

# Chapter 15

## Major Events in Hominin Evolution

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### 15.1 Introduction

Until recently (reviewed in Kim et al. 2008a, b; Lockley et al. 2007a, b, 2008a, b; Lockley and Roberts 2004), the study of fossil hominin tracks had been largely neglected by ichnologists, paleontologists, and anthropologists, with the exception of the famous Laetoli hominin trackways in east Africa. While it may be speculative to consider why this has been so, the study of hominin footprints, like the study of hominins in general, is of potential mutual interest to several disciplines (paleontology, ichnology, anthropology, archeology), and so has not been claimed as the exclusive province of any one of these. The distinction between hominids and hominins is sometimes confusing to nonspecialists. Here we use the term hominin, in reference to the tribe Hominini, to include representatives of the “australopiths” and the “hominans”, as outlined by Wood (2005), and Wood and Richmond (2000).

With a few notable exceptions (Hay and Leakey 1982; Leakey and Harris 1987; Pales 1976) there were almost no hominin footprint-bearing sites that had been subjected to any sort of comprehensive analysis, prior to 2000. Even though a spate of publications in 2004 through 2009 (Meldrum 2004a, b; Lockley et al. 2007a, b, 2008a, b; Meldrum et al. 2010, 2011) marked a re-awakening of interest, most of the few dozen publications to emerge at this time could best be classified as preliminary

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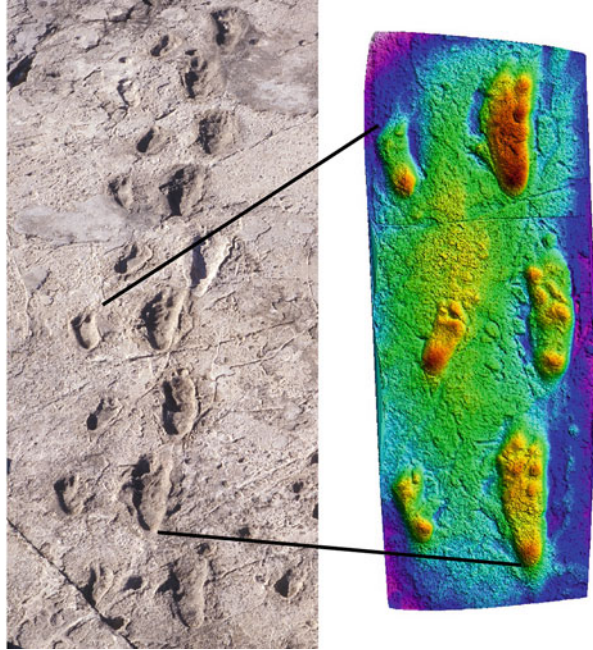
site reports, some dealing with sites that had been known for decades but never studied. Nevertheless, since the publication of two special volumes in *Ichnos* (vol. 15 (3–4) for 2008, and vol. 16 (1–2) for 2009), under the title *Hominid Ichnology*, interest in the subject has been sustained, and a number of papers have emerged dealing both with the oldest African sites, and with other younger more widely distributed sites (e.g., Bennet and Morse 2014). In accordance with the theme of this volume, we herein review the hominin track record from the perspective of the role of trace fossils (primarily fossil footprints) in highlighting major events in hominin evolution, including emphasis on new studies and perspectives not discussed in previous summaries (Lockley et al. 2007a, b, 2008a, b).

While the focus of this contribution is on fossil footprints and their interpretation, the renaissance in “Hominid Ichnology”, represented in part by the *Ichnos* volumes, has been accompanied by independent, but simultaneous, interest in redefining the scope of hominid ichnology (Hasiotis et al. 2007; Baucon et al. 2008; Kim et al. 2008a, b). In short, the authors of these articles, as well as those of the present article (Kim et al. 2004, 2008a, b), simultaneously proposed that hominid ichnology should include the study of a wide variety of traces, in addition to footprints. These traces include, but are not limited to, tool marks and artifacts made by modifying (flaking, engraving, sculpting, excavating), of wood, bone, rock, and earth (soil) substrates, as well as various forms of painting and writing, also on a wide range of substrates. While recently made popular in Crime Scene Investigation (CSI) dramas, involving detection of all manner of traces on diverse substrates (Lockley 1999), such facets of hominid ichnology were already evident during the so called Late Paleolithic Cultural Revolution (discussed below) and raise fundamental questions about the importance of ichnology in understanding and reflecting complex cultural behavior during one of the most debated “major events in evolution”—the emergence of modern humans. Hominid ichnology bridges the gap between tetrapod ichnology and what Baucon et al. (2008) appropriately identified as the important subdiscipline of ichnoarcheology. The etymology of words like *ichnos* and *trace*, discussed below, underscore the deep relationships between trace fossils and writing. Without such ‘ichnologic’ representations of the behavior of modern humans and their ancestors, this volume and all its predecessors would not be possible.

## 15.2 Early Hominin Bipedalism: Laetoli Revisited

Even the non-paleontologist and non-anthropologist is likely aware of the famous footprints from Laetoli in Tanzania discovered by the Mary Leakey team in 1976 (Leakey and Hay 1979; Hay and Leakey 1982; Leakey and Harris 1987). They ostensibly indicate a group, possibly a family unit, of three individuals, one of which was slightly smaller (creating trackway G-1) walking to the left-hand side of the other two (creating trackways G2/3), which appeared to be two individuals stepping in each other’s footprints (Fig. 15.1). Trackmaker height estimates are about 1.10–1.15 m for G-1 and 1.32–1.52 m for G-2/3 (White and Suwa 1987). As noted below, despite this group-of-three scenario, and the many analyses of the trackways that

**Fig. 15.1** Pliocene hominin trackway from Laetoli (*left*) include the G-1 trackway (*left*) and the overprinted, “double” G-2/3 trackways, possibly open to interpretation as a twice-overprinted, “treble” G-2/3/4 trackway. Photogrammetric image (*right*) after Kim et al. (2008b) shows three consecutive tracks (a stride) and highlights the multiple hallux (big toe) traces in the G-2/3 trackways



have been published since 1976 (e.g., Charteris et al. 1981; Tuttle 1990; Tuttle et al. 1990; White and Suwa 1987; Meldrum 2004a, b; 2007a; Meldrum et al. 2011), this interpretation has recently been challenged, and it has been claimed that there are in fact three trackmakers represented by the overlapping series not two (Musiba et al. 2011; Matthews et al. 2011). This observation implies a G-1 + G-2/3/4 scenario.

Clearly, the most significant implication of the Laetoli trackways and the one on which most researchers agree, is that they provide direct evidence of a ~3.6 Ma old hominin that was capable of walking upright. As almost every anthropologic text proclaims, the transition to a fully upright gait was a major event in hominin evolution, perhaps the seminal adaptation of this radiation. Moreover, given the fragmentary state of many body fossils of this age, trackways arguably provide the best evidence that hominin bipedalism was established by 3.6 Ma. Mary Leakey proclaimed this “the most remarkable find I have made in my whole career” (Lewin 1982, p. 220).

A few other facts may be inferred from the Laetoli tracks and their broader geologic and paleontologic context. First, they form part of a huge trackway assemblage dominated by the tracks of non-hominin mammals and birds, including some that evidently represent extinct species (Leakey and Harris 1987). We may also assert that the body fossil record shows that representatives of genus *Australopithecus* were extant at the time when the tracks were made. Lastly, we may note that the tracks were recently given the name *Praehominipes laetoliensis* (Meldrum et al. 2011). The formal name and diagnosis distinguish them from the previously erected ichnotaxon *Hominipes modernus* (Kim et al. 2009), the latter being the formal name applied to fossil footprints unequivocally attributed to *Homo sapiens* (and possibly *H. neanderthalensis*).

Beyond these *facts* there is far less agreement about the interpretation of the trackway evidence, though Kim et al. (2007) discussed their paleontologic, stratigraphic, and sedimentologic significance. As we have seen, even the number of individuals producing a trackway has recently been disputed (Musiba et al. 2011). In addition, there is disagreement as to whether the tracks were made by a trackmaker with a foot architecture manifestly distinct, in its mosaic and/or intermediate nature (Stern and Susman 1983; Susman et al. 1984; Deloison 1991, 1992; Clarke 1999; Meldrum 2000, 2002; 2004; Berge et al. 2006; Meldrum and Chapman 2007; Bennett et al. 2009; Hatala 2014) or as a yet unrecognized relatively derived hominin (e.g., Day and Wickens 1980; Charteris et al. 1981; Alexander 1984; Suwa 1984; Lovejoy 1988; Tuttle 1985, 1996; Tuttle et al. 1990, 1991; Schmid 2004; Sellers et al. 2005; Harcourt-Smith and Hilton 2005; Kimbel and Delezenne 2009; Raichlen et al. 2010; Tuttle 2014). Closely intertwined with this debate is the question of whether the footprints are essentially indistinguishable from arched modern hominin tracks (Tuttle 1990; Tuttle et al. 1990; Crompton et al. 2012) or whether they show evidence of primitive features, including a midtarsal break (*sensu* Meldrum et al. 2011), which would imply that the trackmaker's foot morphology, and dynamic footprint registration differed from that known for modern humans.

It is perhaps surprising that such basic evidence as the number of individual trackways is in dispute. However, it should be remembered that after the initial excavation, molding, and analysis, which included some 3D imaging using 1980s technology, the tracks were reburied and most researchers had to rely on studying planimetric figures or fiberglass replicas representing only a short segment of the G1 and G2/3 trackways (Lockley and Matthews 2007; Meldrum 2007a). Even after the tracks were exhumed by the Getty Conservation Institute (Demas and Agnew 1996) in order to assess disturbances resulting from the reburial, they were again reburied in order to conserve them. It was only in 2011 that they were exhumed for a second time and subjected to high resolution photogrammetric analysis (Musiba et al. 2011; Matthews et al. 2011). These results suggest an assemblage of four, rather than three trackways, in which a group of three rather than two have overlapping footsteps. While popular inference has been tempted to interpret the "group-of-three" scenario as possible evidence for a "family" unit consisting of two larger adults and a smaller juvenile offspring, the new interpretation casts doubt on such a "nuclear family" scenario. Meldrum (2007a), after a careful analysis of two sets of stereophotographs of the G2/3 trackway, determined that the lengths of the G2/3 footprints were approximately 25 cm (G2-25) and 20 cm (G3-9), respectively. The more recent evidence (Musiba et al. 2011; Matthews et al. 2011) calls for a careful reanalysis of the size of the overlapping footprints, which may revise these size estimates. What might the number and size composition imply about the trackmaker demographics and behavior? What induced three trackmakers to follow closely in line, with the two followers stepping repeatedly in the footprints of the leading individual? An unfamiliar substrate? Given the uncertainty surrounding the overstepped footprints (G2/3 or G2/3/4), we can only note that the G1 trail has footprints ~18 cm long and ~8 cm wide with a step of 41–44 cm, indicating a trackmaker with a stature of ~1.32 m (cf. White and Suwa 1987).

As noted by Lockley et al. (2008a, p. 107), the non-hominin Laetoli track assemblages allows a census that ostensibly attributes most trackmakers to “extant species, or species that are indistinguishable from modern species (or generic, and higher categories) on the basis of tracks. The only exceptions are the identification of extinct chalicothere and *Hipparion* tracks, the latter studied by Renders (1984). The census clearly shows that rabbits (or other lagomorphs) were abundant in the area, numerically constituting 88.8% of the non-hominin vertebrate tracks.” Thus, based on rabbit abundance, Laetoli was “the Watership Down” of the ichnologic world (Lockley 1999, p. 241)! However, as this census is based on individual prints—not trackways—it is not a reliable measure of biomass, although potentially useful as a general indicator of ecology and the activity of faunal components.

Lastly, we may note that the Laetoli tracks are preserved in reworked volcaniclastic sediments, which allow for inferences about runoff and seasonal climatic regimes (Hay and Leakey 1982; Houck et al. 2009). In conclusion, therefore, the Laetoli tracks offer us valuable evidence of a major evolutionary event; the emergence and nature of early hominin bipedalism. They also form part of a rich assemblage that has attracted wide scientific interest. However, disparate interpretations of the trackmakers and their behavior continue to be debated, and access to the entire trackways, rather than partial replicas, remains restricted by the need to keep them covered in order to preserve them.

## 15.3 Walking Erect Phase II: In and Out of Africa

### 15.3.1 *On the Shores of Lake Turkana*

There is a huge temporal gap in the hominin track record between the ~3.6 Ma Laetoli occurrence and two ~1.5 Ma track sites recorded in the Koobi Fora Formation on the eastern shore of Lake Turkana. As noted by Behrensmeyer and Laporte (1981, p. 3), the first discovery of Koobi Fora footprints (from a site known as GaJi10) contributed “a reference point on hominin foot morphology, locomotion behavior, and ecology 2 Myr younger than the Laetoli occurrences and ~1 Myr older than the Late Pleistocene human footprints in Europe.” Unlike the Laetoli tracks, which are unequivocally Pliocene in age, the Koobi Fora tracks can be assigned to the Lower Pleistocene, which spans the interval between ~1.8 and ~0.8 Ma.

At the time of the first discovery, Behrensmeyer and Laporte (1981) inferred that the Koobi Fora tracks may have been produced by a *Homo erectus* (*H. ergaster*) individual ~1.5–1.6 Ma. This date is more or less confirmed by Bennett et al. (2009), who stated that the track layer is just below a tuff dated at 1.435 Ma. The decided lack of details of morphology in the tracks provides no evidence of significant changes in the hominin foot since the Laetoli trackway.

Behrensmeyer and Laporte (1981) reported tracks visible in a single trackway at site GaJi120, but Bennett et al. (2009) reported that two more tracks were excavated

at the site. According to Behrensmeyer and Laporte (1981), the tracks range in length from 25 to 32 cm and the mean foot size dimensions are estimated at 26 cm long and 10 cm wide, suggesting an individual 1.6–1.8 m in height. In addition to some isolated tracks at the Ileret site, Bennett et al. (2009) reported at least four trackway segments, one from the lower level, and three from the upper level, and they estimated the height of the track makers as between 1.75 and 1.78 m ( $\pm 0.26$  m), with a possible subadult print from the lower level representing an individual only 0.92 m ( $\pm 0.13$  m).

Bennett et al. (2009) reported another site at Ileret, Kenya, about 45 km north of the GaJi10 site that reveals two hominin track-bearing layers, ~5 m apart stratigraphically, dated at ~1.53 Ma. The Ileret site reveals tracks which have better preservation than the GaJi10 site footprints as they reveal individual digital pad impressions. Dingwall et al. (2013) concluded that some or all of the footprints found on three levels could be either *Homo erectus* (*H. ergaster*) or *Paranthropus boisei*. Bennett et al. (2009) concluded that the footprints provide “the oldest evidence of an essentially modern human-like foot anatomy, with a relatively adducted hallux, medial longitudinal arch, and medial weight transfer before push-off.” We find support for only one of these three points (i.e. a relatively adducted hallux). We find no evidence to support the consistent presence of a longitudinal arch or for a medial weight transfer. The suggestions of a medial longitudinal arch in the clearest examples (such as depicted on the cover of *Science*; Bennett et al. 2009) are the result of distortions caused by secondary impressions with extrusion left by passing ungulates, which obscure the medial margin of the hominin footprints (Fig. 15.2). In other instances, the preservation is so poor that the actual topography of the medial contact surface is indiscernible. A number of the published examples show a clear lack of medial weight transfer. Although differences of substrate properties may influence the general appearance of individual footprints as demonstrated by Morse et al. (2013), we observe consistent distinctions to the specific appearance of modern human footprints, regardless of substrate. Therefore, we maintain that *Homo erectus* (*H. ergaster*) had neither a fixed longitudinal arch (*sensu* Mauch et al. 2008) nor a modern toe-off mechanism, in concordance with analysis of the hallucal metatarsal KNM BK-63 (Meldrum et al. 2010), or that of the Dmanisi hominin post crania (*contra* Lordkipanidze et al. 2007; Pontzer et al. 2010).

### 15.3.2 *Out of Africa*

The phrase “Out of Africa” has become synonymous with the now entrenched view that our hominin ancestors originated in Africa, an opinion that can be traced back at least to Darwin’s *Descent of Man* (Darwin 1872). Certainly there is little or no evidence to refute the idea that australopithecines and early *Homo* had their origins in Africa and may never have left that continent (although interpretations of *Homo floresiensis* from Indonesia, as potentially a relict late australopith/early *Homo* sp. raises the possibility of earlier dispersal out of Africa). Likewise, it has traditionally

**Fig. 15.2** Tracks attributed to *Homo erectus* (*H. ergaster*) at Ileret, Kenya (after Bennett et al. 2009)

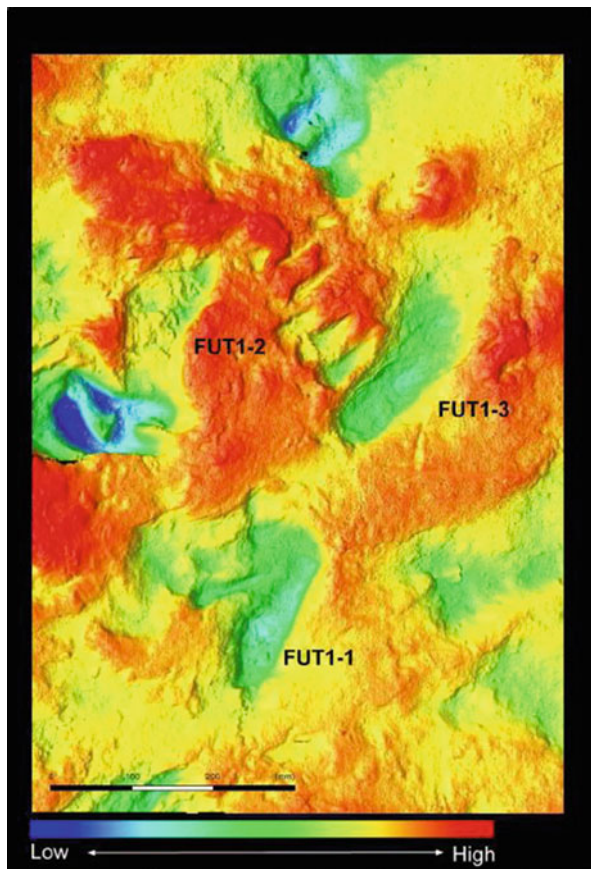


Figure 15.2. Mosaic of scans viewed vertically showing potential hominin prints FUT1-1 to FUT1-3. The surface has been color rendered in to 5 mm vertical isopleths.

been assumed that *Homo erectus* (*H. ergaster*), a species that existed from ~2.0 to 0.2 Ma, with little pronounced morphologic change, originated in Africa, even though primitive representatives of this species dispersed across the old world at an early date. For example, remains are reported from Dmanisi, Georgia as early as ~1.8 Ma, raising the possibility of an Asian origin for *H. erectus* (Ferring et al. 2011).

Following the hominin footprint trail from the early Pleistocene sites east of Lake Turkana, the next youngest reports are from three European sites, one dated to the Early Pleistocene, between 1.0 and 0.78 Ma, and the other two dated to the Middle Pleistocene. The oldest site, recently reported by Ashton et al. (2014), is associated with estuarine sediments of the Cromer Forest-bed Formation at the Happisburgh site in east Anglia, England. The footprints identified at this site occur in parallel-laminated silts, but are not very well preserved. In fact, only one footprint shows toe impressions and none preserve clear evidence of a medial arch. However, although the footprints are susceptible to destruction by marine erosion soon after they are exhumed, about 50 elongate footprints (length 14–25 cm, width

6–11 cm) were nevertheless identified in an area of about 12 m<sup>2</sup>. Ashton et al. (2005, p. 7) argued that “the shape of the footprints suggests that they were most likely made by hominins and none of the prints are consistent with those formed by other mammals.” Moreover, Parfitt et al. (2005) have established that flint tools made by hominins occur in this same formation.

Prior to the reports from Happisburgh, the oldest, best-dated, and best-studied footprint site was the Middle Pleistocene Roccamonfina Volcano site in Italy, reported by Mietto et al. (2003) and Avanzini et al. (2004, 2008), dated between ~385,000 and ~325,000 yBP. The trackways occur in a volcanic ash deposited on the slopes of the Roccamonfina volcanic complex and, due to the slope, one trackway of 27 footprints has a zig-zag configuration, indicating an individual switch-backing. Another trackway of 19 prints follows a gently curved course, with a few hand- or palm-prints where the trackmaker put his/her hand on the ground. A third trackway of ten prints forms a straight line. The footprint details are quite indistinct and not very well-preserved. Most lack clear toe impressions, even though faint traces of the hallux are recognized in some cases, even indicating a gap between digits I and II typical of habitually unshod individuals. The tracks are generally flat, but show possible inconsistent traces of a transient medial longitudinal arch in some cases. They are described as short and broad (~20–24 cm long and ~10–12 cm wide), suggesting a stature for the trackmaker of ~1.56 m. Based on age, these tracks likely represent a pre-*sapiens* or pre-*neanderthalensis* species such as *H. heidelbergensis*, or possibly late *Homo erectus* (*H. ergaster*) (Scaillet et al. 2008).

A second mid-Pleistocene footprint from Terra Amata, in southern France, has been tentatively dated at ~300,000–400,000 YYBP (De Lumley 1966, 1967; Miskovski 1967; Meldrum 2006, p. 246; De Lumley et al. 2011). The site only reveals one track, but it clearly shows a diagnostic hominin big toe (hallux) trace. However, like the Roccamonfina tracks, there is little evidence of a well-defined medial longitudinal arch (Meldrum 2004a, b). It is interesting that the lack of a well-defined arch is noted in both the Italian and French tracks. This is presumably open to several possible interpretations. For example: (1) the lack of a discernible arch could be due to poor footprint preservation, resulting from suboptimal substrate conditions at the time of registration, or post-track-making or post-exhumation weathering of the footprints, (2) the trackmaker may have been an individual or a member of a species in which arches were not well-defined, or inconspicuous as the result of having robust fleshy feet, or (3) hominins exhibit a mosaic pattern in evolution of features of the foot and stability of the foot's medial column was still lacking at this stage of hominin evolution.

Barnaby (1975) noted that hominin footprints from a volcanic ash near Demirköprü, Turkey were assigned an age of 250,000 yBP, suggesting they represent a pre-*sapiens* species (Ozansoy 1969). However, subsequent thermoluminescence dating of associated tuffs in the area gave much younger dates on the order of 65 ± 7 ka and 49 ± 9 ka (Westaway et al. 2003, 2004, 2006). These dates have been amended, yet again, to suggest dates as young as 12 ka (Tekkaya 1976; see Lockley et al. 2008a, b for summary). Some 50 pairs of footprints have been removed and are stored at the MTA Museum (Ocakoglu, personal communica-



tion). They measure ~29 cm in length and 11 cm wide, and show a robust hallux impression and well-developed ball, heel pad, and medial longitudinal arch, suggesting the footprint of a fully modern foot.

## 15.4 Tracking the Dawn of *H. sapiens* in Africa

The fossil footprint record in Southern Africa is important for understanding Middle-Late Pleistocene transitions, which were more or less temporally coincident with the emergence of modern *Homo sapiens*. Roberts (2008) reported the two important tracksites: one at Nahoon Point, near East London (Deacon 1966; Mountain 1966), now dated at about  $127,000 \pm 8000$ , and another in the Langebaan Lagoon area, 130 km south of Cape Town, dated to about 117,000 YYBP (Gore 1997; Roberts and Berger 1997; Roberts 2008). Thus, both track sites represent the last interglacial period that coincides with the sub-Series boundary between Middle and Late Pleistocene (Gibbard 2003). The Nahoon Point tracks are better preserved, showing well-preserved toe impressions and a footprint length of ~19 cm, and are associated with poorly preserved mammal and bird tracks. The Langebaan lagoon tracks are larger (~23 cm long), but less well-defined. They are associated with probable hyena tracks (Roberts 2008). Hatala et al. (2011), Richmond et al. (2011) and Zimmer et al. (2012) reported an assemblage of about 350 tracks comprising 18 trackways from Lake Natron, Tanzania dated at about 120,000 YYBP (Wong 2011). Charles Helm (personal communication 2012) reports a number of other mammal and bird track sites along the South African coast.

## 15.5 The Late Pleistocene: *H. sapiens* Produces a New Type of Ichnologic Record

The ichnologic record of *Homo sapiens* in the Late Pleistocene contains evidence of an evolutionary event that can only be characterized as “revolutionary.” Simply put, this is because humans changed the fundamental nature of the ichnologic record. Whereas they had previously created footprints, and a few butcher marks on bone, only inadvertently, by as early as 30,000–35,000 years ago they were deliberately producing artifacts and artwork, which most anthropologists acknowledge as an unprecedented “creative revolution.” Before proceeding any further we need to explore the justification for including human creations, such as art work and other traces produced by the growth of civilization, under the broad umbrella of vertebrate ichnology. The word *ichnos* derives from the Greek meaning footprint or trace. In this regard the English word “trace” has deep etymologic roots connecting it with the words, draw, drag, and trace. So, for example, a draw horse, drags or draws a plow leaving a furrow or trace (see Smith and Hall 1914 or Harper 2012, for Latin translation of “to drag” as *traho*).

On the one hand, one might argue that it would be simpler and more consistent with our account of the pre-Late Pleistocene record, to confine our discussion of hominin ichnology to footprints left “inadvertently” by humans, or human ancestors, and therefore to “avoid” discussion of a plethora of traces created deliberately by humans, leaving it to be dealt with in the fields of archeology and anthropology (Kim et al. 2008a; Baucon et al. 2008). On the other hand, it can be persuasively argued that it is entirely arbitrary to draw a line between human traces produced inadvertently and those produced deliberately. A bird builds a nest deliberately, not inadvertently, and the same goes for animals that dig burrows. One might also argue that avoiding the problem is the lazy way out, because it fails to address the question of what is legitimately classified as a hominin trace fossil. The separation or avoidance approach would in effect treat humans as a “special” species, somehow outside the evolutionary continuum, creating a charge of unwarranted bias, contrary to much contemporary scientific philosophy. Moreover it is difficult if not impossible to draw an arbitrary dividing line between the cultural artifacts and traces produced by *H. sapiens* and non-*H. sapiens* species. Pre- or non-*sapiens* species were already producing trace fossils, such as butcher marks on bone and knapping marks on flint long before the first *sapiens* cultural revolution was underway in the Late Paleolithic.

As noted in Sect. 15.1, there is also scientific precedent, for including many diverse *sapiens* artifacts as an integral part of hominin ichnology (Hasiotis et al. 2007; Baucon et al. 2008). Kim et al. (2008a) presented some of the aforementioned rationale in arguing for four categories of hominin trace fossils, including (1) Pliocene through Holocene footprints, (2) Pleistocene through Holocene butcher marks (feeding traces), (3) Early and Mid Pleistocene stone tools, and (4) Late Pleistocene multimedia technology (including art, dwelling traces, etc.). Examples of traces in the latter two categories can be found through to the present time. In a similar, but more detailed evolutionary scheme, Rothschild and Lister (2003), in a standard textbook on evolution, listed ten major events in hominin evolution, occurring in the last 5 million years. Among these, a majority leave a trace fossil record, notably (1) bipedal locomotion, (2) utilization of new food resources, (3) stone tool manufacture, (4) control of fire, (6) symbolic communication, (9), and complex cultural and technologic diversification (10). Hasiotis et al. (2007) proposed a classification of hominid trace fossils that is somewhat different from the fourfold classification of Kim et al. (2008a). Their classification includes “features, biofacts/ecofacts and artifacts” which are further divided into multiple categories, including almost all manufactured items or creations including structural remains, lithic, ceramic, and metal items. However, in general, the two classifications are similar in so far as they recognize almost all human creations that leave physical traces as some category of trace fossil. As noted above, this discussion has been enlarged by Baucon et al. (2008) in their definitions of the broad scope of ichnoarcheology.

For convenience, in the sections that follow, we discriminate between artifacts themselves and the traces left by their creation. For example, stones are not trace fossils, but worked stone tools, and especially flake scars are trace fossils. Likewise, a fire is an artifact in a different category from the charred hearth left behind as the trace of the fire. In the same way a shelter or building is not in the same category as the post holes or foundation ditches created during their construction.

In any event, from a philosophic and methodologic perspective, we arrive at the following conclusions. There is no scientific justification for confining discussion of hominin ichnology only to footprints (produced inadvertently or otherwise). Thus, we may include such diverse traces as flaked stone tools, fire traces, cave painting, ditches, and foundations. While these trace fossil categories are commonly different from those associated with animal activity during most of the Phanerozoic, they are nevertheless unequivocal evidence of behavior and activity. Like other trace fossils, evidence of activity of organisms (McIlroy 2004) or work of organisms (ICZN 1999), hominin traces are significant in paleontology, stratigraphy, and sedimentology, but unlike other trace fossils, however, hominin traces can uniquely contribute to understanding the work or activities of our ancestors (Kim et al. 2007). Since it is we humans who attempt to evaluate “differences” between traces produced by different species, some subjectivity is perhaps inevitable, and the question arises as to whether these are “differences of kind or differences of degree.” These issues are further discussed below. It is also worth noting that while the creation of a diverse suite of new hominin trace fossils in the Late Pleistocene is considered a revolutionary leap forward in cultural terms (Diamond 1999; Mellars 2006) appearing as a major ichnologic event in the trace fossil record (Hasiotis et al. 2007; Kim et al. 2008a), it is not necessarily an anomalous evolutionary event. Rather it can be viewed as an example of a “punctuated evolution” scenario, or a change in the tempo of cultural evolution following a long Early–Middle Paleolithic period of relative stasis.

### ***15.5.1 Breaking New Ground: Prelude to the Late Pleistocene Cultural Revolution***

The geologically defined Late Pleistocene age extends from ~130,000 to 10,000 yBP. However, in comparison with the rapid developments of human cultural development in the later part of the Late Pleistocene, which falls within the range of <sup>14</sup>C dating techniques, the early part of this age (before ~50,000) has, until recently, produced comparatively little evidence of any major evolutionary events. There are no Late Pleistocene hominin tracksites dated with confidence in the first half of this interval (between ~130,000 and ~65,000). By contrast the latter part of the Late Pleistocene saw the worldwide spread of *Homo sapiens*. Unequivocal evidence, including footprints, establishes the presence of modern humans (*H. sapiens*) in both Australia and the Americas, as well as in ostensibly remote regions such as the Tibetan Plateau and Jeju island, Korea (Zhang and Li 2002; Kim et al. 2009). Along the way there may have been interactions with, even gene flow between, other late-*Homo* species—Neanderthals, Denisovans, and Red Deer Cave hominins (Meldrum 2012b). Tracks left by any of these species would likely be fully modern in appearance, albeit robust in proportions. In contrast, the persistence of more archaic hominins into this period—*Homo heidelbergensis*, even *Homo erectus* (Swisher et al. 1996) and the enigmatic and as yet very restricted species *H. floresiensis* (Morwood

et al. 2005) raises the possibility of additional footprint morphotypes. Given the perennial interest in the relationship of Neanderthals to modern humans, their inferred extinction as recently as ~25–30,000 yBP is generally considered a major event in hominin evolutionary history (Delson and Harvati 2006 and refs. therein). However, despite a footprint record spanning this time interval, it is not sufficient to shed useful light on the timing of this or other similar events.

However, before accepting that the so called Late Paleolithic cultural revolution or “great leap forward” into modernity (Diamond 1999; Mellars 2006) occurred quite abruptly ~50,000 yBP, perhaps coincident with, or in some way related to, the extinction of the Neanderthals it is important to note that this is a rather Eurocentric view that has been challenged by McBrearty and Brooks (2000). These authors show that many technologic advances, considered typical of European cultures existing between ~10,000 and ~50,000 yBP, have been identified significantly earlier in Africa on the order of >100,000 yBP.

Lockley et al. (2009) reported a total sample of 19 Late Pleistocene hominin tracksites from diverse localities around the world. Such geographically widespread occurrences demonstrate that the hominin track record is consistent with that obtained from archeologic evidence. In comparison with the important Pliocene through earliest Late Pleistocene track record in Africa, the record from most of the Late Pleistocene of Africa is sparse. Scott et al. (2008a, b) reported an isolated and poorly preserved track from the Lake Bogoria area of the Kenyan Rift valley. The track is ~20 cm long and 8.5 cm wide, and occurs in association with the footprints of bovids, suids, and birds.

Turning to Europe, we find some of the earliest of the Late Pleistocene track records associated with caves. Based on published dates, the oldest Late Pleistocene human footprints are those reported from Vârtoș Cave, Romania (Onac et al. 2005) and assigned an age of ~62,000 yBP. Three footprints, one with a well-defined outline (22 cm long and 10.6 cm wide), are preserved. However, details are obscured by infill of soda straws and moonmilk. Of note was a distinctive gap (1.6 cm) between the first and second digits (Fig. 15.3). According to these authors, the Vârtoș Cave tracks may be the only footprint sample unequivocally attributable to Neanderthals.

Human footprints were reported from a “deep Middle Paleolithic layer” at Theopetra Cave in Thessaly, Central Greece (Facorellis et al. 2001). This cave was evidently occupied from the Middle Paleolithic until the post Neolithic, with minimal <sup>14</sup>C dates of ~48,000 yBP obtained for the oldest layers with which the footprints are associated.

### ***15.5.2 The Hominin Track Record Goes Underground***

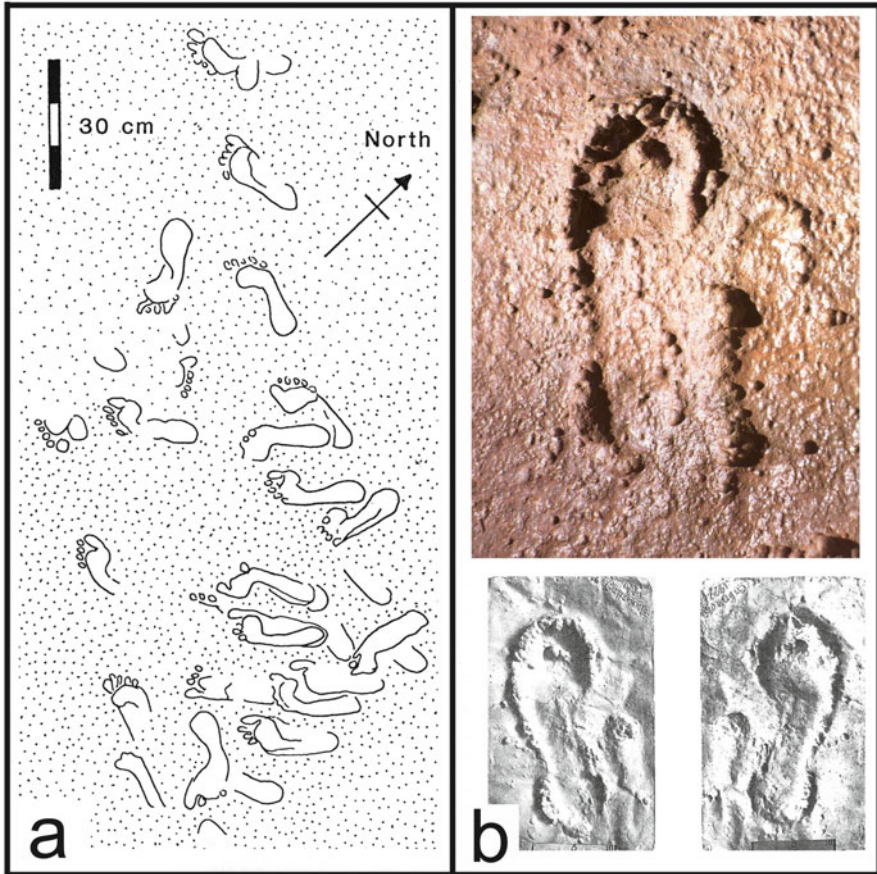
Many Late Pleistocene hominin footprint sites are associated with Late Paleolithic cultural evidence found in subterranean cave sites in southern France, Spain, and Italy. The region is perhaps most famous for cave paintings, but though less often reported in detail, many sites contain tracks and other evidence of Late Paleolithic

**Fig. 15.3** Purported Neanderthal footprints, Vârtope Cave, Romania. Note growth of cave calcite, obscuring track morphology



activity. Tracks are documented from Lascaux (Berriere and Sahly 1964) and the Niaux cave system (Pales 1976). Tracks from the Niaux caves have been described and illustrated in detail by Pales (1976), and apparently include patterned arrangements of footprints that have been interpreted as deliberate activity of children at play (Lockley and Meyer 2000) (Fig. 15.4). Here the issue of intention is raised, reminding us that by the Late Paleolithic not all human tracks were made as the result of purely unintentional passage of individuals through a particular area. Indeed, it is generally assumed, if not explicitly stated, that humans entered underground caves deliberately, even if the motives, other than creating artwork, are not clear. In a similar vein, human tracks from Grotte de Cabrerets or “Pech Merle” cave famously reveal traces indicating an individual using a walking stick (Begouen 1927; Vallois 1927, 1931).

In other cases, the interpretations put on tracks are more ambiguous. Tracks from Grotte Aldène assigned an age of ~15,000 yBP by Casteret (1948), but assigned an age of ~8000 yBP by Ambert et al. (2000), are associated with charcoal, hyena tracks, and cave bear nests, but the behavior of the track maker, in relation to other animal and human traces is unclear. In Fontanet Cave, footprints suggest a child may have followed a puppy or fox into a cave, but this inference can hardly be confirmed or denied on the basis of available analysis (Bahn and Vertut 1988). As noted



**Fig. 15.4** (a) Tracks in a patterned arrangement from Niaux cave, suggest children at play (after Pales 1976 and Lockley and Meyer 2000, Fig. 10.12). (b) Track from Peche Merle cave

elsewhere (Lockley et al. 2007a; 2009), the footprints of children appear as common components of the track record of Paleolithic caves. For example, in Chauvet Cave near Vallon-Pont-d'Arc in southern France, a trail of footprints claimed to represent those of a young boy, about 8 years old and about 1.5 m tall, are possibly the oldest European footprints of *Homo sapiens*, perhaps as old as 35,000 yBP. At Ariège three trackways of children are recorded (Bahn and Vertut 1988). The footprints extend for about 50 m across the cave floor and may be between 20,000 and 30,000 years old (Harrington 1999; García 1999, 2001). Many other Late Paleolithic caves with hominin tracks have been mentioned or illustrated without detailed descriptions (Kuhn 1955; Marshack 1972; Vialou 1986; Bahn and Vertut 1988). As already implied, in many cases these sites reveal evidence that other animals, evidently all mammalian carnivores, shared these cave habitats, at least on some occasions (Lockley et al. 2007a, b; 2009).

Tana della Basura cave near Toirano, Northern Italy is here mentioned separately due to the intriguing but controversial suggestion that the “human tracks” reported by Chiapella (1952) are attributable to Neanderthals (Pales 1954, 1960). At present, despite the skeletal evidence that may be available from various sites to help distinguish *H. sapiens* from *H. neanderthalensis*, we have no reliable criteria for identifying isolated Neanderthal footprints. As pointed out by Molleson et al. (1972) and by Onac et al. (2005), the date of this site may be as young as 12,000 yBP, in which case the Neanderthal claim is questionable. Its morphology certainly does not distinguish it from a *H. sapiens* (Fig. 15.5).

The abundance of human tracks at cave sites is perhaps surprising, especially given the lack of detailed description of many sites. For example, in Ojo Guareña, a cave near Burgos, Spain, hundreds of footprints are reported, but the site is illustrated by only two photographs (Marcos 2001). Dates of 15,600 yBP, suggesting a Late Pleistocene age, were obtained from carbonized wood. As noted by Lockley et al. (2008a, b), a “light patina of carbonate” gives the tracks “a very ancient appearance” (translation of phrases from Marcos 2001, p. 35).

This type of discrepancy between abundance and documentation is understandable when considering the problems of access, and the dangers of disturbing the footprints by walking on them, or otherwise causing damage. Likewise, dating of the cave site tracks is often difficult due to the lack of suitable materials in the

**Fig. 15.5** Footprint from Tana della Basura cave near Toirano, Northern Italy



substrate, the likely differences in age between substrate and tracks, and the preference for dating other materials such as charcoal which may or may not be contemporaneous with the tracks. For example, footprints from Tempranas Cave, near Niembro in the Llanes region of Asturias Spain (Noval Fonseca 2007) remain undated at the present time.

Despite the problems involved in obtaining accurate dates, tracks in caves have good preservation potential and, as noted above, tracks are apparently more abundant, at least at some sites, than the literature might suggest. However, another factor must be considered—that is the attraction of cave paintings. On the positive side, efforts to date cave paintings make it possible to infer the age of footprints, assuming there is no strong evidence to suggest that paintings and footprints represent different phases of activity. On the negative side, paintings distract attention from other features, such as footprints and charcoal. Obviously, paintings indicate that caves were frequented by people on foot, even if footprints are not found. Footprints may occur in caves without paintings or other evidence of human habitation (see below), but it is impossible to speculate on how common tracks are in caves lacking other human-produced evidence.

For all the problems and ambiguities that surround the discovery, documentation, dating, and interpretation of cave site footprints, cave tracks indicate a certain type of behavior and ecology. For whatever reason, modern humans (*H. sapiens*) and perhaps close relatives (e.g. *H. neanderthalensis*) began to frequent caves sometime in the Late Pleistocene. This can be considered a significant event in hominin evolution and, in the most general terms, the evidence seems to suggest a human impulse to colonize new habitats. This was just one example of the geographic spread of humans to colonize new regions, such as Australia and the Americas. In ecologic terms, as explicitly noted by Lockley et al. (2007a, b; 2008a, b), the nonhuman footprints reported from Late Pleistocene caves are almost exclusively those of carnivores (including bear, hyena, and fox), and stand in contrast to open-air hominin track sites, where tracks of ungulates and birds are typically dominant. The aforementioned cave-dwelling carnivores had evidently inhabited caves long before their habitations were invaded by modern humans. Thus, human cave-colonization behavior precipitated new “ecologic” interactions between humans and cave dwelling mammals. While the co-occurrence of footprints of both groups is tangible evidence of such cohabitation, even more evocative evidence of interaction is found in the archeologic record of paintings and supposed shrines indicative of “cave bear cults” (a once-popular notion, especially for the Middle Paleolithic, but long discredited by taphonomic studies [Bahn 2012]).

### 15.5.3 *Vertebrate Ichnology Investigates Cave Paintings*

Lockley and Meyer (2000) and Kim et al. (2008a) noted that cave art (or the more neutral term “painting”) is itself a type of hominin ichnology, as is any type of engraving. Likewise, as noted by Lockley et al. (2008a, p. 113), “[b]



ecause tracks are a type of symbol or signature of the trackmaker, their artistic renderings have sometimes been the subject of debate.” Indeed, as noted above, many human creations can be considered as ichnologic phenomena, including most forms of sculpture and writing. However, in order to constrain the discussion to the realm of prehistory, we confine our discussion to the implications of Late Pleistocene evidence, which sheds light on evolutionary events. For example, just as footprints indicate the co-occurrence of modern humans and Late Pleistocene carnivores in caves, so cave art provides direct evidence of the interaction of humans with the Pleistocene megafauna. The interest for vertebrate ichnology is compounded when Paleolithic hominins also depicted the footprints of the animals they were tracking, observing, or hunting (Mithen 1988). In this regard, it could be inferred that just as tracks are potentially useful as a census of animals in a particular area (Lockley 1991), so cave art is also potentially a census of animals in a given area in the past. For example, at Closquier cave, in southern France, there are depictions of what is interpreted as the now-extinct great auk, “a seabird that could only live in a cold biotope” (Clottes and Courtir 1996, p. 128). Just as these authors at first found it difficult to interpret the depiction of the great auk, so too footprints depicted by Late Paleolithic artists have proved difficult to interpret. As noted by Lockley et al. (2009, p. 113), a particularly “interesting episode in the annals of anthropology was a debate over whether certain symbols represented tracks or were representations of female genitalia (Bahn 1986).”

European Cave art, especially from France and Spain, has been the subject of endless debate. For example, do animal depictions indicate hunting activity, sympathetic magic, or other shamanistic symbolism? Likewise, one can argue endlessly as to whether animal and track depictions are realistic or stylized, the result of superior or inferior artistic ability. Possibly the most significant depictions from an ichnologic view point are these that show the co-occurrence of animals and the tracks they made. One famous example is the bovids depicted at Altamira, Spain, where the animals are seen in profile, but their feet are shown in “plan view” appearing as cloven hooved tracks stuck on the end of the legs. While it is obvious from such examples that Late Paleolithic humans could correlate between animals and their tracks, this is still a highly significant record from the “dawn of vertebrate ichnology” essentially no different from that produced by contemporary vertebrate ichnologists who correlate between tracks and track makers. Thus, our Paleolithic ancestors deserve full credit for being the authors of the first the vertebrate track field guides (Seilacher 2007). Whether, we can infer that they only interpreted the track-track maker correlation in causal terms, the way we do, remains an open question, and we have to consider the possibility that tracks had other significance in various Paleolithic cultures (Lockley 1999); see Baucon et al. (2008) for discussion of podomorphs (footprint representations) and “ichnohierophanies” (traces of religious or spiritual significance).

## 15.6 New Intercontinental Travel Frontiers

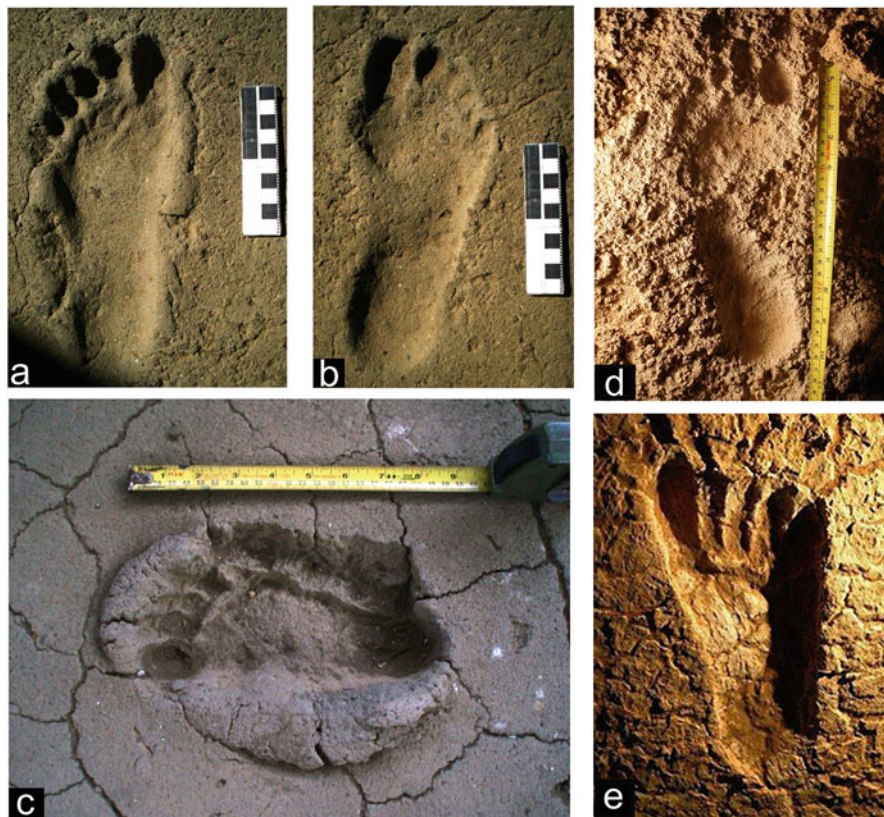
Archeology and anthropology regard the colonization of Australia and the Americas by *Homo sapiens* (if not earlier *Homo* species), as evidence of the ability of modern humans to permanently expand their ranges into previously “uninhabited” territory, by undertaking what we can describe as intercontinental travel. Exactly when and where the first emigrants broke out of the “old world” to set foot in Australia and America is unknown. However, these expansions of range seem to have been part of a pattern that was first manifest with the spread of human ancestors “out of Africa” into Europe and Asia, including inaccessible regions, such as present day Tibet (Zhang and Li. 2002) and various islands of the Indonesia archipelago (Morwood et al. 2005).

### 15.6.1 Into Australia

The colonization of Australia is considered (Bowler et al. 2003) a major event in hominin evolution, reflecting an ever-increasing ability of humans to colonize new continents. Humans probably first colonized Australia around 50,000 yBP, showing their ability to cross the famous Wallace line which separates the marsupial-dominated faunas of Australia from the placental-dominated faunas of southeast Asia (Oppenheimer 2009). Webb et al. (2006) and Webb (2007) reported tracks that have been optically dated to between ~19,000 and 23,000 yBP in the Willandra Lakes region of southeastern Australia. This is evidently one of the world’s largest collection of Pleistocene human footprints, with at least 123 footprints, and the site is part of a property nominated for World Heritage status. The largest tracks measure 29 cm in length by 10 cm wide. The tracks for which close-up photos have been published (Fig. 15.6) present an unusual and less than fully modern morphology: quite flat, exceptionally broad heel, deep and long toe impressions (up to 7 cm) and a large robust hallux, but lack any clear medial arch and ball impressions (Webb et al. 2006, Fig. 4).

### 15.6.2 The Trail to the New World

According to controversial footprint evidence, modern humans may have first set foot in the New World as early as ~40,000 yBP (Gonzalez et al. 2006a; Huddart et al. 2008). According to the initial claims of these authors, footprints from a Late Pleistocene site from Toluquilla Quarry, at Valsequillo, near Puebla Mexico, indicate this reliable 40,000 yBP date for the presence of *Homo sapiens* in the New World. However, while the date may be credible, the features interpreted as footprints are controversial, and several of the original authors now admit that these purported tracks are of questionable origin (Morse et al. 2010). They lack clear



**Fig. 15.6** *Homo sapiens* tracks from the New World and Australia. (a–c) tracks from the Acahualinca site Nicaragua (after Lockley et al. 2009, Fig. 10), (d) track from Cuatrociénegas, Mexico (after Gonzalez et al. 2009), (e) track from Willandra Lakes site, Australia

evidence of the big toe (hallux) impression, arch, or differentiated ball and heel traces. In short they are elongate depressions or traces that may be artifacts produced by quarry equipment. Renne et al. (2005) referred to these features as “alleged” footprints and also questioned the dates, instead inferring much older dates of 1.3 Ma, corroborated by paleomagnetic studies. However, Gonzalez et al. (2006b) and Huddart et al. (2008) held to their claim arguing that the dating of Renne et al. (2005) is incorrect.

According to evidence other than footprints humans are not proven to have been resident in the Americas prior to ~20,000 yBP (Nemecek 2000). Footprints on the western coast of Canada, dating to 12,500 yBP, may indicate a coastal route for colonization of the Americas (De Pastino 2015). Tracks from Buenos Aires Province Argentina (Aramayo and Manera de Bianco 2009), have produced dates in the range of ~12,000–16,000 yBP. Hominin tracksites reported from Monte Verde, Chile are associated with dates of 11,500–12,500 yBP (Dillehay 1999). The rediscovery of a tracksite associated with tufa deposits at

Cuatrociénegas, Coahuila, Mexico has produced tentative dates of ~10,000 yBP (Gonzalez et al. 2006c, d, 2007, 2009). Two sets of tracks from Cuatrociénegas have recently yielded U-series dates of  $10.55 \pm 0.03$  ka and  $7.24 \pm 0.13$  ka (Morse et al. 2010). Given the doubts about the age of the Valsequillo footprints referred to above, Morse et al. (2014) claimed that the former date represents the oldest known for any footprints from Mexico. Other tracksites reported from Mexico (Ordoñez 1945; Aveleyra Arroyo de Anda 1950; Rodríguez-de la Rosa et al. 2004) are poorly known, but likely include mostly Holocene rather than Pleistocene tracks.

Among the Holocene track sites listed by Lockley et al. (2007a, b; 2008a, b), two sites from La Olla and Monte Hermoso Argentina dated at ~7000 yBP (Bayon and Politis 1996, 1998; Aramayo and Manera de Bianco 2009; Bayón et al. 2011) are significant, and comparable in age to a site from Laguna La María (near Villa Cañás) dated to ~8000 yBP. Abundant well-preserved tracks from the footprint museum at Acahualinca, (Huellas de Acahualinca) Managua, Nicaragua (Flint 1883; Brinton 1887) have been  $^{14}\text{C}$ -dated at  $5945 \pm 145$  yBP (Bryan 1973), at 6500 yBP by Bice (1979), and between 2000 and 6000 yBP (Schmincke et al., 2005, 2007, 2008, 2009). The site is now the type locality for *Hominipes modernus* (Kim et al. 2008b) and preserves the trackways of at least 15 individuals, an ungulate, a possum and a bird (Lockley et al. 2007a, b; 2008a, b). Another nearby site, known as El Recreo (Williams 1952), has yielded bison and tapir tracks. Plant remains are also reported (Brown 1947). The Oro Grande Site near Victorville, southern California (Rector 1979, 1983, 1999), has given a  $^{14}\text{C}$  date of  $5070 \pm 120$  yBP (Rector 1983) for tracks of at least four individuals, where tracks of raccoon, coyote, and ungulates were also documented.

Haberland and Grebe (1957) reported a tracksite from El Salvador tentatively dated between ~1200 and 1800 yBP. Undated footprints were also reported from a volcanic deposit near Guaimaca, Honduras (Veliz 1978). Similarly sparse information comes from a report (Anon undated) of a cave site from Naj Tunich, Guatemala, with footprints attributed to indigenous Mayan inhabitants tentatively dated on the basis of artifacts, not footprints, between ~1450 and 1950 yBP.

To complete the New World track record, we may refer to Willey et al. (2009), who noted footprints reported from Pocket Cave in Arizona, and dated at ~1450–1500 yBP based on dendrochronology. Finally, footprints from eastern North America are associated with underground caverns, such as Jaguar Cave, Tennessee, Unknown Cave, Kentucky, third Unnamed Cave, Tennessee, Fisher Ridge Cave, Kentucky, Mud Glyph Cave, Tennessee, Sequoyah Caverns, Alabama, Footprint Cave, Virginia, and Lon Odell Memorial Cave, Missouri (Watson et al. 2005; Willey et al. 2005, 2009). Collectively, these cave sites date from between  $4695 \pm 85$  and ~400 yBP.

### ***15.6.3 Other Exploratory Trails***

As summarized by Lockley et al. (2008a, b), Zhang and Li (2002) and Zhang et al. (2003) reported a series of hand and footprints associated with calcareous tufa deposits at an elevation of 4200 m on the Tibetan Plateau optically dated at about 20,000 yBP. This unusual combination of hand and footprints may be related to the site being a hot springs with a hearth, therefore presumably used as a campsite, rather than an area simply passed through.

Late Pleistocene footprints dated at about 19,000–25,000 yBP from Jeju Island, Korea (Kim and Kim 2004a, b; Kim et al. 2004, 2009, 2010) indicate that humans were exploring remote islands at about the same time that they were exploring the Tibetan Plateau. As a coastal site, Jeju provides evidence of a variety of bird and mammal tracks diverse invertebrate traces and body fossils, at multiple levels, suggesting an ecology obviously different from that found in Tibet. Nevertheless, despite the geographic and ecologic differences between these two Asian sites, they both provide striking evidence of the ability of Late Paleolithic humans to explore habitats that had not previously been frequented by hominins.

## **15.7 The Prelude to History**

### ***15.7.1 Life on the Sea Shore***

Lockley et al. (2007a, b, 2008a, b) have already listed known hominin track sites that bridge the gap between unequivocally Pleistocene and prehistoric Holocene sites, to those that yield comparatively recent dates that bring us into historic time. It is not necessary to repeat detailed accounts of these sites which are already widely distributed. However, a brief summary allows us to pick out features that highlight the utility of footprints in interpreting “events” in historic time.

Among the earliest Holocene tracks to fit in our post-Pleistocene category, we can cite abundant human footprints from near the Sebokra el Azrag, Mauritania (Mafart 2006). These date from ~9000 yBP and are associated with footprints of elephants, hippopotamus, giant eland, and bovids.

Younger Holocene footprint sites are known from near Clare Bay, in South Australia (Belperio and Fotheringham 1990), estimated to be ~5000 yBP. Undocumented tracks are also reported from near Broome in western Australia (Long 1998; Baldwin personal communication 2011). Both are coastal sites. Other significant coastal hominin tracksites are known in Britain (Aldhouse-Green et al. 1995; Cowell et al. 1993; Roberts et al. 1996; Roberts 2009; Doyle 2007; Bennett et al. 2010a, b). An assemblage of exceptionally preserved footprints of between six and nine children (ranging in length from 114 to 206 mm) has been described from Walvis Bay, Namibia (Bennett and Morse 2014). They date to 1500 yBP and are preceded by the tracks of an apparent flock of domesticated sheep/goats.

Human footprints reported from Rawthey Cave, Cumbria, England (Chamberlain et al. 1997) could be as recent as the 14th century AD. Some coastal sites (Patton 1993) have only the tracks of domestic animals. Human tracks have also been reported from Holocene beach rock in Greece (Bromley et al. 2009).

The coastal situation of many Holocene track sites seems to reflect two factors. (1) Suitable environments for track preservation (e.g., estuarine and beach substrates) and (2) preferred habitats or foraging sites of humans. We know from other lines of evidence, such as shell middens, that foraging was an important activity at such sites.

### 15.7.2 *In the Shadow of Volcanoes*

Human tracks are reported from numerous agricultural sites (rice fields) in Japan, (Harada and Noto 1984) that date from ~720 to 1600 yBP. At many of these Japanese sites, volcanic ash played an important role in track preservation. Human tracks also occur at various stratigraphic levels in volcanic ashes dated at 1400 AD on Motutapu Island, New Zealand. Nichol (1982) suggested that track makers were evidently not deterred by the continuing ash falling over the area. Traces of digging sticks suggest that individuals were digging gardens.

Footprints from Hawaii Volcanoes National Park site are from two distinct footprint-bearing horizons, the younger precisely dated to a 1790 Kilauea eruption and ashfall (Meldrum 2004a, b; Moniz Nakamura 2009). The record of modern pedestrian trackways in ash of remarkably similar physical and chemical characteristics as the Laetoli ashfall, provides in the Hawaiian footprints a meaningful comparison and contrast to the Laetoli hominin footprints. This contrast highlights the diagnostic distinctions between *Praehominipes laetoliensis* and *Hominipes modernus* (Meldrum 2004a, b; Meldrum et al. 2011). Because of the drama associated with volcanic eruptions, various scenarios regarding the relationship between ash fall and track-making activity have been proposed, not only for the Hawaiian sites (Jaggard 1921, 1934; Meldrum 2004a, b; Mayor and Sarjeant 2001), but also for the aforementioned Nicaraguan site (Schmincke et al. 2005, 2007, 2008, 2009) and the New Zealand levels (Nichol 1982).

Regarding the Hawaiian sites, Moniz Nakamura (2009) suggested footprints were made in the area both before and after the eruption, thus indicating that individuals were not deterred by the ash fall and not fleeing or about to perish as a direct result of the eruption. Were indigenous populations accustomed to repeat volcanic activity, and undeterred by smaller eruptions? Possibly, but sometimes large eruptions did create truly dramatic, life-threatening scenarios as in the case of the famous 79 AD eruption of Vesuvius. Unlike this eruption, which is not associated with footprints, footprints are found in association with deposits created by the 3780 yBP eruption of Vesuvius, known as the Avellino plinian eruption, that fell on Nola, a Bronze Age village near Naples, Italy (Mastrolorenzo et al. 2006). These devastating ash falls created a remarkable footprint record NNW of Vesuvius where “thousands of footprints [are] directed

NNW away from the volcano.” These “testify to an *en masse* exodus from the devastated zone” (Mastrolorenzo et al. 2006, p. 4368). Footprints registered on “all horizons in the ash bed” indicating that “the evacuation occurred during the settling of the surge cloud.” “Flood and lahar deposits overlying the surge bed also include footprints and local raindrop imprints as well, thus testifying that the ongoing exodus occurred during both the ash fall and the post-eruption rainstorms and floods” (Mastrolorenzo et al. 2006, p. 4368).

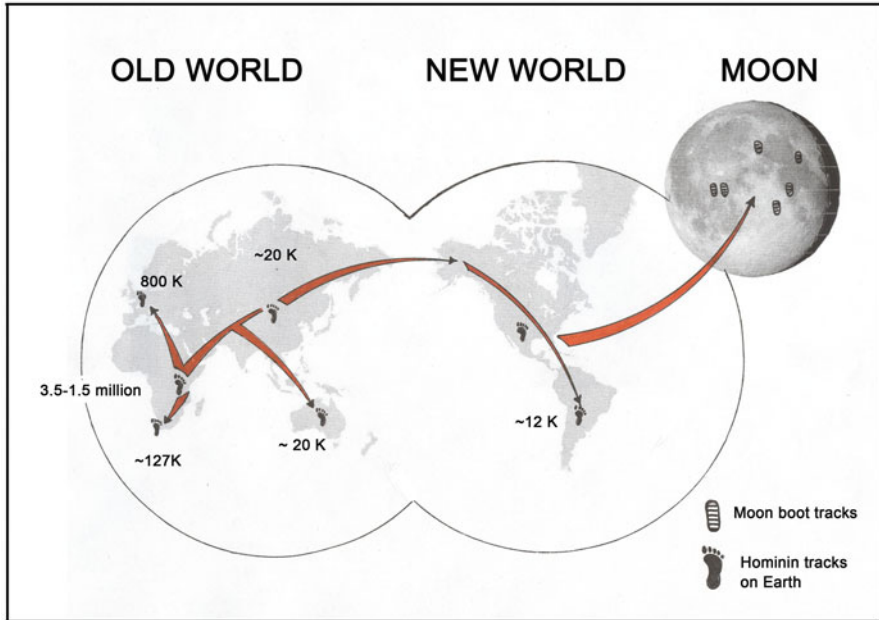
From these accounts of human tracks in volcanic ashes, we can infer that, at the times indicated above, humans lived in volcanic terrains, as they do in some areas today, risking the dangers inherent in such environments. Although we do not know exactly how they reacted to localized or small eruptions, the evidence at some sites (New Zealand, Nicaragua, Hawaii) suggests they were not sufficiently deterred by the threats, to vacate these areas. Thus, on occasion they did not evacuate, or move very far from small eruptions that created small ash falls. However, as the Nola eruption indicates, humans reacted to large eruptions and ash falls by fleeing, although in this case escape was not possible and individuals literally died in their tracks.

## 15.8 Vertebrate Ichnology Transcends Planet Earth

One of the major events in human history was the landing of humans at six sites on the Moon (Fig. 15.7). Arguably, this is a major evolutionary event akin to the migration of a species onto a new continent on which that species had not previously set foot. Just as the fossil record, including the track record, provides evidence of such migrations, so the artifacts and tracks and traces left by humans on the Moon also provide unequivocal evidence that the range of living humans has extended from one celestial body (planet Earth) to another (its moon). In the case of the machines that humans have landed on Mars, the artifact and trace fossil evidence is slightly different, and it is intriguing to speculate as to how it might be interpreted and compared with the lunar evidence, by someone unfamiliar with human history (Lockley 1999).

While most humans regard the Moon landing as a momentous event in human history, it is perhaps too recent an event to have had its evolutionary significance evaluated in the context of deep time. In any event, the track making activity of humans on the Moon, while creating visually spectacular traces, is so distinctive as to have been treated as a special event, unrelated to the long history of hominin track making on Earth. Nevertheless, while it is legitimate to regard lunar and terrestrial tracks records as two quite separate ichnologic records, in obviously different substrates, environments, and geographic locations, they are still indisputable parts of the continuum of an expanding hominin track record (Fig. 15.6). So, what are the implications?

Humans are the only large vertebrate species to have set foot on the Moon. In this regard, they crossed a new frontier in much the same way as they did when they cross the Wallace line between Asia and Australia, or the Bering Straits between



**Fig. 15.7** The dispersal of hominins from the old world to the new world and Moon as demonstrated by the footprint record, is in broad agreement with the evidence obtained from the record of body fossils and artifacts

Asia and North America. The principle is succinctly stated by Morwood and Oosterzee (2007, p. 182): “Modern humans were the only large Asian animals that made the west-to-east crossing to Greater Australia on their own account.” Here, these authors evidently imply that the migration into Australia was not accidental, as in the oft-cited, but speculative, explanation of dispersal of animals, rafted by accident from one land mass to another. Lockley (1999) described some of the configurations of human traces on the Moon. First, of course they are limited to a very small area, and secondly they loop out from the lunar module and back. Secondly the total census of individual trackways is known to represent only 12 individuals. An intelligent species analyzing the footprint evidence might correctly infer that very few individual track makers, of a distinctive bipedal species, had visited the Moon, but had been unable to explore very far. The track makers were not adapted to colonize extensively.

It is perhaps unduly speculative to consider how another intelligent species might interpret the trails of the lunar rover, the actual rover itself, or the trails and machines on Mars (Lockley 1999). We know that the Martian traces were made without humans being present on the planet, but would this be deduced by an intelligent species unaware of the details of an Earth-based space program? It is perhaps debatable as to whether traces left by robotic machines legitimately fall in the category of biogenic sedimentary structures. Clearly, feet and shod foot traces represent human functional anatomy and behavior, but lunar and Martian rovers represent



a different type of function, only indirectly related to human movement. Since these robotic machines are tools, we argue that in principle the traces they leave are similar to those produced by other human-manufactured tools that register traces on a variety of substrates.

In conclusion, as noted below, a broad-based interpretation of hominin ichnology indicates that there have been at least four major threshold events that starkly punctuate the ichnologic record. The first was bipedalism, the second was the spread of hominins to Australia and the New World, the third was painting, sculpture, and tool making, associated with extensive cave exploration, and the fourth was the ability to set foot on other celestial bodies.

## 15.9 Discussion

At least 65 hominin tracksites are reported in the literature (Lockley et al. 2007a, b, 2008a, b) of which about one third (~24) are Late Pleistocene or older. Only a few (4) sites represent pre-*sapiens* track makers. The advent of erect posture and gait was clearly a major event in hominin evolution. However, the question of whether such features as midfoot morphology (flexibility vs. a fully modern arch) and separation of the big toe (digit I) from traces of digits II–V, and their different inferred lengths, constitute evidence of major evolutionary changes remains open to question, and may not be fully resolved without additions to the body and trace fossil records. Debates about the affinity of the 3.6-million-year-old Laetoli track maker are made partly on the basis of the age of the sites and contemporary body fossils. However, they are also at least partially based on footprint morphology, when correlated pedal skeletal fossils are known. Tuttle et al. (1990) inferred that the Laetoli track maker may have been an as-yet-unknown hominin indistinguishable from modern *H. sapiens*, and therefore not an australopithecine as inferred by Stern and Susman (1983; see also Suwa 1984). In contrast, Meldrum (2006, 2007a) pointed to evidence of mid-tarsal pressure ridges and extrusion fronts, in the G1 trail indicating ape-like midfoot flexibility largely if not altogether absent in modern humans (but see DeSilva and Gill 2013). The distinctions in the Laetoli tracks when compared to modern unshod pedestrians are expressed in the introduction of the new ichnotaxon *Praehominipes laetoliensis* (Meldrum et al. 2011) in contrast to footprints of fully modern humans, designated as *Hominipes modernus* (Kim et al. 2008a, b). However, if we exclude the overprinted trackways (G2 and G3), and possibly a fourth (G4) according to Musiba et al. (2011), the *Praehominipes* sample of un-obscured footprints remains small consisting of only the G1 trackway (Fig. 15.1).

The inference of an *H. erectus* (*H. ergaster*) trackmaker, in the case of the poorly preserved Koobi Fora footprints (Behrensmeier and Laporte 1981), is based on age. The Ileret footprints also exhibit insufficient detail to infer modern footprint morphology with certainty. This inference is contra Bennett et al. (2010a), who concluded that these footprints provide “the oldest evidence of an essentially modern human-like foot anatomy, with a relatively adducted hallux, medial longitudinal

arch, and medial weight transfer before push-off.” We find support for only one of these three points (i.e. a relatively adducted hallux). We find no evidence to support the consistent presence of a longitudinal arch or for a medial weight transfer. Preservation is poor, and the actual topography of the contact surface is indiscernible. Even in footprints as young as 300,000–400,000 years old, such as the Terra Amata footprint (De Lumley 1966, 1967; De Lumley et al. 2011), evidence of a modern arch is lacking (Meldrum 2004a, b; 2006). Likewise, tracks from the Middle Pleistocene Roccamonfina Volcano site in Italy (Mietto et al. 2003; Avanzini et al. 2004, 2008), which falls in the same age bracket as the Terra Amata footprint, are not sufficiently well-preserved to determine if a fully modern arch is present.

Thus, given the small size and quality of the pre-Late Pleistocene footprint sample, few universally accepted conclusions can be drawn regarding the possibility of diagnostic differences between tracks made by various hominin species of early to middle *Homo*. However, the strong possibility remains that much of the hominin history of bipedalism took place on flat flexible feet in contrast to the modern human foot form of relatively recent vintage, as characterized by the ichnospecies *Hominipes modernus* (Kim et al. 2009). The scarce fossil record of the distal hallucal metatarsal, a key element in the modern longitudinal arch, clearly points to this interpretation.

Distinguishing between the tracks of *Homo sapiens* and the comparatively unknown track record of *H. neanderthalensis* on the basis of footprint morphology is evidently not reliable at present, despite a few claims to the contrary (Onac et al. 2005). It stands to reason that the robusticity of the neanderthal skeleton would produce footprints with relatively larger breadth to length ratios. However, the sample of Neanderthal footprints is too meager to test this prediction.

As noted by Lockley et al. (2008a, b), although the majority of known sites have assigned ages, in many cases the dates are uncertain, and the literature indicates frequent age date revisions, such as in the case of the Turkish and Nicaraguan sites. These authors also discussed the respective proportion of outdoor or open-air sites versus cave sites as about 65% versus 35%. Likewise, the proportion of sites in well-documented volcanoclastic/pyroclastic rather than non-volcanoclastic substrates is discussed by Houck et al. (2009).

The study of hominid traces raises philosophic issues that deal with the controversial question of the “exclusivity” of the human species in comparison with other vertebrates. Many scientists and philosophers argue for and against the idea that humans are fundamentally different from other species (see Guldberg 2010 for discussion of both sides of this debate). The traditional argument in favor of human exclusivity is that we have language, self-awareness, and culture, not to mention the power to change the environment in ways that other species cannot. This is not to say that other microbial, plant, and animal species have not changed environments dramatically, but in different ways. We also recognize that the exclusivity argument, with respect to tool use, language, and self-awareness, has been challenged in cases where such attributes have been reported for other species (Galef 2003, 2009; Rendell and Whitehead 2001). However, detailed discussion of these debates is beyond the scope of this paper. As the foregoing discussions emphasize, an objective look at the

hominin track record indicates that the ichnologic record of *H. sapiens* is unlike that of any other species, with respect to many features including, geographic distribution, diversity of traces registered, substrates on which traces are registered, and behavioral implications of traces (e.g., Hasiotis et al. 2007; Baucon et al. 2008; Kim et al. 2008a). Again, in the context of this review of footprints and other traces created by *sapiens* and pre-*sapiens* hominins, it is clear that, even though foot and hand prints may be similar among all hominins, the diversity and behavioral implications of most other *sapiens*-produced traces is different from those of pre-*sapiens* hominins and other vertebrates both in absolute and relative terms (i.e. they are both differences of “degree and kind”). Thus, the use and creation of stone, bone and wood tools, and artifacts, while not entirely unknown in pre-*sapiens* hominins or other vertebrate species, reaches a degree of complexity indicating behaviors and cultural shifts that truly represent major evolutionary advances during the *sapiens* phase of hominin prehistory. This shift in turn heralded entirely novel and ultimately historically documented additions to the anthropologic and trace fossil records, such as ceramics, metal-work, and writing which have no pre-*sapiens* precursors (Hasiotis et al. 2007; Baucon et al. 2008; Kim et al. 2008a). In short, as hominins have evolved over the last ~4 million years, their ichnologic record has become increasingly well differentiated from that of their ancestors, a process that shows its most dramatic acceleration or shift after about 30,000 yBP.

While prior to that date multiple hominin species, a half dozen or more, coexisted across the landscape at any given time it is generally inferred that since ~30 kyBP, *H. sapiens* has been the only or “exclusive” extant hominin species. However, there is a growing appreciation for the bushiness of the hominin (even hominoid) tree, as well as accumulating examples of quite recent persistence of individual branches of said tree, as evidenced in the fossil record (Meldrum 2012a, b). Is it justified to simply assume we are “the last hominin standing”? Or is there a case to be made for the possible existence of “relict hominoids” today? The discovery of the extraordinarily recent remains of *Homo floresiensis*, combined with the acknowledgement of historical anecdotes of encounters with little hairy “people” in the mountain forests of Flores should have made that point clearly enough (e.g., Forth 2012).

There is considerable ichnologic evidence for the existence of relict hominoids. By far the most extensive footprint evidence is attributed to the so-called “Bigfoot” (or sasquatch) of North America, as well as reports of similar tracks in Asia (Meldrum and Gouxing 2012), where the comparatively recent existence of the giant hominoid *Gigantopithecus* is unequivocally accepted (Meldrum 2004b, 2006, 2007b and references therein). Meldrum (2007b) formally named and diagnosed the alleged sasquatch tracks as *Anthropoidipes ameriborealis*.

While it is outside the scope of the present review to explore this intriguing but controversial issue further, it is fair to say that the possible existence of relict hominoids represents a significant dimension in hominid evolution. While most anthropologists ignore or refute the existence of relict hominoids without detailed analysis of the evidence at hand, there is nevertheless an extensive literature on the subject including a number of books by *bona fide* scientists who have taken the evidence

seriously (see Lockley 1999 and Meldrum 2006 for reviews). Did *Gigantopithecus* or some similar large bipedal relict hominoid (such as a form of paranthropine) cross from Asia to North America, along with *Homo sapiens*, during the Pleistocene, along with 75 % of the mammals now considered endemic to this continent? And if so, what sort of ichnologic evidence might we expect to find? Are contemporary reports of the tracks of a giant hominid in North America's remote mountain forests, or those of a diminutive "hobbit" in the jungles of southeast Asia, any more surprising than *H. sapiens* tracks on the Moon, or 25,000 year old tracks alongside pictures of Great Auks in a deep cave in the South of France, or 20,000 year old tracks on the Tibetan plateau at the height of the Ice Age?

Finally, it is relevant to consider the extent to which *Homo sapiens*' intentional behavior is affecting the track record as a whole. While large scale megalopolis construction and landscape alteration will surely leave an ichnologic footprint that dwarfs such relatively local traces as Japanese rice paddies, it will at the same time remove or diminish the track record of many other species, by erasing or modifying substrates. This process could be considered similar, or analogous, to other natural, non-human-induced, processes such as erosion, that lead to the differential preservation or destruction of trace-bearing deposits. While such human-generated traces may vastly modify natural cycles of track registration, preservation, exhumation, and destruction, humans also *intentionally* preserve the ancient track record. This is done not just by preserving fossil footprints in museums, but in the creation of a symbolic, documentary record (a type of ichnologic record: e.g., this book) of extinct species and lost cultures that would not otherwise exist without human intentionality. Thus, *Homo sapiens* has created a wide array of highly distinctive and "exclusively" human traces.

## 15.10 Conclusions

We conclude that the track record has significant implications for our understanding of major events in hominin evolution and can be summarized in two categories: major and minor events. Major events include the following:

1. The advent of bipedalism, confirmed by the Laetoli site, and dated not later than ~3.6 Myr.
2. The arrival of modern humans in Australia and the New World (the Americas), confirmed by footprints and other archeologic evidence 15,000–20,000 yBP. A date of ~40,000 yBP has been suggested for colonization of Australia, but in the case of the Americas such an early date, although claimed in one case, is controversial and dubious.
3. The ichnology manifest in the creation of art (painting, sculpture, etc.,) and tools in the Late Paleolithic, especially between ~30,000 and 10,000 yBP, indicates that humans underwent a "cultural revolution" at this time. They made extensive

use of underground cave sites, leaving 2D and 3D art and artifacts and, in one case, a set of footprints indicating a game or ritual.

4. The extraordinary Holocene diversification of culturally- and technologically produced large and small scale traces culminated in the arrival of track making *Homo sapiens* on the Moon, and the generation of traces on Mars by human-manipulated machines.

A common theme of events 2–4 is geographical expansion of the *Homo sapiens*, and a steady increase in the diversity and size range (both large and small) of trace fossils produced.

Other minor but significant events recorded in the hominin track record can be listed as follows:

1. Inferred significant modifications in the morphology of the hominin foot and corresponding footprints between 3.6 million and ~50,000 yBP. The extent to which these modifications are evident in the track record is debatable, but there are two distinct polar morphologies (*Praehominipes* and *Hominipes*) now documented in the ichnological literature.
2. Morphologic distinctions between inferred *H. sapiens* and *H. neanderthalensis* footprints could be of significance, if unequivocally established, but at present, claims of inferred differences are poorly documented.
3. The movements to, or colonization of, remote sites, such as the Tibetan Plateau and remote archipelagos, such as Jeju Island, Korea, or New Zealand, are demonstrated by footprints which are as old as, or older than, other archeologic evidence. As such, these represent significant events in the history of prehistoric human exploration, at least on the regional scale.
4. The colonization and use of caves and rock shelters as art galleries, often depicting animals, represents a significant development in human–animal interactions.
5. An extraordinary diversification and complexification of human-produced trace fossils since the Late Pleistocene and Early Holocene has allowed paleontologists to expand the academic definition of vertebrate ichnology into realms traditionally considered the province of archeology and anthropology.
6. This recent complexification of the trace fossil record by *Homo sapiens* activity has profound implications for how recent, present, and future traces will be registered as dominant components of the deep time ichnological record. In this regard humans are presently creating an ichnological revolution with significant implications for debate about the global impact and exclusivity of our species.

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