness of earth's systems and being part of the rich tapestry of life that surrounded them. It was not by scientific knowledge but by watching and gathering experience during their lifetimes. It was also passing that knowledge on to the next generation. If they didn't have that knowledge and understanding, they died. They lived close to the environment, but like them our future depends on the world around us and how we treat it. Our forefathers wandered through a world that they knew and totally relied on. They survived not only because of what they knew but what they could learn, knowing every tree in their forest and rock on their hillside. Through scientific endeavour we now know more than they did about the intricacies of the earth, so you might think we should know better. But we don't; unlike them our knowledge seems to have had quite the opposite effect and moved us farther from it.

Today, we have swapped the rocky cave for an electronic cave that separates us from the real world and teaches us all we need to know from the comfort of an armchair or desk. Unlike our ancestors we do not leave our cave very much and explore what is around us. But we hope the electronic pathway we tread and computer screen we gaze at incessantly will take us where we want to go. We don't really have to go and see or experience the world for ourselves. We don't have to touch it, smell it, listen to it, taste it or feel its temperature like our ancestors had to do to survive. We hope our earth will naturally save us and continue to provide for all our wants and needs and save us from ourselves: that is if people think about the earth at all but it is clear many do not.

An Old Footprint

What if we could step back two epochs, skipping the Holocene, to the Pleistocene, when most of the footprints discussed in this volume were made? What if we looked for a different footprint than that discussed above? What if we looked around for evidence of humans? Unlike today, it is more than likely we could not readily find it and that would be so even in the Late Pleistocene. If we were very lucky, we might stumble upon an open camp site and find some smashed stone or flakes or even the odd patch of burnt ground or old hearth. We might even find a scarred tree or the meagre remains of an old kill or a broken, discarded implement, perhaps some broken branches if we were very lucky. But any of these things would be few and far between. From the highest viewpoint, we would not see a human presence unless it was a wisp of smoke far in the distance perhaps wafting up from a dense and seemingly endless blanket of forest. We would, however, see quite a lot of different animal species, insects and plenty of clean drinking water. We might even see animal tracks and if we were very lucky the human tracks following the animal, if the weather did not eliminate them first. Tracking was a vital and necessary skill of the people then. Knowing what animal made the track, which way it was going and when it had made the tracks was the real skill of the tracker and the key to survival. That skill is fading away, but it can still be found if one looks hard enough.

A very rare event took place in Australia in 2003. It was during a small survey being carried out by Aboriginal people and myself in the Willandra Lakes World Heritage Area in western New South Wales (Fig. 21.1) that we found footprints. It was almost something akin to the scene just presented above. It was a remote area, and there was no sign of humans or their works except the people I was with. There was no sign of modern humans on the ground either, just a few stone flakes and some freshwater mussel shell left over from a Late Pleistocene gathering expedition. We were walking across a blowout where sand had been removed from a harder indurated surface below. To our right was a large sand dune that we were approaching with someone in front of me. There, in front of the young Aboriginal lady was a human footprint on a unique light grey clay surface, exposed by the retreating sand dune. I was several metres away following behind her when she turned and asked me: “Is this a footprint?”

The Willandra Lakes Region encompasses a series of fossil freshwater lakes that finally dried out around 15–12 ka. The criteria for the Willandra’s World Heritage listing required the area to possess outstanding universal cultural and/or natural heritage values. The Willandra certainly does, so that criteria was satisfied, and World Heritage status was conferred in 1981. The region has been occupied by humans who camped on the lakeside beaches from at least 45 ka. Very special discoveries of both cremated and non-cremated human remains have been made there. From those it has been possible to reconstruct the cultural, ceremonial and belief systems practiced by some of Australia’s oldest residents as well as their artefactual capabilities and use.

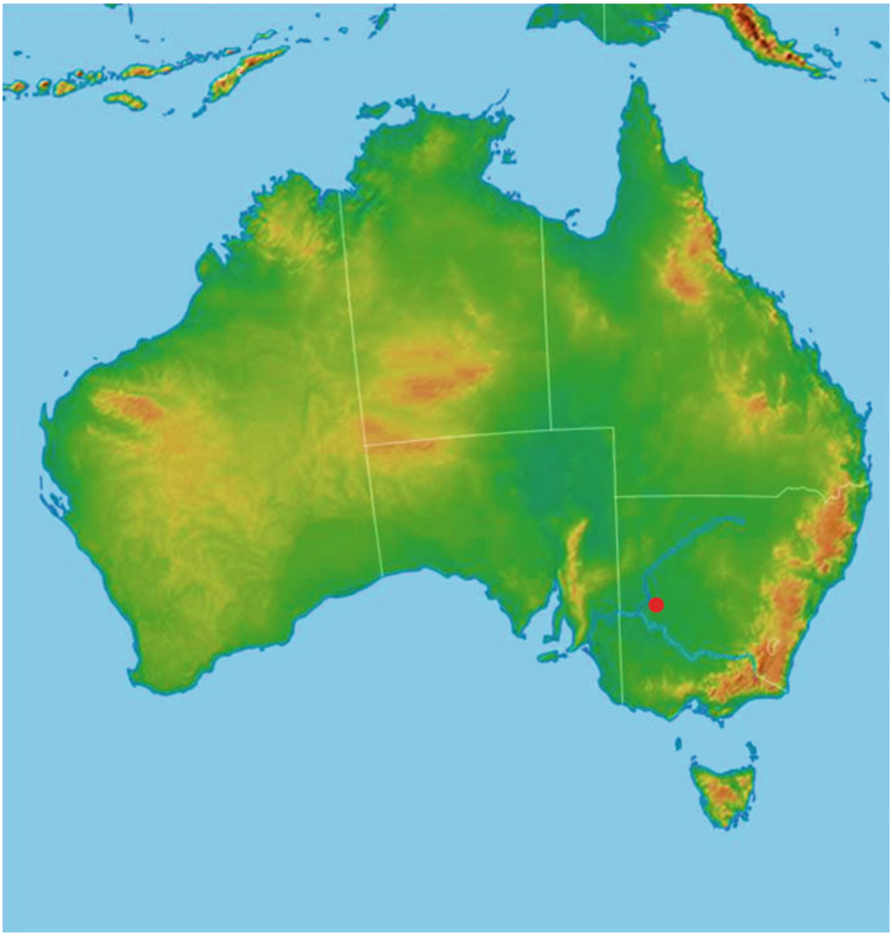

Fig. 21.1 Willandra Lakes World Heritage Area in western New South Wales

The fossil footprint discovery work operated over 2 years revealing hundreds of footprints, dated to between 25 and 20 ka (Webb et al. 2006; Webb 2007). They were found on a rare 850 m^2 magnesite clay pavement, a sediment not previously found in the region (Fig. 21.2). The discovery eventually uncovered over 700 prints, some forming 23 trackways (those composed of four or more consecutive footprints). The longest consisted of 29 prints. The site presented an area of activity by both adults and children moving in various directions with some intriguingly walking side by side, some meandering across the site and others walking over previous prints (Fig. 21.3). The site obviously indicated a group of Ice Age people going about their daily lives but seemingly concentrating on this particular spot in a rather purposeful manner, probably indicating this place was a special natural or perhaps ceremonial site of some kind. There was something else that was fascinating about

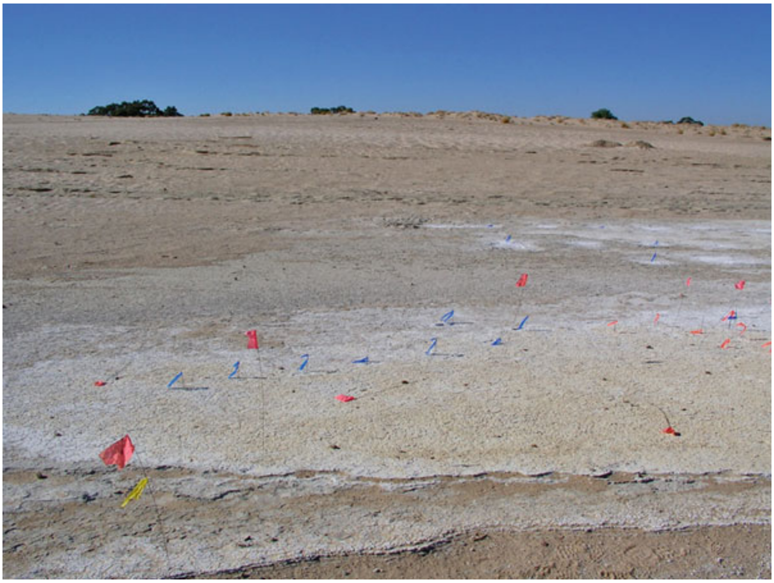

Fig. 21.2 The grey magnesite surface where the prints were found with the retreating sand dune in the background

Fig. 21.3 Uncovering a trackway by predicting its direction and using the stride length to place where the next footprint should be

Fig. 21.4 The site composed of several layers indicating cyclical filling of the pond. All layers had prints and marks on them

the site; it consisted of at least six layers on top of one another (Fig. 21.4). All these had footprints or other marks on them consistent with activity.

Some male prints formed long meandering tracks, while four told of a group of men running fast and parallel to each other while making a slow curve to the right, as they might while hunting game. What was clear was that the footprints represented a unique social gathering of some kind with men as tall as 1.94 m and one running at up to 37 km/h. More importantly, the prints brought the people to life in a way no other archaeological evidence could. Creases beneath the feet of some prints brought that special feeling of seeing flesh, life, tissue and blood. These people were acting out their daily activity at a time when the world was deep in an Ice Age. Someone could walk south from Australia to Tasmania or north to Papua New Guinea by land bridges exposed during low sea levels. An even longer walk was possible from Dublin to Tierra del Fuego without getting your feet wet.

The prints showed life, the life and the actions of people long disappeared. They must have been gathering around a shallow but moderately large pool of water possibly formed when the nearby lake was full and sent groundwater seeping underground across to this place. The resulting vegetation growing in and around the water may have made it an ideal place, attracting birds and animals and an obvious target for hunter-gatherers. These tracks now exposed the activities of such a group or band whether in multiple events of a few people or only one or two of many people. Perhaps it was a transient community that normally lived far away, or was it a local band that focussed on the Willandra Lake system? Whatever the case, the prints made a very real and unique human connection across millennia with those of us who viewed them through the intimate shape and features of their feet. The tracks of three children meandering across one another showed, for example, the typical behaviour of children (Figs. 21.5 and 21.6). Together, wandering about but going in the same general direction as children do: these children of the Ice Age spoke to any father or mother of today.

Fig. 21.5 An adult and several children's tracks move across the surface and off site, disappearing under a large sand dune behind the site. Local Aboriginal Elders look on. The track of the one-legged man crosses below in strides of over 2 metres. (Photo M. Amendolia)

Fig. 21.6 A lone child of 20,000 year ago makes its way across the site at sunrise. (Photo M. Amendolia)

Our interpretations of this special evidence, unique in Australia, were not enough, however. There was the strong feeling that while we could make good educated guesses about the site and offer suitable answers of what it might be about, the unique marks and prints on it needed a deeper interpretation, if possible. This was evidence from the past that was above and beyond the normal archaeological approach. This site was, to all who saw it, something that we had to wring the last piece of information from if possible. We worked for weeks looking at the marks and the prints. We could take various measurements, but it was as though they were enigmatically hiding information that would make them really come alive. It was then I began to think about who could help with interpreting the site. There seemed

Fig. 21.7 (**a**) Mijili Napananga; (**b**) Paddy Japananga; (**c**) Johnny Napurula; (**d**) Paddy Japananga leading the way with members of the local community and Johnny Napurula bringing up the rear while pacing out a track

to be no one, certainly not in the archaeological field that had any experience with such a task. What we needed was someone who knew about footprints and tracking. It seems trite, but what we needed was those who could track!

It seemed logical to turn to any Aboriginal people that could track. While many might be able to do that or claim to be able to, some would be better than others. I contacted a non-Aboriginal friend in Central Australia to ask him about contacting such people there. But is was not just contacting them, would they be willing to come down to the Willandra 2000 km away, and how could we arrange that even if they would? My friend put me in contact with another non-Aboriginal person who knew trackers. That person was Peter Bartlett Japaljari who was married to Cindy Nakamarra, a Pintubi woman. He had spent many years in Central Australia, knew many Pintubi, Warlpiri, Pitjantjatjara and other tribal people from across the region. Importantly, he had been initiated and knew several of the desert languages. Cindy's mother Mijili Napananga was a brilliant and very famous artist and a Pintubi Elder (Fig. 21.7a). Her group had been contacted in the early 1960s by the anthropologist

Donald Thomson (1975). He had mounted two expeditions to look for some of the last desert people living totally isolated in Australia's centre without ever contacting non-Aboriginal people. People were known to be living out in some of the remotest desert regions because as small track building gangs had pushed through some areas, they had encountered a few of the people. Mijili and her group had been living much as their ancestors had been doing for thousands of years. So, when Thomson arrived, it was the first time she and her group saw non-Aboriginal people.

In the late 1950's and early 60's Australia was involved in testing the Blue Streak and other missiles and even the detonation of Atomic devices on behalf of Britain that was the reason for basic tracks being built prior to the launches. Some effort was now being made to contact the desert dwellers who were still living in the remotest parts of Central Australia so they could be removed from the path of missiles. Similar expeditions had contacted Mardu people in the western Gibson Desert in northwest Australia, and they had been removed from missile trajectory paths although, later, it was found a few had remained out there.

Thomson visited the camps of the Pintubi and took many pictures of them and their lifestyle (Thomson 1975). Whether true or not, the Pintubi name is synonymous with living in the harshest of Australian environments. But perhaps an even more truism is that they are known as survivors and the last of them came in as late as 1984. Thomson's record depicts a very harsh landscape that makes one wonder how anybody could have gathered enough food to survive. People were thin, almost completely without body fat, but nevertheless reasonably healthy. In contrast the children were chubby and happy and enjoyed playing at hunting small lizards with toy spears and collecting them in their hair string belts tied around their waists. The key to finding the meagre menu on offer in the eastern Gibson and western Tanami Deserts was being able to make the most of the creatures that lived out there. Unfortunately, the protein mainstay of the diet was only a few small lizards, such as thorny devils (*Moloch horridus*), snakes and witchetty grubs. So the skills of tracking had to be at their best with such small game to follow and tracks that could disappear with a puff of wind.

Besides Mijili and her daughter, Peter Bartlett Japaljari was also able to contact two male Pintubi Elders Paddy Japananga and Johnny Jupurulla who also had had no connection with non-Aboriginal people till their early 30s (Fig. 21.7b, c). Thomson first located Mijili's group near Lake McKay that lies on the Western Australian/Northern Territory border, although her country was situated around Mount Webb in the southern part of the eastern Gibson Desert, southwest of Lake Mackay. These people came from the heart of the continent and a place that at time is so harsh it is unbelievable that anyone could survive there. It quite naturally gives a feeling that if you can survive there, you must possess some very special skills that enable you to do it. One of those is being able to track. But it is not just track; it is the almost microscopic nuances of a track – its shape, size, impression depth, surrounding soil removal and in what direction it's going, as well as other inflections that all together identify what made it, how long ago, its size and age, sex, direction of travel and how far away it might be. And it's not just tracks per se; it is marks on the ground around it or otherwise associated with it. It's also their width, length and circularity, whether they are repeated and at what frequency they repeat. It all sounds very scientific, but the skilled hunter can calculate it all in a split second. Too slow or unsure and the hunter loses food: that cannot be repeated too often!

All this would go into a Pintubi assessment of a track or mark, and that is what survival means. It is a shame, but those with such gifts are the old or elderly because you gather such skills with age and experience. But age and mortality in many situations where Aboriginal people are concerned do not necessarily correlate as they might in non-Aboriginal society. Aboriginal mortality often arrives at an unexpected and early age and with the death of an Elder culture disappears, particularly if the young are not interested in learning about it. The same occurs with languages, and of the 250 languages that once were spread across the continent, only about 50 have some speakers left. Therefore, the art of tracking, which is culture as well as a deeply incisive skill, is disappearing fast with the death of Elders. I can attest to this with the fact that the three humble and proud Elders that helped us are no longer with us.

What was humbling to me was that these particular Elders, with such special skills and nothing really to gain, agreed to come down and help us interpret our site. I believed that travel was going to be the real difficulty because many Aboriginal people, particularly tribal Elders like these, do not like to leave their country, at least not for long. When they first arrived, and before we had visited the site, their immediate observation was that the local Aboriginal people of the Willandra were the same as themselves; they were desert people. All indigenous people got on very well, and the local people were so glad to see these old people had come and visited them in their country. When the trackers came for a second visit, they brought a traditional digging stick for the local indigenous women as a gift for being in their country again and as a bond between them.

Old Paddy was one of the first to walk onto the site itself, and he was visibly amazed by what he saw. His demeanour then is not often seen with these often shy and reticent people from the desert. It was obvious that the trackers did not want to offend anybody or make the wrong move and were deeply aware that they were in someone else's country. Paddy's amazement manifested itself in his face but also his voice. He began to speak in whispers. He spoke his own language and could have spoken in any of the other five traditional languages that were known to him. It was obvious that English was not his favourite language and he did not speak it well. English does not describe his country, and so it didn't matter that he could not speak it well. It is after all a foreign language and not one that is from or describes his country the way it should be in a proper and respectful way. The principle is: if you don't know your language, you don't know your culture or how to understand and know your country.

As he walked across the white surface and spotted the first of the prints, his whispering was closely monitored by Peter Bartlett Japaljari who knew the Pintubi language very well. Peter told me later that Paddy had said this was a very ancient place, a Dreaming Place, a special place made by ancestral people. For Paddy that meant the people that these prints were ancestral beings who, for him, probably made many things in the dreamtime which has no date: it is deep in the past, continues to

Fig. 21.8 (**a**) A hole in the clay surface made by the head of a spear while rested; (**b**) a doodle made by a child’s finger in the mud

the present and goes on into the future. Paddy knew nothing of the age of the site. His whispers were the respect he had for the place and the fact that he believed he was in the presence of ancestral people who had long gone but whose spirits were still there. The only way I can describe it is like we do when we hush our voices when entering a church or cathedral even if we have no religious faith; it is automatic through experience and culture. Paddy almost glided across the surface in his stockinged feet, as was standard for walking on the site. His head under his large, grey bush hat moving very slowly from side to side as he peered through his glasses (Fig. 21.7d). He did not say much, but by that time, Johnny and Mijili were also walking slowly on the site. They were all quiet but looking. It was a special moment for all that were there. Peter told me that whatever could be learned from the surface, they would be able to tell us about it.

Mysterious marks were interpreted for us such as a group of lines of various widths had been made across the surface. The trackers told us this was where someone had dragged sticks or a branch across it possibly to build a fire somewhere. Another long mark we were told was where a spear had been thrown and ricocheted off the surface. There were small round holes in some places, and those were made by someone standing or resting their spear on its blunt end to keep the point sharp: “To keep the point sharp” (Fig. 21.8a). That seems logical, but Johnny wanted to

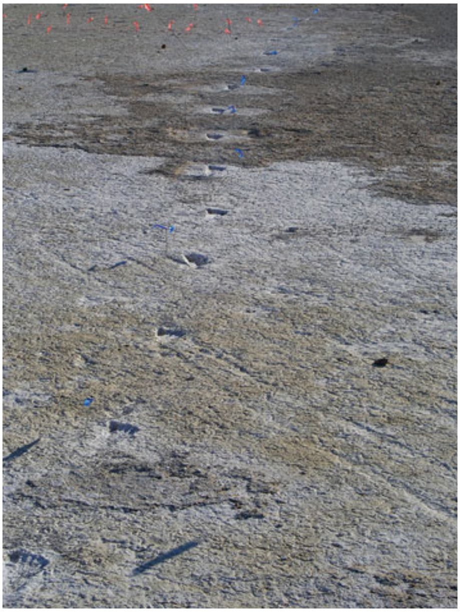

Fig. 21.9 The track of a one-legged man with a missing left leg. The track crosses drag marks made by branches being dragged across the site

make it clear that you don't put a spear in the ground point first because you will blunt it and it will not be useful for hunting. Another feature was a shallow semicircle in the mud that the trackers interpreted as probably a child making a finger mark in the mud, in other words a Late Pleistocene doodle (Fig. 21.8b).

Probably the most baffling thing found on the site was a set of tracks that lacked a left footprint (Fig. 21.9). We looked in vain for any sign of a left foot and began to make up tales to explain what we were seeing. One idea was that this was a very shallow pond, which we were sure it was, but thought perhaps the track was of a man kneeling with his left leg inside a shallow dugout canoe while pushing the canoe along with his right. But footprints under water would have been unclear and largely mush, and the ones we had were very clear with details of the toes and other parts of the foot. So, we had put that on hold till the Pintubi trackers came. They knew immediately what the situation was. It was, indeed, a man without a left foot or leg. However, the stump of the leg with missing foot would have shown up as the opposite track, but that was not the case, so it was probably a large part or the whole of the leg was missing, most probably below the knee. Why? The trackers were not surprised by this discovery because they had known a man that had had his right leg amputated below the knee after it had been speared. The wound turned infectious and had rotted off. The man had then used the aid of a support pole to get about. When I first heard this, I thought of the support pole that would be needed to support the man as he hopped. It would also have left a tell-tale mark behind along one side of the foot track. We looked for such a track, but there was no sign of it. Then, was he hopping without a support pole? That would seem impossible

Fig. 21.10 Site surface showing round imprints, possibly from the use of a support pole

because the spacing between footprints looked too big to accommodate a hopping man. Once again, the trackers surprised us by telling us further details of the man known unsurprisingly as one leg. Peter Bartlett Japaljari had also known the man when he was very old. He was known as a great Elder, and many men had feared him in his younger days because of his strength and powers of sorcery. The trackers then told me of something that I would not have believed if they had told it to me. They said that the one-legged man could get up speed using the support pole and then at a certain point, he would drop it and continue hoping on one leg. This story seemed to exceed all bounds of human adaptation, but I was reassured it was true. That would certainly explain what we were seeing with this right-foot-only trackway. I mentioned before the trackers visited again and brought a gift for the local women. They also brought me one. They had made a support pole like the one-legged man's, made of mulga and with the pointed end fire-hardened. Then it dawned on us that the round marks we had seen in some parts of the site were probably made by a support pole (Fig. 21.10). If they were made in that way, they appeared on other layers below the top surface indicating repeat visits by the one-legged man and his group. That possibly tied down the span of the site to a few seasons or perhaps the lifetime of the one-legged man.

The detail that the trackers were able to provide us with was information that we could not have obtained in any textbook and even a lifetime in archaeology. What was revealing to us was that it was turning a basically flat archaeological site without the normal artefacts into an ancient activity area with living inhabitants with personalities and personal difficulties.

They were there for 5 days and then began to miss their country, so they set off for home. They did return bringing gifts, but that time it was to make a film of them on site. I have never seen the film that was made by an Aboriginal film organisation, and no one has ever mentioned it to me. I should seek it out as an archive, but I feel I saw the best film when the trackers first arrived and when they entered the site. I spoke to them and watched them. I sat with them as they sat round a campfire cooking a kangaroo that had been caught for them by a local parks and wildlife ranger. And I

Fig. 21.11 Paddy Japananga teaching local boys how to use a spear thrower (*woomera*)

was in their presence in a natural way without pressure, not as a contrived scene in front of a camera. They also shared their time with the local Aboriginal people exchanging stories and laughing. One time I saw Paddy teaching some young men how to properly use a spear thrower and throw a spear (Fig. 21.11). That was also a bonus for the local people to mix with these special people from the distant desert country and make friends with them.

Those people had lived lives that represented how humans had survived in the past, whether 20, 50 or 100 thousand years ago. They were people of today but had the skills of people that lived over thousands of years as part of the environment. They had skills that almost nobody on earth has today, and they generously shared them with us in order to help. During the work, I became close to Paddy Japananga during the work although I respected all of them greatly. I also had the great honour of being given the skin name Japananga by them so that I could join them and be involved with them in their universe in a way they could understand. From that they knew who I was and how I fitted into their world. They did not meet my family, but knowing that I was Japananga meant to them that my wife was a Naparulla woman, my son was a Japangarti man, his wife was a Nampinjimpa, their daughter will be Nangala and son Jangala, my daughter was a Napangarti and her husband was a Jampinjimpa, all that from knowing who I am. No writing and no records, it is a cultural system carried in the head. It makes you part of their system and weaves you into the fabric of the environment because all those names, and there are eight others, have obligations dictated by their skin name. By being a part of the skin section system, you know how you should behave, who you can and cannot talk to, who you can and cannot marry and who your offspring must marry and who your skin relatives are who are spread across a vast desert. It ties you to country, and you know where your place is in that country. One of those obligations is to look after your country and to treat it, and the life in it, properly and with respect; otherwise the ancestral spirits will take it from you. This is just a part of the very rich tapestry of knowledge and a closeness to the earth we have lost. Looking at ancient fossil footprints is looking at an echo of that loss.

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Chapter 22
Walking Together: Ways of Collaboration in Western-Indigenous Research on Footprints

Hannah Zwischenberger

Abstract A combination of western analytical methods with experience-based indigenous methods of tracking can be a chance to get closer to individuals of past times. In such collaborative research projects, different western and indigenous knowledge systems meet. These are characterized in more detail below. This chapter examines the question of how respectful and mutually beneficial cooperation is possible against the background of different epistemologies. Recommendations for practical action in collaborative projects are summarized in an ethics guide and an interview guide, and alternative forms of writing and publication are proposed.

Keywords Interpreting footprints · Knowledge systems · Indigenous epistemology · Research framework · Research partnership · Holistic paradigm · Ethic guideline · Interview guideline · Narrative approaches · Subjective knowledge · Community report · Personal journal · Alternative publication

Introduction

Since the beginning of human history, people have left their mark all over the world, as can be seen from the large number of archaeological finds (e.g. Cherin et al. Chap. 8; Ashton Chap. 9; Kyparissi-Apostolika and Manolis Chap. 10) and articles on them (e.g. Kim 2008; Lockley et al. 2008). The interpretation of archaeological footprints opens up the possibility of getting closer to individuals of past times in a particularly direct way. A person's footprint is as individual as a fingerprint (Lowe 2002: 68) and can refer to specific identity characteristics such as gait speed, age and gender, as well as to action scenarios reflected in traces.

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As the history and diverse results of the conference show, footprints are an object of investigation that is relevant both for western researchers of different disciplines and for indigenous communities. The parameters studied are partly similar, while the contexts and methods of interpretation differ. Bennett and Morse (2014) and Liebenberg (1990) give an overview of western morphometrical and indigenous experience-based methods of trace interpretation.

Interpretation methods are embedded in larger knowledge systems. Epistemological questions on the emergence, transmission, validation and possession of knowledge are crucial not only for the method itself but also for the entire research process. The focus of this article is therefore on the traces that the researchers themselves leave behind in the field of collaborative projects:

Leaving a trace means "an action that depends on knowing how to live and leave information for others to follow" (Legat 2008: 37). Umbagai's statement "As a tracker you end up being a person that is being tracked" (pers. comm. Umbagai 2017) can also be understood in this sense.

People move in networks of knowledge and relationships and are always tracker and trackmaker at the same time. What does this mean for the cooperation of western and indigenous trace experts with their different epistemological backgrounds?

Essential characteristics of western and indigenous knowledge systems will be discussed in more detail below. Subsequently, both systems, often perceived as contrary, are related to each other. The image of the networked space forms the basis for practical and ethical considerations on cooperation. What a dialogue based on partnership can actually look like and which aspects are important in this context is made clear in a guideline developed for trace projects. This is followed by a section that examines communicative aspects of the interpretation and validation of the traces investigated. Interpretative conversations at the site are regarded as an interview in the broad sense, and concrete suggestions are summarized in a guideline.

At the end of the research process stands the communication of the results. How the hypothesis developed on the basis of the track read and also how the research itself is communicated is therefore the final topic. In addition to specialist publications and lectures, many other forms between written and oral narratives are possible. Some of them will be presented here, also from the point of view of subjectivity and reciprocity.

Examples of western-indigenous research projects exist from archaeological excavations (Colwell-Chanthaphonh and Ferguson 2008), cultural heritage management (Hollowell and Nicolas 2009), cave art (Rouzaud and Jamet 1993) and material culture/museum (Reyels et al. 2018). Many such projects are based on the community-based participatory research (CBPR) approach, which is characterized by partnership at all stages of the research process (Atalay 2012: 51). In particular, aspects of civil society cooperation and fair benefits are also emphasized by Michael Robinson, who draws a parallel between One World Economy and One World Science with his participatory action research (Robinson 1996). Is fair trade in knowledge the key to a mutually beneficial research partnership? Knowledge as an asset to be acquired and as personal property: This representation reflects an individualistic concept typical of western knowledge systems.

Western and Indigenous Knowledge Systems

Western knowledge systems are hierarchically structured and often associated with the concept of distance (Studley 1998: 9; Smith 1999). The researcher is the expert who needs the distance to the research object to be able to see it up close. Distance, which is seen as a more or less measurable value, implies a neutrality and objectivity of the researcher. It is often assumed that there is only in sciences one reality that can be expressed in laws. An essential feature of western knowledge is therefore that it is based on the hypothesis of a basic mathematical structure of nature (Hountondji 2002: 27; Porr and Matthew 2016: 246). The relationship between man and nature and related concepts influences epistemological questions in many ways. The separation of culture and nature is part of the great dichotomies that have been reinforced since the era of Enlightenment and are reflected in positivist paradigms. The Age of Reason as a response to church dogmas led to classification and representation systems:

> which lend themselves easily to binary oppositions, dualisms, and hierarchical ordering of the world. (Smith 1999: 55)

Such oppositions are deeply rooted in western epistemologies, even though since the Enlightenment, many turns and shifts have led to new directions of thought and today holistic paradigms are more likely to be sought (Studley 1998: 6). Aspects of these holistic paradigms are interdisciplinary and intercultural cooperation and the integration of indigenous knowledge into the academy. This can be both a chance and a challenge:

> The big dilemma and struggle is doing that in a western-indigenous research context, trying to grow something Indigenous there. Out of a box, you're morphing a circle and there is something kind of wacky about that, but there is something kind of challenging about that, too [laughter]. (Absolon in Kovach 2009: 153)

Western and indigenous knowledge systems are summarized here in their basic forms: The box can be seen as a collection of data as result orientation and also contains research conventions, guidelines, time and financial framework conditions. The circle, on the other hand, emphasizes relational and communicative aspects of research and process orientation. In order to bring the two together, it is necessary to be aware of the differences and similarities between western and indigenous knowledge systems.

Differences and Similarities

There is a broad consensus that indigenous knowledge is location- and culture-bound and dynamic and that it has a contrary relationship to western academic knowledge (Studley 1998: 4–6). Arun Agrawal is particularly critical of the latter point. He considers the dichotomy of “western versus indigenous knowledge” to be problematic in principle, since it illustrates western traditions of binary thinking rather than actual knowledge characteristics, and there are also great similarities between the two categories as well as differences within one category (Agrawal 1995: 421).

It is often suggested that indigenous knowledge is primarily concerned with activities related to the immediate world (or even mere survival), as opposed to general analytical abstract models, ideas and philosophies typical of the western world. The point of local knowledge may apply to highly specific environmental knowledge. However, indigenous knowledge goes far beyond this and vice versa; western science also often refers to everyday problem-solving strategies (Agrawal 1995: 423). The distinction local/universal is therefore insufficient to define both forms of knowledge. Knowledge is never universal, neither western nor indigenous. Both forms are locally produced ethno-knowledges (Kincheloe and Steinberg 2006: 150). This insight facilitates an equal and open exchange in joint projects.

Methodological differences between the two knowledge systems that are important for practical cooperation can be found in the epistemological orientation and the different relationship between implicit and explicit knowledge. In indigenous systems, subjectivity is assumed and recognized as a natural source of knowledge (Kovach 2009: 11) but has little place in institutionalized western systems, where it is often regarded as the enemy of objectivity. This conflict can also be seen in joint projects when it comes to the verifiability of experience-based methods or guidelines for scientific writing. It is anchored in epistemologies that initially seem contradictory. In contrast to western epistemologies, in which knowledge is classified in hierarchical systems and predominantly handed down in writing, the focus of indigenous epistemologies is different:

> If indigenous ways of knowing have to be narrowed through one particular lens (which it certainly does not), then surely that lens would be relationality. (Wilson 2008: 58)

Relationality and Validity

Relationality is a fundamental element of indigenous knowledge systems that permeates all aspects of knowledge. It refers not only to interpersonal relations but also to those with the cosmos and the environment. In such an interwoven, non-linear understanding of knowledge, theories and ideas are not guard rails on a straight road of knowledge, but:

> only knots in the strands of relationality that are not physically visible but are nonetheless real. (Wilson 2008: 87)

The environment is not a passive object of knowledge; it is also knowledge itself. The close connection between people and the country as a teacher is also of great importance in reading traces, as Leah Umbagai (Dambimangari Aboriginal Corporation, Australia) makes clear at the conference on prehistoric human footprints in Cologne (Fig. 22.1):

Fig. 22.1 Leah Umbagai (Australia) surrounded by other international tracking experts during the Prehistoric Human Tracks conference in Cologne/ Mettmann 2017; from left to right: Tsamgao Ciqae (Namibia), Leah Umbagai, /Ui Kxunta (Namibia), George Aklah (Canada) and Thui Thao (Namibia). (Photo H. Specht/J. Becker)

> When you're trying to understand tracking, it's also understanding the character of people, how they walk, understanding the animals, where they come from (. . .). So, the country, it teaches you the tracking. (. . .) Everything is there, it's a matter of really taking note, and watching, listening. (Umbagai 2017)

Access to knowledge is created through the awareness of being part of a larger interdependent network of relationships and through precise observation and sensory perceptions.

The question which realities and forms of knowledge are culturally accepted is related to the question of how knowledge is validated. In indigenous knowledge systems, validity is not an abstract measurable value, but, like the other aspects of knowledge, is integrated into relational dynamics. Validation of knowledge is oriented towards cultural rules of knowledge production and representation and is "based on time-honoured and proven principles" (Bishop 1999: 4).

Instead of a measurable validity, the concept of relational accountability (Wilson 2008) or "social accountability" (Studley 1998: 11) can also be used. Reliability in such an understanding does not refer exclusively to knowledge and research data, but is associated with the reliability of social relationships (Wilson 2008: 77). Relationships live through communication. Communicative validation of knowledge through interpretative discourse and consensus building within a group is a particularly relevant validation option for joint projects in trace research.

Following on from the point of relationality, the question now arises as to how western and indigenous knowledge can be related to one another in joint projects. The question of from which direction do we begin research can be extended to the question how can we come together and find a common direction. We do not start at one end, but in the middle. From there we take a look at our field of action, our environment and the ground that supports us and plan our route.

The Networked Space

In order to build the research framework on a sustainable basis and to plan joint steps, it is important to not only take differences into account but also to look at the similarities of knowledge systems. In the academy, some holistic approaches similar to indigenous epistemologies can be found. For example, Tim Ingold's concept of meshwork can be compared with indigenous horizontal educational concepts.

Horizontal Structures of Living and Learning

The environment, the space in which people move, is characterized as a relational network. According to Ingold, this meshwork is not a complex of interconnected points, but a network of interwoven life paths and traces of movement. The connecting points are not to be seen as static units that can be analysed mathematically, but as points of concentration of knowledge and experience that have grown out of the intersection of life paths and are constantly being formed anew. Knowledge as an open and flowing process is integrated:

> along paths of movement, and people grow into it by following trails through a meshwork. (Ingold 2011: 143)

This moving learning and knowledge in motion is described by the term wayfaring. All participating researchers are involved in interpretative processes as wayfaring knowledge-seekers. Research and learning are processes of "reweaving rather than receiving" (Smith 1999: 532).

Horizontal Structures of Power

Horizontal power structures and ethical aspects of cooperation are also associated with such a horizontal understanding of education. Furthermore, they are also important from a postcolonial point of view, because ethics is "emerging from historic relationships with research" (Kovach 2006: 69). In colonial times, research on indigenous peoples served western interests. The production mode of the colonial pact with its continuous exploitation of resources and flooding with products to stabilize power applies equally to material production goods and knowledge production (Hountondji 2002). The processes of marginalization rooted in this period and the ideology of the oppositions

- Western – indigenous
- Centre – periphery
- Systematic – unsystematic
- Rational – empirical

have an effect in many ways even to this day (Smith 1999; Jones and Jenkins 2008). The western tradition of binary thought also raises questions in partnership: Does indigenous knowledge not have to be validated with western analytical methods in order to be perceived as scientifically correct? Or should western knowledge be validated by indigenous knowledge? Both approaches would assume that there is already a favoured truth that is subsequently subjected to control by the other knowledge system. However, a collaborative project aims at the participation of indigenous experts in all stages of the research process. The joint interpretation of the traces and communicative validation are in the foreground. Narrative approaches can contribute to a good basis for joint projects. In the 1970s, the "narrative turn" marked the beginning of a development in academia in which narration was increasingly recognized as a mode of knowledge. It was no longer exclusively an object of research, but became itself a lamp through which other aspects of life and research could be made visible (Kreiswirth 1994: 62). Accordingly, each researcher has his own headlamp (narration/knowledge) in joint projects of trace interpretation, which helps to illuminate the path to the true core of a hypothesis.

Walking and working together in this sense is only possible if a communicative space or middle ground characterized by trust and respect has been created in advance of the interpretation of the traces. A "communicative space/middle ground" provides an opportunity for an open exchange. It:

> can be considered both metaphorical and literal, as defined and operationalized by the group in question. (Lyons 2011: 86)

Fundamentally important aspects of this space are being present, communicating, listening, respect and understanding (Tondu et al. 2014). Especially from a postcolonial and critical point of view, indigenous knowledge and ethical aspects are to be considered not only as part of the research framework but as the heart of the research. They are, in the truest sense of the word, fundamental to all steps in the research process.

Indigenous epistemology can act as a reference point for ethical research. Kovach gives an example of this by comparing the knowledge of the Plains Cree of North America associated with buffalo hunting with research processes. Hunting requires thorough preparation, protocol, method, respect and sharing of prey. Similarly, research includes the preparation of the researcher and the research, the recognition of cultural and ethical protocols, respect and knowledge sharing (Kovach 2009: 65). Self-reflexivity and belonging and openness and care in research as the basis of method choice help to track prey/knowledge. The successful outcome of hunt/research depends on a respectful attitude, the application of cultural and ethical protocols and good communication and cooperation between hunters and / (analog to the previous comparison "hunter/researcher", "prey/knowledge", means rather the cooperation within a hunting or research group) researchers.

Implementing Ethics in Research

The process of tracking is an "ongoing process of problem-solving" (Liebenberg 1990: 89), and the same applies to the research process: clear agreements on various topics and decisions are necessary. In order to ensure that this dialogue takes place at eye level, in recent years and decades, many indigenous communities have drafted their own ethical guidelines or participated in the creation of such guidelines. These differ in the scope and specification of individual topics, but largely coincide in the main topics addressed. In the following, five ethics guidelines will be compared as examples and summarized in Table 22.1, in order to then concretize relevant points in an ethics guideline that can be used for trace projects.

Indigenous Guidelines

The aim of the Royal Commission on Aboriginal People (RCAP) is to provide a new basis to relations between western and indigenous people and political representatives that are described as being based on false premises (Summary final report). The report, published in 1996, focuses on political, social and cultural issues. Researchers from all over Canada submitted proposals on ethics. The resulting guideline is applicable to work with both individuals and indigenous groups in different contexts.

The Dene Cultural Institute (DCI) in Canada describes in a detailed guideline a participatory approach especially for research concerning traditional ecological knowledge. Some aspects of the guide are very local- or topic-specific, while others are transferable to other research contexts. The Inuit Research Guideline of the Inuit organization Inuit Tapiriit Kanatami also originates from Canada. It includes 12 points on consent, communication and access to research data (Grenier 1998: 87–88). The Guidelines for Ethical Research in Australian Aboriginal Studies were published in 2012 by the Australian Institute of Aboriginal and Torres Islander Studies (AIATSIS) and comprise 14 research principles with associated practical recommendations. A current guideline from South Africa is the San Code of Research Ethics of the South African San Institute (SASI). This guideline, published in 2017, is divided into five main topics: respect, honesty, justice and fairness, care and process. These generic terms are also reflected in other, common core points of the ethics guidelines presented. All these guidelines deal with consent, the type of participation, the handling of data and reciprocity.

Important points concerning content and objectives of research, type of participation, funding, etc. should be written down and signed. This step should be seen as a joint design process, during which, in exchange with indigenous communities and organizations, the project plan is discussed and research ideas are jointly developed (SASI 2017). The term cooperative agreement (DCI 1991) instead of informed consent makes this communicative aspect particularly clear.

Table 22.1 Different guidelines for ethical research with indigenous peoples

guideline	Consent	Participation	Data	Reciprocity
RCAP (1996)	Informed consent signed by individuals, groups or representatives Objectives and aims of research, benefits and risks	Participation in planning, implementation and evaluation Revision of research results before publication	Final reports: Open public access Distribution in local communities, using the indigenous language	Community benefits Influence of the research at local, regional or national level Supporting indigenous research
DCI (1991)	Joint/cooperative agreement Several meetings with local community Objectives of research, methodology, commitments and benefits Signed by community representatives	Community administrative committee Indigenous and western representatives Elders Council Assistance in interpretation, recommendation for the selection of community researchers Training programme cross-cultural, interdisciplinary approach	Release form at the beginning of an interview concerning the type of access to information (who, when) Progress reports and a summary of the final report in the indigenous language Community newsletter, video of the work, etc.	Remuneration of the community researchers according to effort and working hours Decision of the community administrative committee
ITC	Informed consent Purpose of research, sponsors, involved persons and institutions, methodology, type of cooperation	Ongoing communication on objectives, methods, interpretation, results Integration of indigenous knowledge in all stages of the research process	Access to raw data, not just summaries should be part of the consent form	Training of indigenous researchers Sharing information and research results in the appropriate language(s)
SASI (2017)	Prior informed consent based on honesty in the communications Research idea that is collectively designed	Open and continuous mode of communication, clear not academic language, absolute transparency, open exchange	Contribution to research is acknowledged at all times Subsequent publications	Co-research opportunities, sharing of skills and research capacity, roles for translators and research assistants
AIATSIS (2012)	Full prior informed consent: Objectives of research, aims, all participants and involved institutions, funding sources,	Define project phases and regularly reflect on methods, results and research process Participation in	Written agreements on presentation, access and ownership of data, rights of use (institutional, personal, collective)	Remuneration, training, community development, presenting results in an easily understandable form, support,

(continued)

Table 22.1 (continued)

guideline	Consent	Participation	Data	Reciprocity
	nature and extent of participation Draft is discussed at a meeting with the community	research as well as in the presentation of the research		e.g. in the archiving of intangible cultural heritage

RCAP Royal Commission on Aboriginal Peoples (Canada), *DCI* Dene Cultural Institute (Canada), *ITC* Inuit Tapirisat of Canada (Canada), *SASI* South African San Institute (South Africa), *AIATSIS Australian* Institute of Aboriginal and Torres Strait Islander Studies (Australia)

Participation is also understood as dialogue in the further course of the research process. A transparent, open exchange in clear, non-academic language should take place throughout the entire process from project planning to the presentation of the results. To ensure this, short interim reports are often recommended. The handling of data includes data of different kinds (e.g. raw data, interview data, media recordings). Access to research data and results should be provided for all stakeholders and interested parties through reports, databases, open access publications, etc. Type and extent of data use and data access should be discussed with all participants and implemented jointly.

As far as reciprocity is concerned, an appropriate remuneration for indigenous participants negotiated in advance and the calculation of travel costs, visa procurement and similar should be a matter of course. The sharing of research capacity, knowledge and skills and other intangible forms of reciprocity, for example, support for indigenous knowledge transfer and research beyond the scope of one's own project, are also frequently mentioned.

The evaluation of the research project should include an exchange on the continuing benefits and significance of the research results for the indigenous community. The following ethical recommendations for action can be applied to trace projects:

Ethics Guide for Tracking Projects

Project Preparation

First Contacts and Contact Persons

> Ethical research "would be conducted in such a way that the organisations that are working at the grassroots level with the different San groups are given recognition, respect, and the opportunity to participate" (Ngakaeaja et al. 1998: 30).

- First of all, indigenous organizations, which may be able to refer to a specific community or experienced trackers, should be contacted.
- The organization concerned should have access to research proposals and drafts.

- The research idea and the possible framework should be discussed and developed together with the community concerned and the proposed trackers.
- This exchange and relationship building is best done personally within the indigenous community.
- Researchers should familiarize themselves in advance with similar projects that have already taken place and the resulting experiences and expectations.
- Researchers should know and act on existing indigenous ethical guidelines such as the South African San Institute.

Declaration of Consent

> "It was understood, upon analysis of past experiences, that in every single transaction involving traditional knowledge or practices, the need for full prior informed consent was perhaps the most important requirement." (Chennells 2009: 219)

The declaration of consent should not be designed in the form of a previously fully formulated information form, but should be seen as the result of an initial communicative negotiation process of the framework conditions in the sense of a "continual dialogue approach" (Kvale 1996: 114). Details of the following points, discussed in advance with indigenous project partners, are recorded in writing and signed:

- Contents and aims of the research
- Persons and institutions involved
- Possible advantages and disadvantages of participation
- Funding sources and sponsors
- Project scope and general conditions (location, time)
- Type of participation
- Type of expense allowance such as travelling expenses and remuneration for trackers, translators, etc.

Research Design

- Discussed with representatives/elders or other respected persons of a community.
- This can be used to initiate further discussions with members of the community and to find project partners.
- Sufficient time (several face-to-face meetings) should be allowed for establishing relationships and shaping the research framework.
- In addition to scientific methods, it makes sense to document methods of relationship building and indigenous participation from the outset (Tondu et al. 2014: 424). This can also be useful or necessary to apply for funding for longer projects. The duration of the project can be justified with the necessary time to establish relationships and the high importance of relationships in collaborative projects.

Project Implementation

Training/Getting Familiar

- Become familiar with the context of the tracks by means of test inspections and information on site.
- Contextual information:
- Room: e.g. light, climate and space conditions in caves
- Ecology: e.g. specific fauna
- Time/history: archaeological background
- The western researcher needs to become familiar with the indigenous tracking method in the field to be sensitized for interview and indigenous interpretation of the archaeological traces.

Interpretation of the Footprints

- Allow sufficient time for interpretation and communicative validation.
- As few interruptions and guiding questions as possible.
- Pauses and summarizing first insights offer possibilities for inquiries and concretization of individual points.

Data Management

- Photo, audio and video documentation of the interpretation process.
- Recordings can be used in many ways, e.g. for further analysis of traces and the trace-reading method in archaeological and indigenous contexts, but also for community reports, etc.
- Data storage accessible to all participants, if necessary a specially set up and indigenous group trained in dealing with databases, translation programs, etc.

Reciprocity

- Compensation of trackers and translators: wage agreed on in advance
- Structuring of the project into phases, interim reports, etc. for the indigenous community, continuous dialogue
- The usefulness of knowledge gained beyond the archaeological project, e.g. self-confidence gained from results and teaching material for the dissemination of the tracking method in indigenous contexts

Evaluation and Completion of the Project

Authorship

- Identifying indigenous sources of knowledge
- Joint publication and naming of all authors
- Joint presentation of the results, depending on the target group (press, specialist audience, indigenous communities), e.g. through lectures, presentation of photos and films accompanying the project

Open Access

- Open data access, sharing of results.
- For example, on suitable Internet platforms, as a blog, in freely accessible journals.
- An overview of journal databases, legal and financial aspects, etc. can be found, for example, on the website https://open-access.net.

Further Use of the Research Results

- Support of indigenous knowledge transfer, e.g. through summary results in local language (possibly in cooperation with the translation group).
- Final evaluation of the project, discuss the benefit/further use of the data and results.

The Common Language

Dialogic approaches are not only relevant from an ethical point of view but also necessary from a practical point of view in order for joint projects to succeed. Concrete communicative aspects include interview and interpretation, hypothesis formation and consensus, and communicative validation.

Indigenous Interpretation and Interview

A definition that also applies to trace projects describes the interview as a "contextually bound and mutually created story" (Fontana and Frey 2005: 696). The aim is to develop an informative story or hypothesis in dialogue with the interviewees, taking into account different contexts (technical, ecological, social). Thus the interpretation of the traces on site is to be understood in the broadest sense as an interview. An important question here is to what extent the interview is structured and in what form questions are asked. Since western categories and classifications are not exclusively used in a collaborative project, highly structured interview forms with questions formulated in advance are unsuitable. An inflexible concept would contradict many indigenous concepts of knowledge generation. The latter focus on learning through observation and stories (Lowe 2002; Bell 2009: 84) and are therefore more compatible with open forms of interviews. In semistructured interview forms, a rough structure (e.g. certain topic complexes) is given. At the same time, the course of the interview is flexible. This form of interview is particularly suitable for joint tracking projects.

Trace interpretation is a communicative process in which observations and experiences are discussed. Language reflects culture-specific experience, interpretation patterns and knowledge concepts. In the joint project, the indigenous language should therefore also be given a lot of space in the interview. Interim results can be summarized and discussed at regular intervals.

Communication is equally a means of data acquisition and validation. Validity in the sense of objectivity is often understood as the pole of a dichotomy, e.g.:

- Objective – subjective
- Quantitative – qualitative
- Fact – value/fiction

But objectivity unites many facets. It can arise both through impartiality or reflection on the nature of a research object and through intersubjective knowledge (Kvale 1996: 64). In the common process of interpreting the traces, dialogical intersubjectivity as rational discourse and reciprocal critique between the interpreters can lead to a consensus on a hypothesis.

In summary, the following points can serve as a guideline for the communicative interpretation of traces on site:

Interview Guide for Joint Projects on Footprints

Preparation

Participants

- Interview group consists of western researchers (one of whom ideally speaks the language of the indigenous trackers) and a group of two to three indigenous trace experts (one of whom may be able to provide a summary of observations in English).
- The focus should be on the dialogue between the indigenous trackers in order to interrupt the flow of interpretation as little as possible.

Setting

The interview should take place in places where the participant is most comfortable (DCI 1991). This requirement is not met for footprints in caves, so the following is important:

- Intensive preparation before the actual interview
- Getting to know the room (light, temperature, room conditions), e.g. through shorter test runs
- Background information on local environmental aspects (fauna, geological features, etc.)
- Planning of breaks.

Even in the case of open trace fields/track sites, comprehensive preparation and context information are important, on the one hand because of the above-mentioned aspect of familiarity and on the other hand because of the easier and more comprehensive possibilities of interpretation this makes possible. Therefore, a detailed preliminary discussion on the following points is also part of the preparation:

- Background information (see above)
- Kind of the desired interpretations (e.g. number of individuals and action scenario in a defined range)
- Information on time, duration and location
- Required equipment
- Type of data recording/documentation and use of data

Interview Conduct

- Interim results of indigenous interpretations may occasionally be summarized.
- Summaries offer the opportunity to ask concrete questions on the spot, which can be incorporated into further interpretation.
- Semistructured interview form suitable: Certain topics are worked through; the type of information required is determined in advance. However, the order of the topics, pace, etc. is determined mainly by the indigenous way of working.
- Interview as a dynamic process: Possibilities for questions arise in the course of the conversation.
- In order to be able to recognize and use these possibilities, it is necessary to keep an eye on the type of interactions as well as the observed and communicated contents and previously formulated questions or main topics.
- Duration: The possibility of interruption should be given at all times.

Media and Data Management

- For further analyses, an audio recording of the interpretation or the summaries can be helpful in addition to archaeological and photographic methods of recording findings.
- In order to be able to understand the reference to individual imprints and features afterwards, video recordings are also suitable.
- Clear agreements on the evaluation, storage and use of this data should be made in advance.
- Images, audio and video recordings should be accessible to all research participants and (at least a few commonly selected files) should also be available to the indigenous communities concerned.

Evaluation

- Evaluation of the data: Individual sequences and summaries, e.g. on specific trace characteristics, can be evaluated by western researchers in consultation with indigenous experts.
- For a more in-depth analysis of interpretations and indigenous interpretation methods, evaluation and translation should be carried out by native speakers.
- Several people are needed for this complex and time-consuming work. A local translation group can take over this task. The remuneration of the translators can, for example, be based on the length of the media sequences processed.

The appropriate interview form and structure depends on the aim and content of the study, as well as on the time and cost factor: If the research framework is less extensive, e.g. indirect or only occasional direct contact or the interpretation of individual impressions or traces via photos and other media, more structured interview forms such as questionnaires with concretely formulated questions on individual characteristics are possible. However, this form leads to more clearly predefined and therefore limited statements, and even with such a form of cooperation, the above-mentioned points regarding a continuous open exchange and clear agreements on the use of data, etc. must be considered.

Finding and Communicating Stories: Between Paper Talk and Fireside Talk

So far, the importance of an open exchange between the project participants has been demonstrated. Finally, the question arises as to how the (hi)story of traces reads and the research process is communicated.

The research process was characterized by a variety of methods and relationships. Interest in the research and the results can be expressed by many groups, e.g. funders, academies, broader public, media and community of indigenous trackers. The narrative and media of the publication are correspondingly diverse. Not only the adaptation to recipients plays an important role but also traditional patterns of knowledge transfer. Which western and indigenous narrative forms do exist, and how can they be brought together? Traditional academic final reports that present facts are only one way of imparting knowledge.

Research and Stories

Knowledge and imagination, classification and narration are not contrary, but complementary. If research is not limited to the search for knowledge that can be expressed in quantifiable laws, but is understood as learning in a relational holistic understanding, then stories are comparable to research, because a story:

> provides insight from observations, experience, interactions, and intuitions that assist in developing a theory about a phenomenon. (Kovach 2009: 102)

Narratives can offer orientation, and they establish connections between different generations and between man and the environment (Sommerville et al. 2010: 97). The strength of stories lies in:

> structuring (. . .) beyond dichotomies between cultural/natural, human/inhuman, life/death and material/immaterial. (Porr and Matthews 2016: 261)

The dualism-dissolving property of stories can be useful in joint tracking projects, because:

Fig. 22.2 George Aklah (Canada) giving his paper talk during the Prehistoric Human Tracks conference in Cologne/Mettmann 2017. (Photo H. Specht/J. Becker)

Fig. 22.3 Fireside talk during the Prehistoric Human Tracks conference in Cologne/Mettmann 2017. (Photo H. Specht/J. Becker)

- The premise that every form of knowledge acquisition is narrative (Hendry 2010: 77) promotes dialogue between different epistemologies.
- The (hi)story of trace formation recorded in the soil directly connects man/individual and environment.
- It connects the past and the present.

In the trace project we have two stories: the research story and the researched story. Both are equally important and can be communicated both in written form as paper talk (Fig. 22.2) and in oral form as fireside talk (Fig. 22.3) or in a jointly conceived mixed form.

The paper talk focuses on the facts of the researched (hi)story. Paper talk means writing down a map of which steps we took and what we found along the way that we can pick up, analyse and present. The fireside talk offers more freedom of direct communication and exchange of experiences. It resembles a reflection on what steps we took, what we experienced and observed along the way, where we should go and what will guide us.

Oral Forms and Mixed Forms of Sharing Knowledge

Smaller discussion groups, in which questions and knowledge on various aspects of a topic are discussed and in which each participant can contribute something, can orient themselves on indigenous methods such as the sharing circles (Lavallée 2009). As the conference on prehistoric human footprints has shown, such open forms of exchange can also be well integrated into western formats such as a conference programme.

A community report as the one which emerged from this conference (Ludwig et al. 2017) can be a mixture of oral and written forms of presentation. By conveying research as a living story, the report resembles oral narrative forms or can be easily combined with them. Design possibilities are manifold and project-specific. The report should in principle be based on the following points:

- Thematic key points of research and selection of relevant findings
- Interests of the target group
- Previous way of communication between research group and indigenous community
- Points mentioned in ethics guidelines such as transparency, nonacademic language, short summaries in indigenous language if necessary
- Joint reflection on the research process and design of the report
- Diversity of media, e.g. pictures, portraits, quotations, etc.
- Balance of professional and social/personal impressions
- Presentation of professional and social contexts and contexts

Similar to the community report, the relationship between the authors and the readers is also at the forefront in other forms of publication. Publications in an academic context raise the question of subjectivity: How can the acceptance of subjective experience and interpretation serve a research project? In what form are contents traditionally published, and what alternatives are conceivable?

Alternative Forms of Writing

Tilley describes interpretation as a process of contextualization. This refers to both the archaeological context and the context of the interpreter (Tilley 1993: 8). Often, however, the personal context of the interpreter is hidden, and the author appears as an omniscient, anonymous narrator. Narrative structures are linear sequences of problems, evidence discussion and a conclusion that reveals the “true meaning” of the evidence presented (Tilley 1993: 143).

A collaborative research project with indigenous trackers is in many ways an opportunity to use alternative forms of publication: Narrative relational approaches to knowledge and the acceptance of subjective knowledge are essential indigenous characteristics and thus also flow into the research process. Jointly formulated reports can be directed at different target groups, and different media can be used. Alternative forms of publication should not only be seen as adaptation to a diverse readership, but can also lead to new findings and questions on the research side (Van Dyke and Bernbeck 2015: 4).

The way we write in the research process can already influence later forms of publication. Kovach uses a personal journal as a tool for meaning making:

> This journal captured reflections on thoughts, relationships, dreams, anxieties, and aspirations in a holistic manner that related (if at times only tangentially) to my research. (Kovach 2009: 50)

A personal journal is particularly useful for the following reasons:

- Associative thinking and reflexivity are promoted, and the personal relationship to the topic is recorded.
- Some new correlations may not be revealed until a later look at the records.
- Excerpts from the journal (e.g. special situations/meetings) may be included in later publications.
- A personal journal can be an important source for the design of a community report as well as for the communicative reflection and presentation of the research process in general.

Many forms of design are conceivable, e.g. a collection of notes, sketches, descriptions of formative moments in the research process, associated keywords and many forms of design are conceivable. If we pursue a narrative approach to knowledge and assume that an object of research is not a dead object but speaks its own language that we want to understand, then it can make sense, similar to bilingual books, to juxtapose our own language (subjectivity) and the initially more or less foreign language (individual features/data and context of the object of research) on one page each. Thus, there is always enough space for reassignments. Connections between archaeological and subjective aspects can easily be established. The areas are not completely mixed, and yet both have their place.

How professional and subjective contents can be combined in the presentation of research results becomes clear in some publications of indigenous researchers. In Wilson's book *Research is Ceremony*, sections written in academic style alternate with sections written in letters to his children, relatives and friends. This makes content aspects in relational contexts visible to the reader and at the same time makes it easier for the author to freely write and clarify contexts by not seeing the reader as an anonymous counterpart (Wilson 2008). Kovach chooses descriptions of situations and landscapes to illustrate a context, and individual chapters are supplemented by thematically appropriate personal interviews (Kovach 2009).

Kovach's methods are particularly suitable for trace projects. For example, an atmospheric portrayal of the environmental context can provide the reader with a clearer, sensually perceptible picture of the contexts important for the interpretation of traces. Short interviews with indigenous trackers can illustrate interpretation methods and research contexts in a lively way.

Subjective elements in the text shift the balance of power between the omniscient anonymous narrator and the often equally anonymous reader. Alternative text forms can actively involve the reader in the process of knowledge production instead of exclusively presenting results. Such producer texts instead of consumer texts occur when an open text form is chosen:

> in which the author systematically attempts not to close the text down, to produce a spurious coherency but leaves gaps and fissures for the reader to fill in, threads and strands to follow up. (Tilley 1990: 146)

A possible alternative to closed, linear forms of text organization is the parallel texts already mentioned above in the personal journal. Here a phenomenon (e.g. a trace) can be viewed from different angles (e.g. objective description of the trace and its context, subjective sensory impressions, insights into research methods, possible reconstructed scenarios). Particularly in the case of traces that allow different interpretations, it would be possible to juxtapose the description of the traces and the interpretation context with fictitious action scenarios, or to combine these two aspects of the shared space with the aid of time leaps built into the text.

Even smaller thematic leaps within a text can contribute to an openly informative and multilayered text, without getting lost in individual fragments. In a “tangential text” (Tilley 1990: 144), a theme is followed, and at the same time branches of the main plot are used to trace different facets of the theme. Thus the text itself becomes a trace field, and the reader can actively participate in tracking down meaning.

A horizontal linking of diverse perspectives and contents in archaeological trace projects is important, but can also be a challenge if there is a danger of losing an overview of the structure. This can be avoided by a sketch or table of the connections. The Internet is a medium that makes it easier to horizontally network content in a variety of ways. Research can also be presented in the form of a home page (e.g. Tringham 2015) or a blog.

Different forms can be used in parallel or be combined in joint publications. From a practical point of view, it is useful to ensure easy accessibility as it is necessary from an ethical point of view. Which forms of publication are ultimately chosen is left to the creativity and resources of the researchers involved in a project.

Conclusion

From the first steps of approaching different epistemologies to the concrete implementation of joint interpretation of prehistoric human footprints up to the final presentation of the results, with this article, an attempt was made to look closer at the expert’s steps and traces in collaborative research projects.

Not every aspect of this large thematic field could be investigated in detail. Accordingly, the aim of the article was to draw a rough sketch and to show various connecting approaches that could facilitate cooperation. The proposed recommendations are to be understood as drafts, which should be adapted to the requirements of concrete projects and to the work and cultural background of the respective experts involved.

In summary, the research process can be reflected as a joint journey. The topic of interpreting footprints is a point of common interest for western and indigenous trackers. So, the theme itself is the point in the meshwork where western and indigenous knowledge paths overlap – paths that come from different directions.

Researchers who meet at this point bring with them their own stories, perspectives and methods. They become familiar with each other, and by entering into discourse, they create a communicative middle ground and decide together on the next steps.

Coming back to the question from which direction we begin our research, both answers are true: Our research starts with ourselves, and it starts with the common middle ground. Starting with ourselves means both self-reflection in the sense of "*miskasowin* – to go to the center of yourself and find your own belonging" (Kovach 2009: 49) – and our own scientific background. The first research idea usually emerges in the western archaeological context, and the research framework is to a large extent linked to western conditions (e.g. financial support, documentation, etc.). The way in which spaces of joint design can be opened up in the research process has become clear under ethical and communicative aspects and, in particular, in the diverse design possibilities of publications.

Framing and structuring research as well as being able to think outside the box and following trails in a meshwork are equally important. We come from different directions and bring with us different traditions, experiences and methods. Besides our differences, there are also points of convergence, and even differences do not have to stand in the way of a successful project.

A continual dialogue and participation in all stages of the process is both crucial and decisive. In order to initiate and maintain this dialogue, openness, respect and trust are necessary. The theoretical background of the joint research project should be based on a holistic paradigm and include various western approaches such as critical theories and qualitative methods as well as indigenous epistemologies. Accompanying quantitative scientific methods for documentation and further analysis of the footprints may be integrated in such a framework, but should not be the main focus of the research or used for the validation of indigenous knowledge.

How walking side by side can become walking together cannot be answered conclusively and will be tested in further projects. The research journey of the project not only leads to answers but also points out further nodes and paths. What influence joint projects have in indigenous communities and how long-term partnerships beyond one's own project can be established and shaped are just two examples of possible further questions.

However future collaborative projects may look like, we (especially as archaeologists) should never forget the ground under our feet while looking ahead for new points of data and argumentation. It bears the traces we explore as well as the traces our research leaves behind, and stories of interactions and connectedness are inscribed into it.

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