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The origins of the Acheulean: past and present perspectives on a major transition in human evolution

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The emergence of the Acheulean from the earlier Oldowan constitutes a major transition in human evolution, the theme of this special issue. This paper discusses the evidence for the origins of the Acheulean, a cornerstone in the history of human technology, from two perspectives; firstly, a review of the history of investigations on Acheulean research is presented. This approach introduces the evolution of theories throughout the development of the discipline, and reviews the way in which cumulative knowledge led to the prevalent explanatory framework for the emergence of the Acheulean. The second part presents the current state of the art in Acheulean origins research, and reviews the hard evidence for the appearance of this technology in Africa around 1.7 Ma, and its significance for the evolutionary history of *Homo erectus*.

This article is part of the themed issue 'Major transitions in human evolution'.

1. Introduction

Spanning *ca* 1.7–0.1 Myr, the Acheulean is the longest-lasting technology in prehistory. Its emergence from the Oldowan constitutes one of the major transitions in human evolution and is also an intensely investigated topic in current Early Stone Age research. This paper reviews the evidence for the origins of the Acheulean from two perspectives: the history of research, where changes in the historiographic conception of the Acheulean are discussed, and the current state of the art on Acheulean origins, which will include a review of the hard evidence and an assessment of its implications.

A brief overview of the origins of the term Acheulean is interesting not only because of its intrinsic importance as one of the major transitions in human evolution, or for its relevance to our current understanding of this technocomplex, but also because of historiographic reasons; for many decades, not only was the Acheulean thought to be the earliest human culture but, even more valuable from the point of view of the history of science, it was Acheulean remains which, back in the nineteenth century, demonstrated that humans had inhabited Earth long before the biblical deluge. The stone that shattered the time barrier, as some would put it [1], was an Acheulean handaxe.[1]

Causes for the emergence of the Acheulean, its filiation to earlier cultures, and the chrono-stratigraphy and palaeoecology of Early Acheulean sites, are some of the questions dominating current debate, and will be discussed after the historical review. Considerations on the earliest Acheulean have gravitated from early reports of assemblages in Western Europe to current research in other regions, primarily Africa; accordingly, the following assessment will focus on the evidence from East Africa (where the earliest Acheulean sites are documented) and, for the sake of conciseness, will limit (somewhat arbitrarily) the review to assemblages older than 1.2 Ma.

2. The Acheulean as a technocomplex

As will be shown in this paper, the term Acheulean has undergone substantial revisions from its definition in the nineteenth century to the present day. In order to be concise, however, and embracing Clarke's [2] meaning of a technocomplex, it is considered here that the Acheulean encompasses assemblages in three continents (Africa, Europe and Asia), during the Lower and Middle Pleistocene (currently from *ca* 1.75 to 0.125 Myr), associated with pre-modern humans (*Homo erectus* and Middle Pleistocene pre-*sapiens* hominins), and characterized by the presence (irrespective of their frequency) of (normally) amygdaloidal, hand-held artefacts. As any generic definition, on the one hand this is too inclusive, as Lupemban, Sangoan, Micoquian and other Early-to-Middle Stone Age transitional industries potentially could be incorporated in it, therefore overlooking contextual, technological and behavioural nuances which are important to the evolutionary interpretation of archaeological sequences. On the other hand, such a basic consideration of the Acheulean could also become too narrow, as handaxe-free assemblages from both Africa (e.g. Hope Fountain industries) and Europe (e.g. Clactonian) are likely to belong to the same technocomplex as geographically and chronologically similar handaxe-bearing assemblages, in which variability is better explained by ecological and/or functional differences within a single technological tradition.

Despite this inter-site variability and recognition of the need to study whole assemblages (rather than specific tool types) in order to describe Early Stone Age technologies [3,4], it must be admitted that, since its definition and until today, all characterizations of the Acheulean eventually end up referring to its most emblematic artefact, the amygdaloidal, hand-held stone tool: from 'weapons of war' [5] and *hache* [6], through *langue de chat*, *coup de poing* [7], to handaxe, biface and large cutting tool (LCT), a myriad of terms have been used to name it. While the term biface is probably the most widely used in recent literature to encompass all typical Acheulean forms (i.e. picks, knives, cleavers and bifacial handaxes), it is here advocated that 'handaxe' would be more accurate as a generic term, for in many Acheulean assemblages (particularly in the early African sites), LCTs are often unifacial (rather than bifacial) tools. At any rate, terminological descriptions of Acheulean tool types have already been the subject of lengthy discussions in the past [8–11], are admittedly unpopular at present, and are certainly beyond the aim of this paper. Instead, the set of parameters used by Gowlett [12] to characterize any Acheulean handaxe is useful here; these handaxe 'imperatives' include, among others, a glob butt (i.e. a handling area which embraces the concept of centred mass), forward extension (providing support for the working edges of the tool), lateral extension around a major plane, and thickness adjustment (which enables the mass to be reduced without affecting most other morphological features [12]).

3. A historical context for the Acheulean

(a) The Acheulean and the establishment of human antiquity

The Acheulean was first defined by Gabriel de Mortillet [13, p. 436], who considered it to be the earliest of the Stone Age periods. Although at present we certainly embrace a more comprehensive conception of the Acheulean, de Mortillet's consideration of the defining stone tool type of the Acheulean (a roughly amygdaloidal bifacial hand-held artefact), is still essentially valid today. De Mortillet was explicitly attempting to define Palaeolithic cultures on the basis of characteristic stone tool types, and to name periods after the first and/or more relevant site where such stone tool types were discovered. Hence he named the Acheulean after the locality of Saint Acheul (Amiens), in the Somme valley (northwest France).

Saint Acheul had become popular before de Mortillet's definition of a new culture based on this locality, but claims for a coexistence between ancient humans and extinct animals [14,15] were widely ignored; such theses, as those proposed earlier by Boucher de Perthes [6] (the first to put forward the premise that humans had lived alongside extinct animals well before the deluge) simply could not be accommodated within the dominant system of thought, based on the time depth framework provided by the Bible (see review in [16]). But the cumulative evidence in northern France and southern England was to bring about a paradigmatic shift, and such occurred in 1859, when Prestwich and Evans visited Abbeville and Saint Acheul, and witnessed personally the unearthing of stone tools in indisputably 'pre-Diluvium' strata (see review by Gamble & Kruszynski [1]). After 1859, it was an inescapable fact that humans had lived in very ancient times, and the Bible ceased to provide the temporal framework for the past of humankind. However, this did not result from the major event in the history of Science also occurring in 1859 (i.e. Darwin's *On the origin of species* [17]), but due to confirmation of the great antiquity of stone tools from Saint Acheul, which enabled de Mortillet [13] to coin the name of Acheulean ('Époque de Saint Acheul' or 'Acheuléen').

A decade on, de Mortillet would propose changes to his original nomenclature. Invoking stratigraphic admixture problems at the type locality of Saint Acheul, he stated: 'J'ai été alors force, malgré l'inconvénient qu'il y a á changer un nom déjà généralement admis, de choisir une localité plus pure, plus caractérisée, plus typique. J'ai pris celle de Chelles' [7, p. 133]. Apart from this change of name, other novelties in de Mortillet's classification system were also introduced; for example, the culture formerly known as Acheulean (now Chellean) was still the earliest of the Pleistocene, but de Mortillet [7] recognized the existence of older, Pliocene humans, makers of crude artefacts of the Eolithic culture. Setting aside the issue of Tertiary man and the Eolithic age, hugely contentious throughout the following decades, and to which fierce opposition existed from the beginning [18,19] until the term was eventually dropped (see review in [16]), de Mortillet's [7] scheme for the earlier stages of human evolution was mostly successful.

By the 1920s, however, new evidence was making terminological and conceptual revisions necessary. Typological variations in the 'coups de poing' across Western Europe were seen as evidence of diachronic change, and it was customary to differentiate between an earlier phase with cruder artefacts (the Chellean) and another with more refined handaxes (the Acheulean) [19]. Alternatively, Breuil [20] suggested dropping the term Chellean and using instead Abbevillian, after Abbeville, the northwest France locality where Boucher de Perthes first reported handaxes. In the meantime, research in sub-Saharan Africa was forcing the creation of a new cultural evolutionary scheme, sensitive to the particularities of a sequence thousands of kilometres away from the classic Western European sites. For example, Goodwin [21,22] differentiated between an Earlier, Middle and Later Stone Age, but refused to use the terms Chellean or Acheulean, and proposed instead a local sequence which started with the Stellenbosch industry. In East Africa, the succession of discoveries would also force accommodation of new cultures unknown in Europe; thus, Leakey [23] reported a pebble industry in the lowermost deposits of Olduvai Gorge. While a discussion of the historical roots of the Oldowan is beyond the scope of this paper (see review in [24]), it is relevant here to stress that Louis Leakey presented for the first time a credible (i.e. excluding the Eolithic) technological precursor to the handaxe-bearing culture; this provided a basal limit to the Chellean/Abbevillian-Acheulean, for which previously only the upper boundary (i.e. the Mousterian) had been clearly established.

Bordes [25] emphasized techno-typological features to distinguish the Chellean/Abbevillian from the Acheulean, but the lack of absolute ages was a handicap for the seriation of handaxe-bearing assemblages, a problem accentuated across Western Europe due to the patchy nature of the archaeological record and the absence of long stratified sequences. Although this did not deter scholars from establishing detailed industrial successions in Europe (e.g. [26]), the African sequence had begun to enter the spotlight.

The terminology became relatively standardized; the first Pan-African prehistory conference had agreed on the use of the term Chelles-Acheulean for handaxe assemblages, and pre-Chelles-Acheul—which included Oldowan and Kafuan (see [24] for a review of this latter term)—for earlier core and flake industries [27]. This framework was endorsed in research across Africa during subsequent years (e.g. [28,29]). Nonetheless, it would be the archaeological record from Olduvai Gorge in Tanzania which, due to its richness and stratigraphic continuity, became best known; Louis Leakey [30] distinguished five stages of evolution in the Olduvai Chellean, which were followed by six during the Acheulean. This scheme would then be further refined in the first monograph on Olduvai Gorge [31], where 10 stages of cultural evolution from the Early Chellean to the Late Acheulean were reported to succeed the Oldowan. By the end of the 1950s, the concept of Chelles-Acheul still prevailed, although some advocated that all handaxe assemblages should be included within the general term of Acheulean [32]. The Chelles-Acheul was associated with the ‘Pithecanthropus stage’ of human evolution [33], while the pre-Chelles-Acheul industrial period was attributed to *Australopithecus* [34].

(b) A geochronological framework for the Acheulean

Innovative quantitative approaches [8–10] were instrumental in developing a new perspective in the study of the Acheulean, as they enabled the classification of handaxes (where terms such as biface and cleaver were now normal currency) in (allegedly) discrete morpho-types. In this context, Louis Leakey’s [31] scheme of handaxe evolution was entirely revised by Mary Leakey [35], who following her systematic excavations in Olduvai was in a position to establish a new industrial scheme; now, the Chellean was only reluctantly used with quotation marks, the 10 stages of the Acheulean had been dropped, and a Lower Acheulean was differentiated from the so-called Developed Oldowan B (DOB) on the basis of handaxe frequencies. Isaac [36] also criticized the rigid divisions of handaxe evolutionary phases, arguing that intra-site variability was often higher than that supposed to exist between Acheulean stages. The Early Stone Age (where terms such as pre-Chellean, Chellean and Chelles/Acheul were no longer in use) was divided into four cultures, or perhaps even only three: the Oldowan, the Early Acheulean, the DOB (which Isaac [36] proposed could be just a facies of the Early Acheulean) and the Late Acheulean (but see [37] for an alternative terminology).

By the mid-1960s, therefore, there was an awareness of the major problems of contextualization and temporal organization of the Lower Palaeolithic sequence [38], due largely to the lack of absolute ages. A breakthrough of the decade would then be the addition of a temporal dimension to handaxe-bearing assemblages. Dating of Olduvai Bed I [39] revolutionized conceptions of the age of the earliest technologies, but a wide gap existed between the Oldowan (dated at *ca* 1.8 Ma) and the (still called) Chellean, for which potassium/argon dating estimated an age of less than 1 Myr [40]. The upper part of Olduvai Bed II was dated at 0.50–0.45 Ma [40], and therefore, it was assumed that the Acheulean began no earlier than 0.5 Ma, and terminated at 60 ka [41].

Slightly later, Isaac [34] noted that the Early Acheulean from Olduvai Bed II could be as old as 1.4 Myr. However, the classic report on the archaeology of Beds I and II [42] was still conservative regarding the age of the earliest handaxes at Olduvai, and therefore a chronology of 0.7–1 Myr was suggested for the top of Bed II (see also [43]). Notwithstanding age estimates, *Olduvai Gorge. Volume 3* [42] became a milestone in the history of Acheulean research, for it contained a priceless wealth of data on the succession of stratified handaxe-bearing assemblages which were preceded by an Oldowan technology.

While new radiometric ages for the Olduvai sequence would have to wait two decades [44], by the early 1970s it was suspected that the Early Acheulean could have succeeded the Oldowan at 1.0–1.5 Ma [45]. In this context, the publication of the Peninj ages became another landmark for studies on the origins for the Acheulean, placing its emergence in East Africa more than 1.35 Myr [46], and therefore well before any known Acheulean instance in Europe. Leakey [47] then estimated that the Early Acheulean at Olduvai was *ca* 1.2–1.3 Myr, and Clark [48] was confident that there was enough evidence to state that the Acheulean had emerged in East Africa 1.4–1.5 Ma.

By the 1970s, it had become paradigmatic that the Acheulean, a generic term now used to designate most of the handaxe-bearing assemblages from the Lower and Middle Pleistocene, had originated in East Africa, and that such emergence occurred *ca* 1.5 Ma. However, apart from the hugely influential monograph on Olorgesailie [11] (which advocated stochastic variations in handaxe types, and therefore discouraged seriations within the Acheulean based on artefact morphologies), major advances in research on the origins of the Acheulean during the following years were less dramatic. An exception was the cumulative evidence towards a very early expansion of the Acheulean out of Africa and into the Near East [49], where ‘Ubeidiya showed features remarkably similar to the Olduvai Early Acheulean [50].

In recent years, the hypothesis for an Early Acheulean out of Africa has been supported with finds from India [51]. In Europe, for decades it was thought that the earliest European Acheulean would be no older than 0.5 Myr [52], but there is now solid evidence that the Acheulean existed in Europe

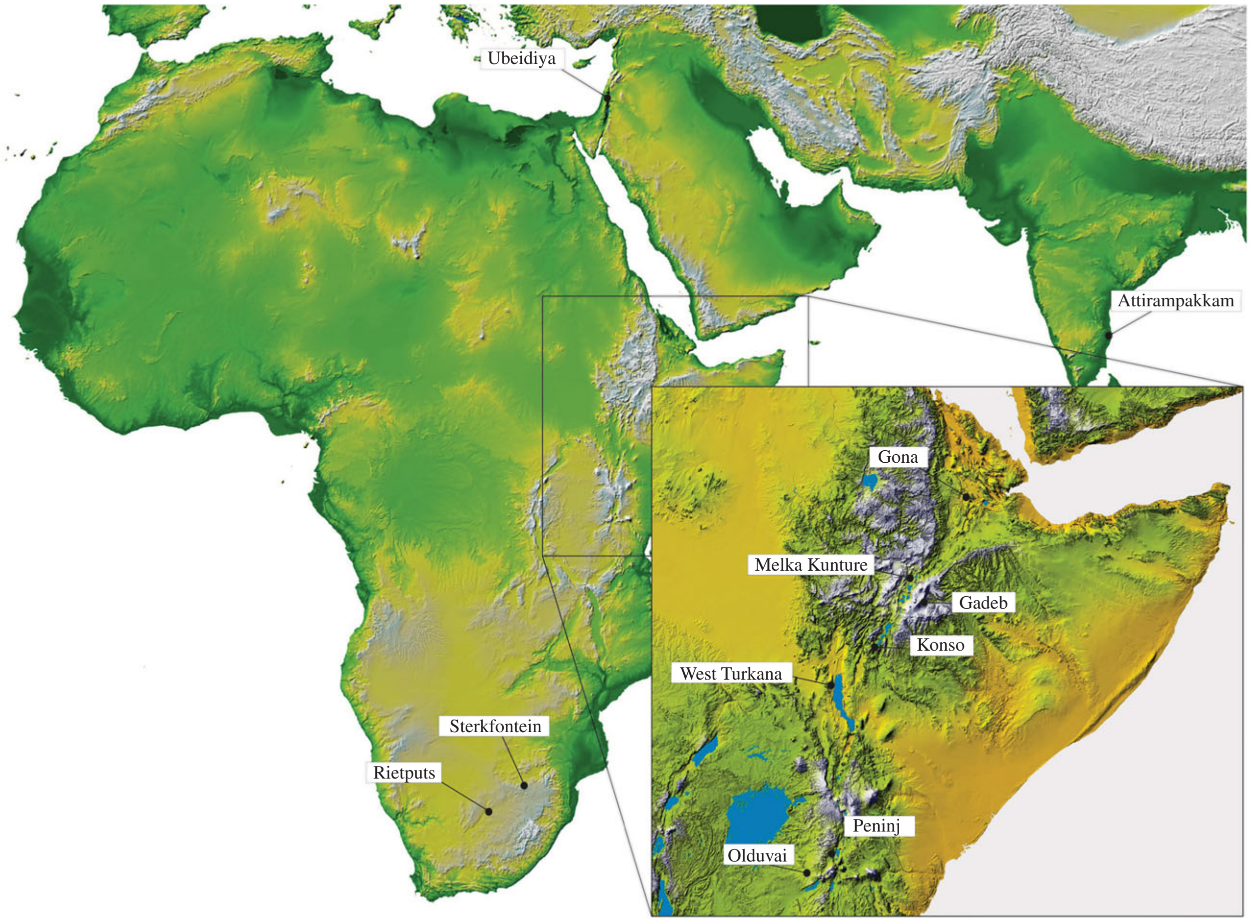

Figure 1. Location of Early Acheulean sites older than 1.2 Myr. (Online version in colour.)

ca 1 Ma [53], roughly at the same time as in North Africa [54]. In the African continent, all Early Acheulean sites are still located in East Africa, with the exception of Sterkfontein [55] and Rietputs [56] in South Africa. More recently, new data from Konso [57] and West Turkana [58] have pushed back the 1.4–1.5 Myr lower limit for the emergence of the Acheulean previously established at Peninj and Olduvai Bed II, as will be reviewed in §4.

4. The hard evidence for the earliest Acheulean: the current view

(a) Chrono-stratigraphy

Nearly identical ages *ca* 1.76–1.74 Ma are now available for Kokiselei 4 (KS4) in West Turkana [58], and KGA6-A1, the earliest Acheulean site in Konso [57]. This chronological overlap and their geographical proximity (figure 1) point to a remarkably well-defined focus for first handaxe-making in the northern part of the East African Rift. Interestingly, no other Early Acheulean sites have been documented in West Turkana as yet, while there are a number of stratigraphically and radiometrically well-constrained assemblages in Konso between 1.4–1.6 Myr (figure 2). Further north in Ethiopia, Gona contains Acheulean sites dated at 1.4–1.7 Myr [60], but their particular chrono-stratigraphic order has yet to be established. Also in Ethiopia, there is possible evidence for very Early Acheulean in Melka Kunture [68] and Gadeb [69]. Garba IVD (Melka Kunture sequence) has recently been reassessed as Early Acheulean at *ca* 1.5 Myr [63], but new radiometric dates can only firmly date its minimum age at more than 0.8 Myr [64]. Similarly, it is possible that early assemblages in Gadeb are in the region of 1.4 Myr [70], but there is poor radiometric control for most of the archaeological sequence with a minimum age of more than 0.7 Myr [65] that complicates chrono-stratigraphic comparison with other Early Acheulean sites.

The other cluster of Early Acheulean sites in East Africa is located in northern Tanzania, at Olduvai Gorge and Peninj. The minimum age for the Early Acheulean assemblages at Olduvai is relatively well constrained, with dates for Tuff IID ranging between 1.33 [66] and 1.48 Ma [62] (figure 2). The maximum age is nonetheless more elusive, as Tuff IIA (dated to 1.71 Myr by Curtis & Hay [43] and to 1.66 Myr by Manega [62]) predates a substantial unconformity over which assemblages are still Oldowan. New radiometric dates for units above Tuff IIA could nonetheless push back earliest Olduvai handaxes to more than 1.66 Myr [67]. Dating of the Peninj Group has also proven difficult (see review in [71]), but the relative consistency of radiometric ages for the Moinik Formation [46,62] provide a minimum age of *ca* 1.3 Myr for the earliest Acheulean in Natron.

The earliest Acheulean sites beyond East Africa seem to be nearly as old as in some parts of the Great Rift Valley: handaxes in South Africa are reported to be more than 1.2 Myr at Rietputs [56], and within a 1.7–1.4 Myr range for the Sterkfontein Member 5 Acheulean infill [55,72]. In the Northern Hemisphere, several assemblages are reported

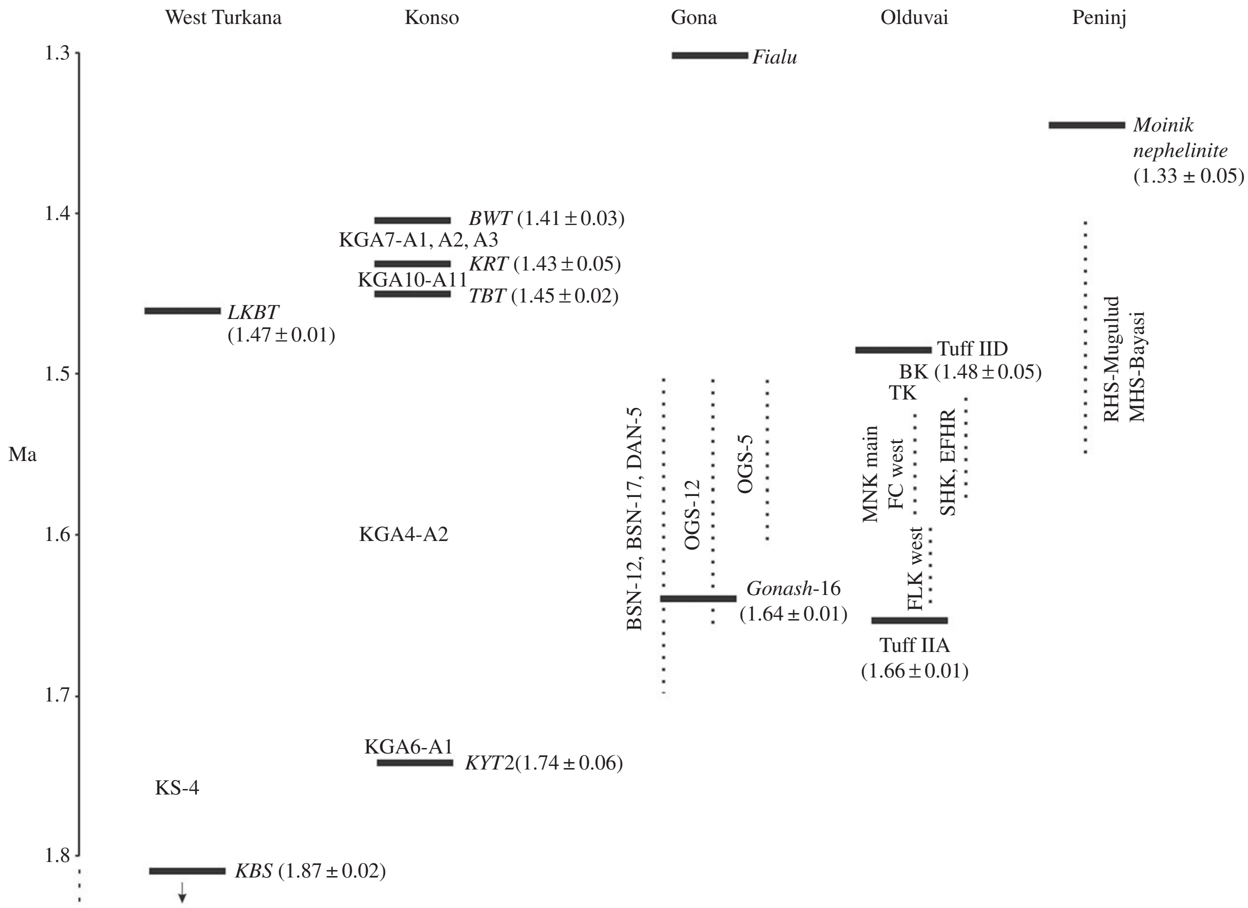

Figure 2. Chrono-stratigraphy[a] of selected[b] early handaxe-bearing assemblages in East Africa. West Turkana ages from [58]. Konso [59], Gona [60,61], Olduvai[c] [62], Peninj [46]. [a]Only sites with an estimated age of more than 1.2 Myr are included. [b]Both Melka Kunture and Gadeb may contain Early Acheulean assemblages around 1.4 Ma (see reviews by [3,63]), but minimum ages are less than 1 Myr [64,65], and therefore these sites are not included in the figure. [c]Manega's [62] dating is here selected over other radiometric results for Tuff IIA [43] and Tuff IID [66], and a regionally uncorrelated tuff (FLKWb) dated at 1.698 Ma [67]. Bars and names in italics refer to local tuffs.

at 'Ubeidiya (Israel), which on the basis of biostratigraphic correlations [49] has been proposed to date to 1.5 Ma [73]. This same age of *ca* 1.5 Myr is reported through radiometric dating and palaeomagnetism for the Acheulean from Attirampakkam in South India [51]. This seems to confirm the rapid expansion of the Acheulean from East Africa, although interestingly, Acheulean sites older than 1 Myr are still unreported in North Africa [54].

(b) Palaeoecological settings

Ecological reconstructions for the Kokiselei Complex are general (i.e. based on data not only from KS4 but also from other sites, mostly Oldowan) and report the presence of small rivers, lagoonal and beach settings by the shore of palaeo-lake Lorenyang, where bovids indicate both wooded and grassy elements, the abundance of hippopotamus signals a perennial water source nearby, and paleosol carbonates point to a wooded grassland [74]. All sites in Konso are located in lake-margin floodplain or alluvial fans flowing into the lake [75]. Bovid tribe composition indicates that KGA6-A1 in Konso was located in a wet and relatively closed setting [76]. Faunal associations in KGA4-A2 suggest a lake-margin environment [59], whereas fossils at the younger site of KGA10 portray a dry savannah [76]. Basin-wide reconstructions for the following period in Konso (i.e. Interval 5, Karat Member; table 1) report a return to wetter conditions and expansion of woodlands [75], and it is inferred here that such would be the general setting for the *ca* 1.4 Myr assemblages of KGA7-A1, A2 and A3.

The high-altitude (2300–2400 m.a.s.l.) location of the Gadeb assemblages has been reported as the earliest evidence of human occupation of the highlands [69] and, with Melka Kunture [68], contain Early Acheulean sites in deposits of large river drainages, rather than lacustrine basins such as at West Turkana and Konso. In Gona, where archaeological sites are also located in a fluvial valley context, the Upper Busidima Formation contains a drier and more herbaceous component than in previous periods, where an alluvial fan with ephemeral streams prevailed [61]. Some of the Early Acheulean sites in Gona, such as DAN-5, are in fluvial deposits of the palaeo-Awash floodplain [60], as is the case for all older Gona Oldowan sites [61]. However, other assemblages (e.g. OGS-5 and OGS-12) were formed in smaller tributaries [60], which are interpreted as a potential habitat expansion by Early Acheulean hominins from the Awash gallery forests into more open savannahs across secondary drainage systems [61].

Classic studies on the Olduvai Gorge palaeoenvironments [78,79] demonstrated progressive aridification of the basin until the eventual disappearance of the Olduvai palaeo-lake at the top of Bed II. All handaxe-bearing sites in Olduvai Bed II are located in the distal part of alluvial fans in or close to the lacustrine floodplain [78]. Nonetheless, the pressing need to refine the specific palaeoecological setting of each

Table 1. Contexts of Early Acheulean handaxe-bearing assemblages in East Africa (see selection criteria in caption of figure 2).

area	site	age	stratigraphic interval	context	regional setting	main references
Peninj	RHS-Mugulud	1.6–1.3	Humbu Formation-USC	fluvial	lacustrine basin	[77]
	MHS-Bayasi	1.6–1.3	Humbu Formation-USC	fluvial	lacustrine basin	[77]
Olduvai	BK	1.6–1.3	Upper Bed II	lake-margin floodplain/alluvial fan	lacustrine basin	[42,78]
	TK	1.6–1.3	Upper Bed II	lake-margin floodplain/alluvial fan	lacustrine basin	[42,78]
	EFHR	1.6–1.3	Middle/Upper Bed II	lake-margin floodplain/alluvial fan	lacustrine basin	[42,78]
	SHK	1.6–1.3	Middle Bed II	lake-margin floodplain/alluvial fan	lacustrine basin	[42,78]
	FC West	1.6–1.3	Middle Bed II	lake-margin floodplain/alluvial fan	lacustrine basin	[42,78]
	MNK Main	1.6–1.3	Middle Bed II	lake-margin floodplain/alluvial fan	lacustrine basin	[42,78]
	FLK West	1.69–1.66	Middle Bed II	river channel	lacustrine basin	[67]
Gona	BSN-12	1.5–1.7	Upper Busidima	fluvial	major river valley	[60]
	BSN-17	1.5–1.7	Upper Busidima	fluvial	major river valley	[60]
	OGS-12	1.5–1.6	Upper Busidima	fluvial-tributary	major river valley	[60]
	OGS-5	1.4–1.5	Upper Busidima	fluvial-tributary	major river valley	[60]
	DAN-5	1.5–1.7	Upper Busidima	fluvial-main stream	major river valley	[60]
Konso	KGA7-A3	1.4	Karat Member-Interval 5	lake-margin floodplain/alluvial fan	lacustrine basin	[59,75]
	KGA7-A2	1.4	Karat Member-Interval 5	lake-margin floodplain/alluvial fan	lacustrine basin	[59,75]
	KGA7-A1	1.4	Karat Member-Interval 5	lake-margin floodplain/alluvial fan	lacustrine basin	[59,75]
	KGA10-A11	1.45	Kayle Member-Interval 4	lake-margin floodplain/alluvial fan	lacustrine basin	[59,75]
	KGA4-A2	1.6	Kayle Member-Interval 3	lake-margin floodplain	lacustrine basin	[59,75]
	KGA6-A1	1.75	Kayle Member-Interval 2	lake-margin floodplain/alluvial fan	lacustrine basin	[59,75]
West Turkana	KS-4	1.76	Middle Kaitio Member	lake-margin floodplain	lacustrine basin	[58]

assemblage has been advocated [80], as most palaeoenvironmental reconstructions have focused on Bed I and lower Bed II, and comparatively much less attention has been paid to the palaeoecology of the Early Acheulean. Recently, the aridity trend often depicted for Bed II has been nuanced [81], highlighting the persistence of woodland habitats throughout. Still, taxa composition seems to indicate that, at least in the case of post-Tuff IIC sites such as SHK, TK and BK [82–84], assemblages are dominated by open habitat mammals.

In Peninj, pollen from the Humbu Formation deltaic sediments in the Type Section [85] portrays a dry environment, hence supporting earlier results on the prevalence of an open savannah as indicated by the faunal remains [86]. However, palaeoecological reconstructions for the two handaxe-bearing sites discovered by Isaac [77] are more limited: in the middle course of the Peninj river network, phytoliths from MHS-Bayasi are interpreted as corresponding to an open and xeric environment [87]. Owing to the lack of palaeoecological proxies, it has been speculated [88] that the proximity of RHS-Mugulud to volcanic foothills and its association with a river course could be indicative of less xeric conditions and a more closed habitat.

Early Acheulean sites beyond East Africa do not follow any particular palaeoecological pattern: as a cave deposit, Sterkfontein presents a unique setting when compared with the other Early Acheulean assemblages albeit, similar to some East African sites, Sterkfontein Member 5 fossils indicate grazing animals in open or wooded grassland [89]. Conversely, the 'Ubeidiya Formation includes several transgressive and regressive lacustrine episodes, with handaxe-bearing assemblages in lake floodplain and riverine contexts [50], and where the importance of woodland taxa is highlighted [73]. A third palaeoecological setting is present at Attirampakkam, which is the Early Acheulean site closest to the sea (figure 1): this assemblage is located near the meander of a tributary stream of a major river flowing into the Indian Ocean and contains several archaeological layers in overbank contexts [51].

(c) Fossil and artefact associations

Published data on the association between fossils and Early Acheulean stone tools are disparate and generally limited. Bone preservation in Gadeb, RHS-Mugulud and MHS-Bayasi in Peninj and EFHR at Olduvai is generally too poor to enable taphonomic discussions (see reviews in [3,88,90]), and no data are available yet for Attirampakkam and the Gona Acheulean. Vertebrate fossils are documented in KS4 and include hippopotamus, bovids, equids, rhinoceros, suids and carnivores [58], but their taphonomic signatures are yet to be discussed, and therefore their contextual association with the Early Acheulean stone tools is unclear. In KGA6-A1, mammal bones seem to have been accessed by both humans and carnivores, and in the KGA4 and KGA10 outcrops there is pervasive evidence of human modification on animals of various sizes, including cut-marked rhino [76]. The most remarkable indication of such interactions in the Konso Early Acheulean is the presence of flaked bone tools alongside stone artefacts [76]. Evidence of medium-sized mammal hunting is suggested for the 'Ubeidiya assemblages [91] and, despite the importance of water disturbance in the formation of Garba IVD, some percussion-marked bones attest to human action on part of the Garba IVD fossil assemblage [92].

Artefact and bone associations in Olduvai Gorge handaxe-bearing sites have received comparatively more attention so far; human action on part of the fossil assemblages is documented in TK [84], SHK [82] and FLK West [67], but other agents of accumulation (e.g. water disturbance, background scatters) might have largely contributed to site formation. MNK Main may correspond to primary human accumulations subsequently accessed by carnivores [93]. New evidence from BK is proposed as confirmation of large-sized mammal hunting by hominins [83], an interpretation that does not differ significantly from the original behavioural reconstructions for the site [31,34,42,93].

(d) Technological features of handaxe-bearing assemblages

The earliest handaxes in KS4 are made on local phonolites cobbles, blocks and, less often, flakes [94,95]. Handaxes include trihedral and quadrangular picks, and other unifacial and bifacial crude LCTs [58], including some 'atypical cleavers' [95]. Handaxe length ranges between 13 and 25 cm, shaping usually covers less than 50% of the surface, and in the case of LCTs on flakes, the ventral face is largely unmodified [95]. The oldest Acheulean assemblage in Konso (KGA6-A1 Locus C) is mainly composed of basalt picks, followed by other LCTs and cleavers [59]. There is a dominance of handaxes on large (more than 15 cm) flakes, where bifacial shaping is generally lacking and ventral faces often remain unmodified [59]. Picks are even more dominant in KGA4-A2, a site where cleavers are also documented. LCTs are also mostly produced on flake blanks which, as in KGA6-A1, are on average over 15 cm long [59]. These authors report inter-assemblage variability within the 1.2–1.5 Myr Acheulean sites, including differences in raw material use, preferred blank types and morpho-types. Although more careful shaping of the tip and planform symmetry are observed, LCT volume remains thick and handaxes still show sinuous cutting edges characterized as typical of the Early Acheulean in Konso [59].

In the Early Acheulean of Gona, there are picks, cleavers and crudely made bifaces on both flakes and cobbles [96]. According to these authors, raw material selectivity is based on cobble size rather than rock quality, the tips of handaxes are deliberately shaped and cutting edges are bifacial. RHS-Mugulud and MHS-Bayasi in Peninj have abundant handaxes, dominated by unifacial and bifacial knives, followed by a few picks, cleavers and some crudely made bifaces [97]. Most LCTs are made on lava flake blanks; as in Kokiselei and Konso, shaping often neglects the ventral face of flakes and does not substantially modify blank volume, producing artefacts which resemble massive scrapers [97]. Similarities between the Peninj assemblages and LCT technology at EFHR at Olduvai have long been pointed out [42,77,90], with the latter containing abundant crudely shaped knives, picks and occasionally cleavers.

Simple and elaborate LCTs are reported in the new Early Acheulean assemblage from FLK West [67]. The other Middle/Upper Bed II assemblages from Olduvai (e.g. MNK Main, FC West, SHK, TK and BK [42]), and the sites of 'Ubeidiya [50], Gadeb [69] and Garba IVD [68], have low frequencies of handaxes, which led to a debate on the possible existence of a Developed Oldowan and its affinities with the Early Acheulean [42,98]. Re-assessments of classic collections from Gadeb [3], Garba IVD [63] and Olduvai [80,90] have underlined technological similarities over LCT frequency differences between sites, and therefore vindicated the Acheulean character of all these handaxe-bearing assemblages. Thus, it has been advocated that the Developed Oldowan is not a valid cultural entity [96], in which case inter-assemblage variability within handaxe-bearing sites could be better explained by ecological or functional reasons [78,99].

In addition to handaxe-bearing assemblages, the *ca* 1.6–1.3 Myr African record also contains sites where, as yet, no LCTs have been reported, further complicating considerations on the meaning of technological variability during the emergence of the Acheulean. In Koobi Fora, for example, large artefacts from the so-called Karari Industry [100] have some formal resemblance to LCTs, but are considered single-platform cores and assigned to the Developed Oldowan [101]. Sites lacking handaxes which resemble earlier Oldowan core-and-flake assemblages are also found in the same 1.6–1.3 Myr time interval at West Turkana [102], Konso [59] and Koobi Fora [103], and in Chesowanja [104] and Nyabusosi [105], although structured debitage systems in the latter two, along with Peninj-Type Section, have been connected to flaking strategies typical of the Early Acheulean [3,88].

(e) Human fossils and stone tool associations

The emergence of the Acheulean as a technocomplex has been secularly linked to the appearance of *Homo ergaster*/*erectus* (early *H. erectus* hereafter) as a species. This association works relatively well for 1.6–1.3 Myr Acheulean assemblages in Konso [106] and, possibly, Olduvai Gorge—as no *Homo habilis* remains are reported from Middle Bed II (i.e. when handaxes begin to appear in the Olduvai record), and the OH9 *erectus* calvaria is attributed to Upper Bed II. It is nonetheless interesting to note that such associations are not always straightforward: in Konso, no human remains are associated with the earliest Acheulean at 1.75 Ma. Likewise, no *H. erectus* remains have been discovered so far at West Turkana in the stratigraphic interval of the KS4 handaxes, whereas the KNM-WT15000 *erectus* skeleton is dated at *ca* 1.5 Ma, a time span when no handaxe-bearing assemblages are so far reported in West Turkana. In Sterkfontein Member 5, contextual association between the Early Acheulean and the human remains attributed to *H. erectus* is unclear [72]. While the early age of *H. erectus* remains in East Turkana—1.9 Myr for KNM-ER 1813 (but see [106]) and *ca* 1.63 Myr for KNM-ER 3733 [107]—is often cited to highlight the co-emergence of a new technology alongside a new human species, Koobi Fora is precisely the area where no clear evidence of earliest Acheulean exists.

The current situation is thus certainly thought-provoking: no *H. erectus* remains associated with the earliest Acheulean in Konso and West Turkana, early *H. erectus* in East Turkana in deposits lacking handaxes, and the best contextual early *H. erectus*/stone tool association in Dmanisi (an Oldowan assemblage). And this leaving aside the conundrum of *Paranthropus boisei*, a species pervasively associated to Early Acheulean sites in Konso, Olduvai and West Turkana, but which is conventionally excluded from the discussions on artefact and hominin associations. This complex panorama, together with the temporal overlap between early *H. erectus* and *H. habilis* observed in East Turkana [108], might tempt some to revive biological divides to explain inter-assemblage variability in the 1.7–1.3 Myr interval (see review in [80]).

(f) Mode of the transition

Although current evidence supports the *tempo* of the emergence of the Acheulean being at least 1.75 Ma, the mode of this transition is less clear. If the early age of KNM-ER 1813 is accepted, it could then be assumed that *H. erectus* emerged slightly before the Acheulean, hence providing a biological precursor framework for this technocomplex. However, the archaeological record is in itself almost impenetrable as far as technological precursors of this transition are concerned: in Koobi Fora, the KBS assemblages are plainly Oldowan, and although the Karari Industry has on occasion been proposed as a potentially transitional technology, its age which is younger than the earliest Acheulean assemblages in Konso and West Turkana, along with the fact that no early LCTs are found across the Koobi Fora deposits, somehow make the proposal less likely. Core-and-flake 1.75 Myr sites from Konso are reported as Oldowan [59], and in Gona it is explicitly stated that no transitional features linked to the Acheulean are observed in the earlier Oldowan assemblages [96].

In Olduvai Gorge, Mary Leakey [42] observed an evolution of the classic Oldowan into the Developed Oldowan A (DOA), yet she ruled out the possibility that this DOA was a precursor of the Acheulean, and instead proposed that the latter technology arrived in Olduvai from somewhere else. Furthermore, DOA sites are positioned after 1.66 Myr (the currently available age for Tuff IIA [62], above which all DOA assemblages lie), and therefore are younger than the earliest Acheulean in Konso and West Turkana.

At present, the only chrono-stratigraphically consistent assemblage with purported transitional characteristics is Kokiselei 5 (West Turkana), which is slightly older than KS4, and which is alleged to show technological features reminiscent of the Acheulean [109]. Apart from the potential case of Kokiselei 5, however, the East African archaeological record is currently lacking assemblages older than 1.75 Myr that are not classic core-and-flake Oldowan, and hints of the major technological change represented by LCT production are absent. Whether this is due to the intrinsically patchy nature of the archaeological record or to a punctuated, rather than gradual appearance of the Acheulean technology, is nonetheless a matter of discussion beyond the scope of this section.

5. Discussion

(a) Technological significance of the Acheulean transition

It has been argued (e.g. [36]) that a key difference between Acheulean technology and the Oldowan (from which the Acheulean is parsimoniously accepted to derive) is the acquired ability to produce large flakes (more than 10 cm). Experimental [110,111] and ethnographic [112] accounts have confirmed the technical complexity involved in the production of large flakes which, returning to the point above on the *tempo* and mode of the transition, support Isaac's [36, p. 21] argument that Oldowan and Acheulean technologies were 'separated by a comparatively rapid change dependent on a single technical step which by its very nature could not have been taken gradually'. Isaac [113] expanded on the significance of technological change involved in Acheulean toolmaking when he identified two additional main innovations: one is the inclusion of an extra stage in manufacture, as large flakes are first produced from large cores and subsequently used as blanks for shaping tools; the second innovation was the imposition of specific mental templates over such blanks, which were shaped to produce handaxes with overall similar morphologies.

It is relevant to dwell on these two aspects, as they enable the exploration of cognitive skills involved in Acheulean stone toolmaking. For Wynn [114], the addition of a new step in tool manufacture (i.e. production of the handaxe blank) entails a planning sequence largely missing in the previous Oldowan, which is linked to the emergence of the spatial notion of interval. Concerning the imposition of broadly similar morphologies over the blanks, Gowlett [12] sees handaxes as multivariate objects whose conception and manufacture impose a heavy cognitive load: technical prerequisites involved cannot be implemented independently and are closely interrelated, hence adding levels of intentionality. Wynn [114] stressed that the concepts of interval, 'spatial amount' and symmetry definitely separate handaxe-making from the previous Oldowan, and emphasized the production in the Acheulean of certain overall shapes and the hierarchical organization of cognitive activities. The hierarchical complexity of Acheulean flaking actions is underlined in recent cognitive studies [115], and comparative brain imaging data between Oldowan and Acheulean toolmaking [116] have concluded that handaxe shaping includes manipulation functions and information monitoring of the working memory, which are related to technical judgements (e.g. explicit evaluation and prediction of toolmaking outcomes) not observed in the Oldowan.

In summary, the Acheulean technological innovations identified by Isaac [36,113] and discussed above entail substantially higher cognitive demands than Oldowan toolmaking. Embracing the conventional wisdom pairing *H. habilis* = Oldowan/*H. erectus* = Acheulean, the inferred technical requirements of Acheulean flaking are consistent with the dramatic increase in brain size observed in early *H. erectus* [117], which would enable better computation of the cognitive demands of this technology.

The temporal and spatial fragmentation of lithic reduction sequences has also been proposed as a major innovation of the Acheulean [3], and it is a most energy-efficient strategy, given the technical requirements of Acheulean large flake technology [118]. Apart from the cognitive demands involved in task partitioning (i.e. planning of a geographical and sequential segregation of quarrying, production and use), it is relevant here to emphasize the implications for a wider use of the landscape by Acheulean hominins when compared to Oldowan tool-makers; this is evidenced by longer distances in the transport of some raw materials, and also in the intensity of occupation, with substantially larger archaeological assemblages in Early Acheulean contexts which could indicate a more pervasive use of territory [90]. Although more work is needed to ascertain whether this higher intensity in the use of lithic raw materials in the Acheulean was matched by a more efficient exploitation of animal resources (see discussion above), hominin palaeobiology is again consistent with the archaeological data; smaller teeth and their microwear suggest a more diverse diet in early *H. erectus* when compared with earlier *Homo*, which might be linked to an increase in meat consumption [119]. In addition, the larger body size of *H. erectus* could be associated with an extension of the home range and to changes in foraging strategies [117] leading to a highly adaptive level of niche construction [119], once more in agreement with conclusions derived from the structure of the Early Acheulean archaeological record.

Interesting inferences can also be made with regard to social implications of the emergence of the Acheulean; thus, extension of the ontogenetic period as suggested by the palaeobiology of early *H. erectus* entailed greater group cooperation [119], and indeed it might have been complexity of social life which drove encephalization [120]. So far the Early Acheulean record *per se* has proven refractive to this inferential process, but ethnographic work has emphasized the relevance of tight social relationships in handaxe-making [112]. Likewise, experimental studies suggest a change in the social mechanisms of learning and knowledge transmission from the Oldowan to the Acheulean, with more efficient communication systems in the latter [121], which could then be linked to a more complex nature of social structures.

(b) Causes of the transition

Mechanisms that triggered the emergence and spread of *H. erectus* have been discussed in length in recent years, and are often linked to changes in global climate during the Early Pleistocene (see reviews [122,123]). In the context of a general trend towards increased aridity and pulses of climate instability, it is assumed that *H. erectus* adaptations enabled this species to extend their dietary breadth and home range, and ultimately colonize regions out of Africa (e.g. [117,119]).

In general terms, the Acheulean can be seen as a behavioural response (i.e. innovation of a new tool repertoire) to changing ecological conditions (ever-increasing aridity in the context of climate pulses) endured by a newly emerged species (*H. erectus*). However, this broad picture does not entirely explain the emergence of the Acheulean technocomplex; for example, *H. erectus* colonized Java and Dmanisi with a core and flake technology, perhaps before Acheulean innovations took place. Thus, even though the Acheulean was a more complex and potentially more efficient technology than the Oldowan, the cause–effect relationship between environmental changes, speciation and behavioural response requires further elaboration: if *H. erectus* emerged as an adaptation to new ecological conditions, the Oldowan repertoire seems to have been successfully geared to enable this species to expand their home range and colonize new continents without the need for a major technological innovation.

Therefore, even if a correlation between technological and biological changes is undeniable on an evolutionary timescale, future research may profit from exploring alternative and/or complementary causal mechanisms to explain the emergence of the Acheulean. These efforts should avoid formulation of hypotheses based exclusively on mechanistic premises of technological innovation under environmental variability [124], and seek potential interactions between evolutionary and alternative perspectives [125], where social [120] and demographic [126] parameters could play a fundamental part.

6. Conclusion

More than 200 years after John Frere published the first account of handaxes, and over 150 years after de Mortillet coined the name Acheulean, this technology is now well documented across Africa, Western Europe and parts of Asia. The term

Acheulean has so far resisted all attempts (including that of its baptizer) to get rid of it, and is widely used to refer to handaxe-bearing assemblages throughout the Lower and Middle Pleistocene.

This paper has reviewed our cumulative knowledge of the origins of the Acheulean, from its definition in the nineteenth century to the present day. The Acheulean played a fundamental role in the history of science as it was the first to demonstrate that humans had lived in a remote past, long before the time suggested by the Bible. For many decades, and until the Oldowan was discovered in Africa, the Acheulean was also the oldest undisputable human culture. By the mid-twentieth century, the centre of attraction for those interested in Acheulean origins had shifted from Europe to Africa, where the Acheulean seemed to have first evolved from the Oldowan. While estimates of its emergence have varied through the development of the discipline, there is now evidence that the Acheulean appeared at least 1.75 Ma in the East African Rift Valley, which on an evolutionary scale coincides with the emergence of *H. erectus*.

Although at present we enjoy a reasonably good broad picture of when and where the Acheulean first emerged, a closer look at the specific sequence of the earliest Acheulean assemblages reveals important gaps both in the hard evidence and research approach. With regards to the record, much more work is needed to clarify chrono-stratigraphic, palaeoecological and contextual issues, and to build solid comparative frameworks on the technological and subsistence strategies of Early Acheulean hominins. Equally important is implementation of new theoretical perspectives to shift an approach which is still today (five decades after Binford's [127] critique of the then-dominant explanations for the Early Acheulean) mostly normative, and which still structures the archaeological record on the basis of a single artefact category, the handaxe. In spite of the challenges, these are exciting times for the study of Acheulean origins, when the increasingly available data and the fast pace of new discoveries yield the potential to accurately portray one of the main transitions in human evolution.

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Endnote

[1]The fact that this issue of Phil Trans is a Festschrift to a descendant of the first discoverer of Acheulean handaxes, John Frere, is a happy coincidence that hopefully justifies this paper's indulging historical review of the term.

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