The first use of bone tools: a reappraisal of the evidence from Olduvai Gorge, Tanzania

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Purported early hominid bone tools from Olduvai Gorge are studied for microscopic traces of use-wear, and evidence of intentional flaking by knapping. Comparative microscopic analyses of the edges of the purported tools, and areas far from the potential functional zone, as well as edges of bone pieces from the remainder of the assemblage, show that possible modifications due to utilization are not distinguishable from features attributed to post-depositional abrasion. Taphonomic analysis of the bone tool collection, a control sample of bone shaft fragments from the remainder of the Olduvai assemblage, and experimentally broken elephant long bones, identifies significant differences in the size and type of mammals represented. The bone tool collection records an abundance of large to very large mammals, while the control sample comprises mostly medium-size bovids. Puncture and cut-marks occur on one third of the bone tool collection, and on only a few pieces in the control sample, suggesting hominids were the agent responsible for the breakage of most of the bones previously described as tools. Analysis of the number, location and length of flake scars in the three assemblages, reveals that a reduced proportion of purported bone tools bear invasive, contiguous, often bifacially arranged removals, not seen in the control or experimental collections. This makes these specimens good candidates for having been shaped and used by early hominids. Complete bones with tool-generated puncture-marks, previously interpreted as anvils, are interpreted here as hammers used on intermediate stone tools.

Keywords: Olduvai Gorge, early hominid, bone tools.

INTRODUCTION

Many bone, antler, and ivory tools are reported from Lower and Middle Palaeolithic sites in Africa and Europe (Schmidtgen 1929; Bastin 1932; Breuil 1932, 1938; Koby 1943; Dart 1957; Kitching 1963; Breuil & Barral 1955; Bonifay 1974, 1986; Freeman 1978, 1983; Cahen *et al.* 1979; Howell & Freeman 1983; Howell *et al.* 1995; Gaudzinski 1999); for a review of the evidence see Henshilwood & Sealy (1997), Villa & d'Errico (1998, 2001), Henshilwood *et al.* (2002) and d'Errico & Backwell (2003). These claims have, however, been repeatedly called into question. Studies demonstrating that a number of natural processes occurring during the life of an animal or after its death can produce pseudo-tools that have been, or may be, misidentified as intentionally modified or used bones. Pre-mortem phenomena that produce pseudo-tools or pseudo-anthropic use-wear include the remodelling of the bone structure (d'Errico 1996), vascular grooves (Shipman & Rose 1984; d'Errico & Villa 1997), teeth use-wear (Gautier 1986), breakage and wear of deer antler (Olsen 1989) and elephant tusk tips (Haynes 1991; Villa & d'Errico 2001). Post-mortem processes are more numerous and include gnawing or digestion by carnivores, rodents and herbivores (Pei 1938; Sutcliffe 1970, 1973, 1977; Binford 1981; Haynes 1983; Villa & Bartram 1996), fracture for marrow consumption by hominids and carnivores (Bunn 1981; Gifford-Gonzalez 1989, 1991), trampling (d'Errico *et al.* 1984; Haynes 1988, 1991) root etching (Binford 1981; Andrews 1990), weathering (Brain 1967) and the action of different sedimentary environments (Brain 1981; Lyman 1984, 1994). As suggested by these and other authors (Shipman 1988; Shipman & Rose 1988; Bonnichsen & Sorg 1989; Villa *et al.* 1999), in order to distinguish between pseudo-tools and true tools, it is necessary to adopt an interdisciplinary approach, combining taphonomic analysis of the associated fossil assemblages, microscopic studies of possible traces of manufacture and use, and the experimental replication of the purported tools. It is by applying this approach, for example, that Dart's (1957) theory for an early hominid 'Osteodontokeratic' culture has strongly been challenged and largely refuted (Klein 1975; Shipman & Phillips 1976; Maguire *et al.* 1980; Brain 1981). Dart's hypothesis created the conditions for a receptive environment, one in which potentially used or manufactured bone could be recognized and its designation as an artefact tested, using more reliable frames of inference.

The South African evidence

Building on this premise, Robinson and Brain in South Africa, and Mary Leakey in East Africa, proposed again that early hominids used bone tools. In 1959 Robinson published a single bone tool from Sterkfontein Member 5 West (*c.* 1.7–1.4 Mya) consisting of a pointed metapodial shaft fragment with evidence of use on the tip. In the course of 24 years of excavation at Swartkrans, Brain (Brain *et al.* 1988; Brain 1989; Brain & Shipman 1993) identified 68 bones, bovid horn cores and one equid mandible from Members 1–3 (*c.* 1.8–1 Mya) bearing similar modifications. Comparative microscopic analysis of the wear pattern on the smoothed tips of these bones, and on modern shaft fragments used experimentally to dig up tubers and work skins, suggested to Brain and Shipman

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that the surface modifications were not natural, and that the activities they tested experimentally were indeed those in which the Swartkrans tools were involved.

A recent reappraisal of this material confirmed the anthropic origin of the use-wear (Backwell 2000; Backwell & d'Errico 2001; d'Errico *et al.* 2001). Comparison between the Swartkrans tool wear pattern and that on bones from 35 reference collections, consisting of fauna modified by 10 non-human agents, identified no natural counterpart for the Swartkrans modifications. These authors also showed that the wear on the bone tools does not represent an extreme in variation of a taphonomic process affecting to a lesser degree the rest of the assemblage. In addition, analysis of the breakage patterns and size of the bone tools from this site, compared with the remainder of the faunal remains, indicated that early hominids selected heavily weathered, elongated and robust bone fragments for use as tools.

Quantification of striation width and orientation comprising the wear pattern suggested that these tools were not used to extract tubers or work skins. The wear pattern more closely fits that created experimentally when bone is used to excavate in a fine-grained sedimentary environment, such as that found in the pre-sorted sediment constituting termite mounds present in the Sterkfontein area. This led them to propose that the main, if not exclusive function, of the Sterkfontein and Swartkrans bone tools, and of the similar 23 undescribed specimens from Drimolen (*c.* 2–1.5 Mya) (Keyser 2000), was that of extracting termites. In another paper, Backwell & d'Errico (2003) report 16 additional bone tools from Swartkrans and show that there are no significant differences between Members in the type and size of the bone fragments used as tools, as well as in the length and type of the wear pattern, indicating that no major changes occurred through time in the subsistence strategy for which the tools were used. Previously unrecognized evidence of intentional shaping through grinding is also identified by d'Errico & Backwell (2003) on the tips of six horn cores and an ulna, indicating that southern African early hominids had the cognitive abilities to modify the functional area of bone implements with a technique specific to bone material, in order to achieve optimal efficiency in digging activities. No firm evidence exists on who used these bone tools. Brain (Brain *et al.* 1988: 835) and Susman (1991, 1994) suggest they were used by both early humans and robust australopithecines. Backwell & d'Errico (2003) consider instead the robust australopithecines as the more probable modifiers and users of these tools. The reasons they put forward in support of this scenario are the absence of *Homo* remains in Swartkrans Member 3 – where *Paranthropus (Australopithecus) robustus* fossils occur in association with relatively few stone and many bone tools, together with the virtual absence of diagnostic stone tools at Drimolen – a site dominated by robust australopithecine remains, and a substantial collection of similar bone tools. In addition, no such bone tools are found at South African sites postdating 1 Mya, the time of the robust australopithecine extinction.

The East African evidence

Mary Leakey (1971) reports 125 artificially modified bones and teeth from Olduvai Beds I and II bearing evidence of intentional flaking, battering and abrasion. These specimens derive from massive elephant, giraffe and *Libytherium* limb bones, and to a lesser extent from equids and bovids, as well as from hippopotamus and suid canines. In a comprehensive reappraisal of this material, Shipman (1989) correctly points out that Leakey's identification of Olduvai bone tools was not based on explicit criteria, and lacked analogies that would allow the ruling out of alternative interpretations.

In her reappraisal of the Olduvai material, Shipman (1984, 1989) uses a control sample consisting of scanning electron microscope-analysed resin replicas of bones submitted to a number of natural phenomena (e.g. weathering, chewing, licking, digestion, wind), and experimental or ethnographic bone tools used for butchering, digging, grinding, and hide and meat processing.

Microscopic analysis of these collections provided criteria (Shipman & Phillips-Conroy 1977; Shipman *et al.* 1984; Shipman & Rose 1988) to identify the material on which bone tools were used (hide, meat, soft vegetables), the kinesis and function (digging, bark-working, grinding hard grains, butchering), and the duration (brief, moderate, extensive) for which they were used. Shipman's ability to distinguish between unused and used bones, and to identify their main function, was verified through blind tests. The control sample also includes experimental reproduction of wind abrasion through the use of an abrasion gun driven by pressurized air. Sedimentary abrasion was mimicked using a tumbling barrel with different types of sediments, with and without the addition of water. According to Shipman (Table 1), utilization produces differential wear between functional and non-functional zones of the tool, and at a microscopic scale, between more exposed and recessed/concave areas, while aeolian and sedimentary abrasion with no water creates a pitted or pebbly texture, homogeneously altering the entire surface. Pits caused by striking harder particles may occur on areas worn by utilization, but they are irregularly spaced and sized. Also, experimental abrasion only rarely creates scratches, while utilization on mixed substances produces a glassy polish crossed by striations. Shipman stresses, however, that these criteria are provisional and that further experimental studies of abrasion are needed to firmly identify distinctive features.

Application of these criteria to 116 of the 125 pieces described by Leakey – teeth were excluded from Shipman's analysis – led her to conclude that 41 were utilized by hominids and the remainder bore ambiguous traces, or evidence of abrasion by sediment. Four of the tools bearing punctures – a patella, astragalus, femoral condyle and magnum – are interpreted as anvils due to the triangular or diamond shape of the impressions, which are different from those produced by carnivores; the absence of counter-bites; large size of the bones difficult to bite; location of the marks consistent with their proposed use, and their apparent antiquity. Shipman, following Leakey, proposes that the marks on these tools

Table 1. Summary of the criteria proposed by Shipman and Rose (1988) and Shipman (1989) to distinguish natural abrasion from utilization and identify the task for which bone tools were used.

	Utilization							Experimental abrasion		
	Soft		Mixed and hard substances							
								Aeolian	Sediment flow	Hydraulic
Task	Hide working	Cutting meat	Vegetable processing	Digging soil	Bark-working	Grinding hard grains	Butchery	Abrasion gun	Tumbling barrel with sediment (from loess to gravel)	Tumbling barrel with sediment (from loess to gravel) and water
Location	Edge	Raised areas of the edge	Raised areas of the edge	Raised areas of the edge	Raised areas of the edge	Raised areas of the edge	Raised areas of the edge	All over	All over	All over
Edge shape	Round and smooth	Round and smooth	Round and smooth	Round and smooth	Round and smooth	Round and smooth	Round and smooth	Round and smooth	Round and smooth	Round and smooth
Polish	Fine glassy polish	Polish	Fine glassy polish	Fine glassy polish	Fine glassy polish	Fine glassy polish	Fine glassy polish	Absent	Absent	Absent
Striations	Few or none	Few or none	Fine and coarse striations	Fine and coarse striations	Fine and coarse striations	Fine and coarse striations	Fine and coarse striations	Absent	Few	Few or none
Pitting	Few or none	Few or none	Irregularly spaced and sized pits	Irregularly spaced and sized pits	Irregularly spaced and sized pits	Irregularly spaced and sized pits	Irregularly spaced and sized pits	Evenly pitted surface	Evenly and heavily pitted surface	Absent

may have been produced by stone awls, found at the same localities, used to pierce leather/hide.

Among the remaining 37 specimens diagnosed as implements, 35 are described as bones broken and shaped by flaking prior to use. Twenty-six are interpreted as light-duty implements used on soft substances (hide-working), and the remaining 11 described as heavy-duty tools utilized on mixed substances, perhaps in butchering or digging activities. According to Shipman, wear patterns cannot be confused with sedimentary abrasion or weathering, since bone tools show, with the exception of three cases, a low degree of natural alteration. Variables such as taxon, body part, breakage (location, orientation, type and number) and type of surface alteration (weathering, abrasion) were recorded by Shipman on the 41 tools and on 350 randomly selected bones from Olduvai and a few other sites. Comparison of these parameters indicated that the bone tools had a significantly higher occurrence of flaked fractures, flake scars and punctures, and a lower presence of stepped, jagged, or smooth fractures, suggesting that the bone tools were broken shortly after the death of the animal. It also showed that humeri, scapulae and femora, particularly from giraffids and elephants – relatively rare taxa at Olduvai – are over-represented among the bone tools.

Objectives

In sum, South and East African early hominid sites dated to between 1.8–1 Mya have yielded what appear to be very different types of bone tools. The former are characterized by long bone shaft fragments and horn cores of medium- to large-sized bovids, collected after weathering, and possibly used in specialized digging activities. Marginal shaping by grinding occasionally involves robust horn core tips. Those from East Africa mainly consist of freshly broken or, more rarely, complete irregular bones from very large mammals, used as such, or modified by flaking. Irregular bones or epiphyses appear to have been used as hammers, while the others were apparently involved in a variety of light- and heavy-duty activities. What are the reasons for such differences? Were these bones used by the same or by different hominid species, if not taxa? If the first applies, do they reflect different cultural traditions? One may expect, if this is the case, to find additional differences between these two regions in other aspects of material culture and adaptation. Although the Oldowan is associated with sites from both regions, this lithic technology appears to occur in East Africa at least more than half a million years earlier than in South Africa (Kibunjia 1994; Kuman 1994, 2003; Semaw *et al.* 1997; Kuman & Clarke 2000). This gap may be due to a time lag in the diffusion of this behaviour, staggered independent invention, or a scarcity of late Pliocene deposits in South Africa. Since few studies (Petraglia & Korisettar 1998) have tried to address this question by a detailed comparative technological analysis of contemporaneous lithic assemblages, as currently conducted by Roche's team on East African sites (Roche *et al.* 1999), it is difficult at present to know whether what is generally called Oldowan in these two regions corresponds to a single cultural tradition, or the expression of distinct regional trends. In addition, exactly who was responsible for the Oldowan technology is still a matter of debate. Since the identification of *Homo habilis* (Leakey *et al.* 1964; Tobias 1965), it has fallen into common usage to consider this species as the more probable maker of the Oldowan tools. The hypothesis of a robust australopithecine authorship, though marginal, has not been abandoned (Brain 1993; Susman 1994). A date of 2.6 Mya for the oldest occurrence of stone tools in the Afar, Ethiopia, slightly predating the oldest evidence for early *Homo* in East Africa (2.4–2.3 Mya) (Suwa *et al.* 1996; Deino & Hill 2002 in Semaw *et al.* 2003) brings new interest to the subject, with *Australopithecus garhi* proposed as the best candidate for the first user of stone tools in this region. An attribution to *Australopithecus* is further suggested by the relatively sophisticated stone tool technology and raw material procurement strategies recorded at the Gona sites. One may assume that to reach the advanced stage of technical and gestural competence recorded at Gona, the makers of the stone tool assemblages had already established a history of stone working. This may already have been in place by 2.9 and 2.7 Mya, a period poorly represented in the sections exposed at Gona, and for which no evidence of early *Homo* exists.

In this ongoing debate, bone tools have not received the attention they deserve. Variability in bone tool manufacture and use may provide a means independent of lithic technology to address crucial issues such as the characterization of early hominid cultural traditions. However, the artefactual nature of Lower Palaeolithic bone tools and the reality of the associated behaviours identified must be verified before we use this evidence to create scenarios of early hominid cultural evolution and adaptation. In this respect, the evidence for bone tool use is quite different from these two regions. Bone tools from South Africa are documented at a number of cave sites and may now be regarded as unquestionably utilized, if not modified, by hominids. Those from East Africa are attested only at Olduvai Gorge Beds I–II, in spite of the numerous sites excavated in the region, and their identification is based on results that may be preliminary. There are various reasons for this uncertainty. The first problem stems from the frame of inferences used by Shipman to assess the artefactual nature of the Olduvai bone tools. Although criteria are provided to distinguish between experimentally-used and abraded bone, it is uncertain whether such experiments successfully reproduce the entire range of post-depositional phenomena that may have affected the Olduvai bone assemblage, and whether the actual site formation processes that occurred there produced modifications that may closely mimic experimental traces of use, and be the source of misinterpretation. This is more so, considering that other studies postdating Shipman's research on Olduvai, including her own work (Olsen & Shipman 1988), have expanded our knowledge of natural modifications (e.g. Marshall 1989; Haynes 1991, Dechant Boaz 1994, Backwell 2000) and produced results that in some instances challenge her criteria. It has been shown, for example, that tumbling individual bones or bone objects with sand in leather bags produces a fairly large number of striations (d'Errico 1993a). The absence of striations on the bones tumbled by Shipman is most likely due to the presence of water during the experiment. However, no proof exists that water was a constant feature during the deposition of Beds I and II faunal assemblages (Potts 1988). Therefore, the presence of striations associated with polish on the edges of the purported bone tools does not necessarily result from use. In contrast to Shipman's proposition that digging produces a fine glassy polish, experimental reproduction of this task has produced a wear pattern dominated by individual striations (Backwell & d'Errico 2001) associated with a smoothing of the active zone, but not producing a glassy polish. While scanning electron microscopy (SEM) provides a useful means to study microscopic bone surface modification, intimate use of this tool shows that strong lateral variations often occur on adjacent areas, making a true documentation of the entire appearance of the inspected surface a challenging endeavour. This may be overcome by quantifying the surface features (e.g. Backwell & d'Errico 1999, 2001; see González-Urquijo & Ibáñez-Estévez 2003) on bone tools and/or increasing the number of micrographs presented to illustrate the variability of the surface features. To date, the microscopic evidence that documents the use-wear on the 41 bone tools from Olduvai consists of only 3 SEM micrographs. No documentation is presented on the appearance of the surface of the bone tools away from the area interpreted as utilized, nor on bones from the remainder of the Olduvai assemblage from where the bone tools derive, which prevents control comparison between clearly natural and purportedly anthropic modifications. Recognition of tools on the basis of use-wear alone may be misleading because tools may have been shaped for a number of reasons, and subsequently not, or only marginally, used. Identification of tools based on use-wear alone may thus result in the discarding of a number of true tools. Use-wear results should therefore be crossed with analyses of possible evidence of intentional shaping. Also problematic is the relationship between specific tools and the tasks Shipman assigns to them. Perhaps because of the preliminary nature of the work she published on the Olduvai material, Shipman only provides percentages of tools used for different functions and duration, without specifying which tool was used for what. Correlating tools with tasks is crucial to evaluating whether tools of particular morphology, weight, degree of shaping, and size, i.e particular types, were used for specific tasks. This would also enable comparison between knapped bone and stone tools, and the evaluation of degrees of gestural competence in the working of different raw materials.

Although tools are identified on the basis of their wear and not on evidence of manufacture, all but two are described as clearly broken and shaped prior to use. However, criteria to identify bone tools shaped by flaking are unclear. Experimental flaking of large- and medium-sized mammal bones, either to produce blanks, or to shape core tools, has shown this technique may be used with some success on bone, though it is conditioned by the unisotropic nature of this material (Bonnichsen 1979; Bonnichsen & Will 1980; Stanford *et al.* 1981; Walker 1999). The use of this technique at Lower Palaeolithic sites is demonstrated by the discovery of bone hand axes made of *Elephas antiquus* limb bones at three Italian sites (Biddittu *et al.* 1979; Biddittu & Segre 1982a, b; Biddittu & Bruni 1987). However, pseudo flaked bone tools may be produced by anthropic processes, such as bone breakage for marrow extraction (Peretto *et al.* 1996), or non-human modification, such as tramping by animals (Haynes 1988; 1991) and gnawing by large carnivores (Binford 1981; Villa & Bartram 1996). In spite of valuable work conducted in the last decade to identify firm criteria for distinguishing between individual percussion marks and carnivore notches (Blumenschine & Selvaggio 1988; Capaldo & Blumenschine 1994; Blumenschine 1995; Blumenschine *et al.* 1996; Capaldo 1998; Selvaggio 1998), the identification of bone tools shaped by flaking, especially those bearing a low level of modification and no compelling tool morphology, remains a matter of debate. This uncertainty affects a number of Lower and Middle Palaeolithic sites from Europe such as Morin (Freeman 1978, 1983) La Polledrara (Villa *et al.* 1999), Casal dei Pazzi (Anzidei *et al.* 1999), Castel di Guido (Campetti *et al.* 1989; Radmilli & Boschian 1996), Vaufrey (Vincent 1993), Torralba (Aguirre 1986), Bilzingsleben (Mania & Weber 1986; Mania 1990, 1995), Rhede (Tromnau 1983), Kulna (Mania 1990) and the Vallonnet (d'Errico 1988a). It also applies to Palaeo-Indian sites, such as Lange-Ferguson (Hannus 1990, 1997), where mammoth epiphiseal fragments and bone flakes have been interpreted, based on studies of traces of knapping and use-wear conducted by Shipman, as tools used by Clovis hunters to butcher mammoth carcasses.

In addition, Leakey and Shipman do not provide a complete list of the bones identified by the former as tools, nor give a complete representation of the bones interpreted as tools. A photograph of one aspect is given for some specimens, while others are represented by line-drawings. This prevents independent evaluation of the basic features characterizing these objects.

In this paper we provide a complete photographic record of this collection and reassess both Leakey's and Shipman's arguments for these being tools, using a multiple approach study based on data provided by microscopic, taphonomic, and morphometric analysis of the purported bone tools, faunal material from Olduvai, and experimentally and naturally modified bone.

MATERIALS AND METHODS

Contextual information

Olduvai Gorge is probably the most famous ensemble of Palaeolithic sites in the world and certainly the area which provides the most continuous record of human presence during the past two thousand millennia. Located in the eastern Serengeti Plains of northern Tanzania over an area that measures about 30 miles in length (Fig. 1) , the sites within the Gorge date from 2.1 My to 15 kya. Geologically, the formation is divided into seven main beds or levels (Hay 1976; Potts 1988): Bed I (about 2.1–1.7 My), Bed II (1.7–1.15 My), Bed III (1.15–0.8 My), Bed IV (0.8–0.6 My), the Masek Beds (0.6–0.4 My), the Ndutu Beds (0.4–32 ky), and the Naisiusiu Beds (22–15 ky). Radiometric dating of the tuff layers has clarified the age of the various levels within each bed. Comprehensive geological and palaeoenvironmental analyses (Hay 1976; Bonnefille & Riollet 1984; Cerling 1986; Kappelman 1984) have helped greatly in reconstructing the geomorphological, taphonomic and palaeoclimatic history of the Gorge. Table 2 summarizes available data on the location, stratigraphic provenance, age, associated hominid remains, stone tools, taphonomy, site function and number of faunal remains at sites yielding purported bone tools according to Leakey (1971), Hay (1976) Shipman (1989) and this study.

Mary Leakey defined three industries at Olduvai. She called these the 'Oldowan', 'Developed Oldowan' and 'Early Acheulean'. The Developed Oldowan was further subdivided into Developed Oldowan A, and Developed Oldowan B.

Stone tools from Bed I and the base of Bed II, attributed to the Oldowan, include side, end, two-edged, pointed, and chisel-edged choppers, polyhedrons, discoids, scrapers, a few subspheroids and burins. Hammers, utilized cobbles and flakes, some of them retouched, probably used in light-duty functions are also present. The Developed Oldowan A, found at sites from lower Bed II, differs from the Oldowan for an increase in spheroids and subspheroids, interpreted as the introduction of missiles as hunting weapons; light-duty tools are more varied. The Developed Oldowan B, from Middle and Upper Bed II contains very few bifaces. Although bifaces are absent in Bed I, 'proto-bifaces' appear in upper Bed I and Lower Bed II, picks are discovered above the base of Bed II.

Crude choppers and scrapers occur throughout Beds I and II, and spheroids and sub-spheroids, modified and battered nodules and blocks increase in frequency in Bed II. This corresponds to a rise in the number of artefacts relative to fauna in middle-upper Bed II. This may be due to better tool-making abilities and accessibility of raw materials, or to large mammals being common at these sites. Fewer large animals are needed to subsist, and fewer bones are recorded at sites if meat is transported (Leakey 1971).

The beginning of the Acheulean is marked by the appearance of bifaces with cleavers and hand axes, which appeared in Bed II. Compared to the Acheulean, the Developed Oldowan tools evidence greater variability and seem to differ technologically from the more recent tradition. Indications are that these two traditions coexisted. Discovery of human remains attributed to *Homo erectus* in association with hand axes in Bed II suggested to Mary Leakey that this human type and early forms of *Homo sapiens* were the makers of the Acheulean.

Early hominid behaviour at Olduvai

Olduvai assemblages have represented for the last four decades an arena that has challenged hypotheses on early hominid behaviour and subsistence strategies. Dense concentrations of animal bones and stone tools from Bed I

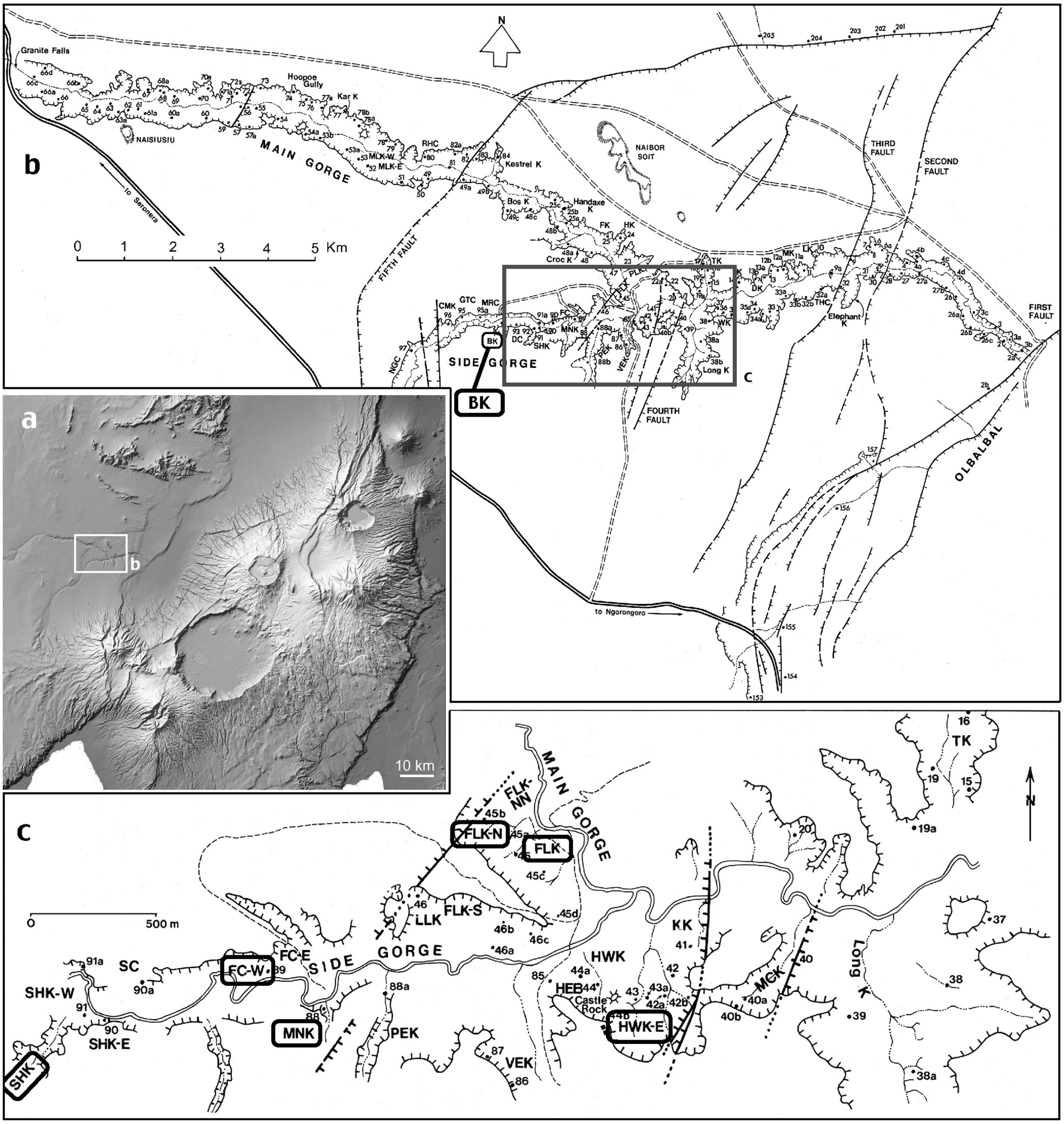

Figure 1. **a**, Regional topographic map of northern Tanzania, showing extent of Olduvai area in (b). **b**, Outline map of Olduvai Main and Side gorges showing faults, topographic features and localities. Faults are shown as heavy hachures. Roads are shown as dashed lines. **c**, Map showing localities near the junction of the Main and Side gorges (modified after Hay 1976). Encircled are sites that have yielded bone tools according to Leakey (1971).

and II sites were in the early phases of Olduvai investigations interpreted as living sites, home bases or central foraging places, where hominids processed the meat of animals using stone tools (Leakey 1971; Isaac 1971, 1978, 1983). In the late 1970s the campsite interpretation, based on analogy with behaviours recorded among modern hunter-gatherers, became the object of thorough scrutiny. Binford (1981) proposed that sites from Beds I and II simply represented zones where dead animals were scavenged by carnivores and hominids. Analysis of six levels from Bed I (FLK North Level 6, FLK *Zinjanthropus,* FLKNN Levels 2 and 3, DK Levels 2 and 3) led Potts (1988) to reject Binford's interpretation and propose that although the attraction of carnivores to these sites prohibited their use by hominids as home bases, bone remains from these sites should be interpreted as hominid accumulations of carcasses obtained by scavenging/hunting, and stone tools as 'stone caches' repeatedly used to process carcasses and possibly for other activities. Hunting is discarded by Shipman (1986a) based on her study of the occurrence and location of cut-marks on 2700 specimens from 10 Bed I contexts (DK I, FLK *Zinj.* and other levels, FLKN 1–6, FLKNN, PDK) and comparison with modern butchery sites from Kenya.

Table 2. Contextual information on Olduvai sites that have yielded important archeological features and putative bone tools. Data after Leakey (1971), Hay (1976) and Potts (1988).

Locality		Age range	Hominids	Loc.	Cultural attribution	Stone tools																Bone tools			Cut-marks	Site function	No. stone tools	No. faunal remains
Bed	Site					ch	pb	bf	pl	ds	sp	no	sh	sl	bu	aw	oe	an	ha	fl	co	L.	S.	This study				
II upper	BK	1.7–1.15	*H. erectus* *A. boisei*	rw	Dev. Oldowan B, Acheulean	101	0	38	8	33	199	512	18	105	23	45	37	4	18	5343	627	46	11	14	?	?	6801	2957
II middle	FC West	1.7–1.15	sp. indet.	cw	Dev. Oldowan B	49	0	5	4	4	48	53	11	9	1	2	0	7	23	748	159	5	2	1	?	Occupation site	1184	127
II middle	MNK	1.65–1.53	sp. indet. *Homo* sp. *H. habilis* cf. *H. erectus*	cw	Oldowan, Dev. Oldowan B, Acheulean	96	0	9	9	19	159	72	24	59	0	7	0	24	64	3269	449	42	15	17	Medium t overy large mammals	Occupation site	4399	1723
II middle	SHK	1.7–1.15		cw	Dev. Oldowan B	293	0	68	21	62	318	115	131	86	11	12	3	26	0	577	27	9	5	1	?	Occupation site	185	?
II lower	HWK East	1.7–1.15	sp. indet. *H. habilis* *A. boisei*	cw	Oldowan Dev. Oldowan A	41	1	0	0	3	1	14	4	0	2	0	0	0	21	24	0	6	3	1	?	Occupation site level 1	154	425
I upper	FLK North Levels 1–5	2.1–1.7	sp. indet. *Austr.* sp. *H. habilis* *A. boisei* *H. erectus*	cw	Oldowan Dev. Oldowan A & B	143	7	0	14	16	18	90	18	18	0	0	0	21	103	1126	118	0	0	0	Small mammals	FLKN 1–5 interpreted as occupation floor, home bases or central foraging sites	1594	7687
I upper	FLK North 6	2.1–1.7	*H. habilis*	cw	Oldowan Dev. Oldowan A & B	4	1	0	0	1	0	2	0	0	0	0	0	6	4	85	6	0	0	0	Large mammals	Butchering site with artefacts and elephant embedded in clay	130	2 258
I middle	FLK NN 3	2.1–1.7	sp. indet. *H. habilis*	cw	Oldowan	2	0	0	1	0	0	19	1	0	0	0	0	0	1	30	8	1	0	0	Rare, only on small mammals	Occupation site	72	2261
I middle	FLK levels 21, 17, 16, 15, 13, 12, 11, 10, 7	2.1–1.7	*H. habilis* *A. boisei*	?	Dev. Oldowan B	2	0	0	1	0	0	4	0	0	0	0	0	2	0	0	2	0	0	0	?	?	11	187
I middle	FLK *Zinj.* level 22	2.1–1.7	sp. indet. *Austr.* sp. *H. habilis* *A. boisei*	cw	Oldowan Acheulean	17	0	0	9	3	1	40	9	18	4	0	0	5	13	2193	155	6	3	0	Large & small mammals	Living floor, home base or central foraging site	2647	40 172
I lower	MK	2.1–1.7	*H. habilis*	?	Oldowan	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	1	0	0	?	?	?	?
I lower	DK	2.1–1.7	*Homo* sp. *H. habilis*	cw	Oldowan	47	1	0	32	27	7	79	10	20	3	1	0	3	48	776	118	2	2	1	Large & small mammals	Occupation site. Stone circle in level 3	1163	7855
? ?	FCKII	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	5	0	1	?	?	?	?

?: data fragmentary or absent.
Loc.: Location
rw: reworked stream chanel deposit; cw: close to water (lake shore/river/stream).
ch: choppers; pb: proto-bifaces; bf: bifaces; pl: polyhedrons; ds: discoids; sp: speroids/sub-speroids; no: nodules & blocks; sh: scrapers, heavy duty; sl: scrapers, light duty; bu: burins; aw: awls; oe: outils ecailles; lt: laterally trimmed flakes; an: anvils; ha: hammerstones; fl: flake; co: core.
Zinj.: *Zinjanthropus.*
L.: Leakey; S.: Shipman

Focusing on skeletal part frequency and cut-mark data on 60 000 bone specimens from the FLK *Zinjanthropus* site (middle Bed I), Bunn & Kroll (1986) found a high limb to low axial skeleton representation, with cut-marks located in places consistent with butchering practices. These data are interpreted as evidence of hominids transporting selected portions of carcasses to favoured localities in the landscape (Bunn 1986). In addition, a high proportion of prime adult mammal remains suggests to these authors that hominids aggressively scavenged and may even have hunted large animals. Bunn & Kroll (1986) note that sharp-edged stone flakes are among the best-known cutting tools, and numerically constitute the bulk of the Oldowan assemblages from Olduvai. The meat-cutting function of the flakes is supported by microwear studies (Keeley & Toth 1981) demonstrating that unmodified flakes from Koobi Fora were used to cut meat.

Using a landscape archaeology approach, Blumenschine & Masao (1991) sampled the spatial distribution, density and character of archaeological occurrences in a 1 km^2 area of the HWKE site, lower Bed II. A high percentage of core tools and long bone specimens preserving fractures or percussion marks indicative of hammerstone breakage, suggests to them an association with marrow extraction. Trenches near the lake shore preserve a greater proportion of large mammal long bones showing evidence of hammerstone breakage. This pattern is consistent with modern observations of lower levels of competition among carnivores for bovid carcasses in the near-lake environs surrounding Lake Ndutu in the Serengeti (Blumenschine 1987). It suggests hominids had better opportunities to gain access to whole marrow bones near the shore of palaeo-Lake Olduvai. Blumenschine & Masao (1991) argue that the apparent continuous distribution of artefacts and associated bones away from purported occupation sites show that repeated visits to particular loci cannot be proved for Bed II times. A lack of trees in the palaeo-lake margin zone meant no refuge from predators while processing carcass parts, which they propose were most frequently procured through scavenging of predator kills. Stone tools were transported to the butchering sites, and the variability in density of bones and artefacts suggests that hominids at times concentrated carcass parts for processing, attracted perhaps to isolated patches of shade or stone caches. The hypothesized paucity of trees suggests hominid visits were brief, and that their subsistence and social activities were focused elsewhere in the Olduvai Basin.

To test the various hypotheses concerning the timing and nature of hominid and carnivore activities in Plio-Pleistocene bone assemblages from Olduvai (Bunn 1986; Bunn & Kroll 1986; Leakey 1971; Binford 1981), Blumenschine (1995) focused his attention on the bone assemblage from the FLK *Zinjanthropus* site. Frequencies of percussion and tooth marks reject the hypothesis that carnivores had first access to long bone marrow. This contradicts Binford's interpretation of hominids as marginalized scavengers of already heavily ravaged carcasses. A high proportion of tooth-marked long bone mid-shaft fragments also rejects the alternative hypothesis, that carnivore access was secondary to butchery and marrow extraction by hominids (Leakey 1971; Bunn 1986). Blumenschine (1995) proposes that the sequence of carnivore and hominid access to long bones and their marrow is consistent with scavenging by hominids.

The Olduvai bone tool collection

The Olduvai bone tool collection housed in the Department of Archaeology at the National Museums of Kenya in Nairobi consists of 125 specimens that were analysed by us in October 2001. These include some pieces that were not designated as tools by Leakey (1971), since seven specimens interpreted as tools by her and later by Shipman (1989: 323), could not be located in the museum (HWKEII 368; HWKEII 886; MNKII 23369; MNKII 1099; BKII 2494; BKII 068-6688; BKII 3240). Annotated line-drawings, comprising two to four aspects of each specimen were made. These recorded the location of macro- and microscopic modifications such as original or post-depositional breakage, flake removals, punctures, carnivore traces, cut-marks, trampling and polish. Recorded variables also included taxon, body part, bone region involved, dimensions of each specimen, the weathering stage according to Behrensmeyer (1978), and location, number, association and length of flake scars according to fracture axis. While some of these variables have already been recorded by Shipman, others such as the number, location on the bone flake, occurrence on the periosteal *versus* medullar face, and dimension of removals, possibly due to intentional shaping, were recorded in the framework of the present study for the first time. The term 'flake' is used here to describe pieces detached from long bones, and may be taken to encompass fragments. Long bone ends or shaft pieces are described as such, or referred to as 'pieces'.

The same variables were recorded on a control sample of 86 randomly-selected limb bone shaft fragments from the FLKI, FLKNI, FLKII, BKII, MNKII and DKI Olduvai sites. This was to establish whether the modifications recorded on the purported bone tools did not represent an extreme in variation, affecting to a lesser degree the remainder of the Olduvai assemblage. Colour slides and digital images of two to four aspects of each piece were also taken in order to document the collection.

Using high-resolution dental impression material (Coltene President), 76 replicas were made from different areas of the purported tools and the control sample, which consisted of shaft fragments from the FLKI, FLKII and MNKII Olduvai sites. Cast areas included the edges of the tools, whether described by Shipman as utilized or not, regions located away from the purported functional zones, and similar areas on the control specimens. All puncture marks and some cut-marks were also moulded. Transparent replicas made with RBS resin (T2L Chimie, France) were cast from these moulds. All were examined in transmitted light using an optical microscope (Wild M3C) equipped with a digital camera, and 300 digital micrographs were captured. Forty-one replicas were analysed with a scanning electron microscope (840A Jeol) (Bromage 1987; d'Errico 1988b) and 380 SEM micrographs

Table 3. Elephant bone breakage and flake use experiments

Skeletal element	Bone No.	Weight (kg)	Preservation	Breakage technique	Gender of breakers	Tasks Flaying	Working fresh hide	Working dry hide	Digging soil	Removing bark
Femur	1	19	Semi fresh	Struck against rock	m	2	2	1	2	1
Femur	2	22	Semi fresh	Rock on bone bridge	f	–	3	1	–	–
Ulna	3	11	Semi fresh	Struck against rock	f	–	–	–	–	–
Ulna	4	11	Semi fresh	Thrown against a rock	f	–	–	1	–	–
Femur	5	13	Weathered	Rock thrown on bone	m	3	2	–	1	2
Humerus	6	9	Semi fresh	Struck against rock	m	–	–	–	–	–
Humerus	7	22	Semi fresh	Struck against rock	m	1	–	–	–	–
Tibia	8	9	Semi fresh	Rock on bone bridge	m	–	–	–	–	–
Humerus	9	12	Semi fresh	Thrown against a rock	m	–	–	1	–	–
Total						6	7	4	3	3

were taken at ×15 to ×350 magnification. The presence of striations (either single or multiple, parallel or intersecting) and evidence of smoothing, polishing, pitting, and possible residues was recorded.

Comparative collections

Thirty-five non-human reference collections of known taphonomic history were examined and studied using the same microscopic techniques described above (Backwell 2000; Backwell & d'Errico 2001). These represent nine damage categories derived from both modern and fossil contexts, including animals (hyaena, dog, leopard, cheetah, porcupine) and geological processes (river gravel, spring, flood plain, wind, trampling).

Experimental material

Nine modern elephant limb bones (Table 3) were experimentally broken by 26 university students of mixed gender. Ranging between nine and 22 kg each in weight, eight of the bones originated from a young adult *c.* 20 years old that had died five months before the experiment. Only one bone originated from a teenage individual and was weathered. The experiment was conducted at Plovers Lake in the Sterkfontein Valley, South Africa. The students were asked to work in groups of three to five in order to break the bones and produce flakes, employing only resources available in the environment. Knapping of bone flakes was attempted by one of us (F.D.) using elongated pebbles to replicate the flake removals recorded on the Olduvai purported bone tool collection. Un-retouched flakes were used for flaying and cutting the fresh meat from an adult male eland, working fresh hides with the addition of sand, dry hides with the addition of salt, and digging in soil to extract tubers and grubs, as well as removing bark from trees.

RESULTS

Microscopic analysis

Olduvai

Edges or tips of the bone specimens described by Shipman as probable tools, show at microscopic scale a great deal of variation in their appearance (Table 4). The large majority are characterized by smoothing associated with or without either parallel or intersecting single or multiple striations (Fig. 2a–i). This pattern is more pronounced on some pieces or areas of a single specimen, where it may in places completely obliterate the anatomical structure of the bone (Fig. 2b–c). The smoothing often decreases from the edge toward the inside of the object and in one case (Fig. 2d), a clear worn band of 1 mm wide appears on the edge. A minority of these bones present edges covered by a more-or-less glossy polish associated with no or very few striations (Fig. 2j–l). Although features that appear as micro-pits are common on most pieces (Fig. 2b,o), it is often difficult to distinguish between concavities produced by impact or pressure of sedimentary particles, and damaged bone structures such as vascular openings and Haversian canals (Fig. 2m,l).

Interpreting these wear patterns as evidence of tool use is problematic. Comparable wear is identified on areas of the purported tools located a considerable distance from the worn edge unsuitable for use (Fig. 2m–n). Microscopic analysis of the edges of the specimens described by Leakey as tools, but rejected by Shipman, also cautions against an anthropic interpretation, since a number of them (e.g. BK 3122, BK 201, MNKII 848) record wear that falls within the three categories described above on the Shipman tools (Fig. 2o–r). Examination of the control sample also reveals the same range of surface features seen on Shipman's and Leakey's tools (Fig. 3a–f), and consists of randomly selected shaft fragments from Olduvai Beds I–II, bearing no apparent traces of anthropic modification.

In addition to these observations, we have found on three specimens (two purported tools and one bone from the control sample) micro-crystals of calcite growing predominantly on vascular openings and cracks (Fig. 4). These crystals were probably created by the slow dehydration of bone containing water rich in calcium carbonate. The excellent state of preservation of the crystals and the fact that they clearly overlie the traces of abrasion, suggest that they appeared only after the abrasion process took place and that their growth represents the final taphonomic event that affected part of the bone assemblage. These crystals are easily affected by mechanical and chemical alteration and would not have survived in such a good condition if the bone had undergone even to a small degree (e.g. simple re-hydration) one of these processes.

Table 4. Summary of surface modifications recognized by microscopic analysis on specimens described as bone tools by Leakey and by Shipman, and on a control sample from Olduvai Bed I–II.

		Previous studies		Present study										
				Location			Surface modifications							
Site	Specimen and replica *	Tools **	Modification ****	Tip	Edge	Body	Smoothed	Polished	Randomly oriented single striations	Sets of parallel striations intersecting	Sets of parallel striations	Shallow grooves	Pitting	Cut-mark
DKI	067/4259	1, 2	Wear	–	■	–	■	–	–	■	■	–	■	–
FLKII	884a	1, 2	Punctures	–	–	■	■	–	■	■	■	–	■	–
FLKII	884b	1, 2	Punctures	–	–	■	–	–	–	–	■	–	–	–
FLKII	884c	1, 2	Punctures	–	–	■	–	–	■	–	–	–	–	–
FLKII	884d	1, 2	Punctures	–	–	■	■	–	■	–	–	–	–	■ (x)
FLKII	884e	1, 2	Punctures	–	–	■	–	–	■	–	–	–	–	–
FLKII	884f	1, 2	Punctures	–	–	■	–	–	■	–	■	–	■	■ (x)
FLKII	884g	1, 2	Punctures	–	–	■	–	–	■	–	■	–	–	–
FLKII	884h	1, 2	Punctures	–	–	■	–	–	–	–	■	–	–	–
FLKII	884i	1, 2	Punctures	–	–	■	–	–	–	–	■	–	■	–
FLKII	spit 5+a	1, 2	Wear	–	■	–	■	–	■	■	■	–	■	–
FLKII	spit 5+b	1, 2	Wear	–	■	–	■	–	■	–	■	–	■	–
FLKII	spit 5+c	1, 2	Wear	–	■	–	■	–	■	–	■	–	■	–
HWKEII	068/6690	1, 2	Wear	■	–	–	■	–	■	■	■	–	■	–
HWKEII	/3 (head)	1	Wear	■	–	–	■	■	■	■	■	■	■	–
FCII	068–6679	1,2	Wear	■	–	–	■	■	■	■	■	–	■	–
MNKII	475	1, 2	Wear	■	–	–	■	–	■	■	■	–	■	–
MNKII	068/6676	1, 2	Wear	–	■	–	■	–	■	–	■	–	■	–
MNKII	848	1	Wear	■	–	–	■	–	■	■	■	–	■	–
MNKII	925	1	Cut-mark	–	–	■	■	–	–	–	–	–	–	■
MNKII	1051a	1	Wear	–	■	–	■	–	–	–	–	–	–	–
MNKII	1051b	1	Punctures	–	–	■	■	–	■	–	■	–	■	–
MNKII	2889a	1, 2	Wear	–	■	–	■	–	–	■	–	–	■	–
MNKII	2889b	1, 2	Wear	■	–	–	■	–	–	■	–	–	■	–
MNKII	2474a	1, 2	Wear	–	■	–	■	–	■	■	■	■	■	–
MNKII	2474b	1, 2	Wear	■	–	–	■	–	■	■	■	–	■	■
MNKII	738	1, 2	Wear	–	■	–	■	–	–	–	■	–	■	–
MNKII	1731a	1, 2	Wear	–	■	–	■	■	■	■	–	–	–	–
MNKII	1731b	1, 2	Wear	–	■	–	■	–	■	■	■	–	■	–
MNKII	2903a	1, 2	Wear	–	■	–	■	–	■	■	■	–	■	–
MNKII	2903b	1, 2	Wear	–	■	–	■	–	■	■	■	–	■	–
MNKII	1046a	1, 2	Cut-mark	–	–	■	■	–	–	■	■	–	■	■
MNKII	1046b	1, 2	Cut-mark	–	–	■	■	–	■	■	■	–	–	■
MNKII	1741a	1, 2	Wear	–	■	–	■	–	–	–	■	–	■	–
MNKII	1741b	1, 2	Wear	–	■	–	■	–	–	–	–	–	–	–
MNKII	1741c	1, 2	Wear	–	■	–	■	–	–	–	■	–	■	–
MNKII	471a	1	Wear	■	–	–	■	–	■	■	■	–	■	–
MNKII	471b	1	Wear	–	■	–	■	–	■	■	■	–	■	–
MNKII	744	1	Wear	–	■	–	■	–	–	–	–	–	–	–
MNKII	1116	1	Wear	–	■	–	■	–	–	–	–	–	–	–
SHKII	068/6684	1, 2	Wear	■	–	–	■	–	–	–	–	–	–	–
SHKII	068/6688	1, 2	Wear	–	■	–	■	■	■	–	–	–	■	–

Continued on p. 105

Table 4 (*continued*)

Site	Specimen and replica *	Previous studies		Present study										
		Tools **	Modification ****	Location			Surface modifications							
				Tip	Edge	Body	Smoothed	Polished	Randomly oriented single striations	Sets of parallel striations intersecting	Sets of parallel striations	Shallow grooves	Pitting	Cut-mark
SHKII	068/6687	1, 2	Wear	–	■	–	■	–	■	■	–	–	■	–
SHK–EII	068/6681	1	Wear	–	–	■	■	–	■	■	■	–	■	–
SHKII	068/6685	1	Wear	■	–	–	■	–	–	–	–	–	■	–
BKII	3122a	1	Wear	■	–	–	■	–	–	–	–	–	–	–
BKII	3122b	1	Wear	■	–	–	■	■	■	■	■	–	■	–
BKII	068/6680a	1	Cut-mark	–	–	■	■	–	■	–	–	–	–	■
BKII	068/6680b	1	Cut-mark	–	–	■	■	–	■	–	–	–	–	■
BKII	1938a	1, 2	Wear	–	■	–	■	–	■	■	■	–	■	–
BKII	1938b	1, 2	Wear	–	■	–	■	–	■	–	–	–	■	–
BKII	1938c	1, 2	Wear	–	–	■	■	–	■	■	■	–	–	–
BKII	53–9 ex 1953a	1	Wear	■	–	–	■	–	■	■	■	–	■	–
BKII	53–9 ex 1953b	1	Wear	–	–	■	■	■	■	■	■	–	■	–
BKII	53–9 ex 1953c	1	Wear	–	■	–	■	–	–	■	■	–	■	–
BKII	201	1	Wear	■	–	–	■	–	■	■	■	–	■	–
BKII	2933a	1, 2	Punctures	–	–	■	■	–	–	–	■	–	■	–
BKII	2933b	1, 2	Punctures	–	–	■	■	–	–	–	■	–	–	–
BKII	2933c	1, 2	Punctures	–	–	■	■	–	■	–	■	–	–	–
BKII	068/6678	1, 2	Wear	■	–	–	■	–	■	■	■	–	■	–
BKII	068/6666	1	Wear	■	–	–	■	–	■	■	■	–	■	–
BKII	068/6670	1	Wear	–	■	–	■	–	■	■	–	■	–	–
BKII	933	1	Wear	■	–	–	■	–	–	–	–	–	–	–
BKII	187a	1	Cut-mark	–	–	■	■	–	–	–	–	–	–	■
BKII	187b	1	Cut-mark	–	–	■	■	–	–	–	■	–	–	■
BKII	187c	1	Cut-mark	–	–	■	■	–	■	■	■	–	■	■
BKII	068/6668	1	Wear	■	–	–	■	–	■	■	■	–	■	–
FCKII	068/6682z	1	Wear	–	■	–	■	–	–	■	–	–	–	–
FLKI	340a	***	***	–	–	■	■	–	–	–	■	–	–	■
FLKI	340b	***	***	–	–	■	■	–	–	■	■	–	■	■
FLKI	112	***	***	–	■	–	■	–	–	–	–	–	–	–
FLKI	341	***	***	–	–	■	■	–	■	–	■	–	■	■
FLKII	339a	***	***	■	–	–	■	–	■	■	■	–	■	–
FLKII	339b	***	***	■	–	–	■	–	■	■	■	–	■	–
FLKII	780	***	***	■	–	–	■	–	■	■	■	–	■	–
MNKII	2770	***	***	■	–	–	■	–	■	■	■	–	■	–
FLKII	TRI+	***	***	■	–	–	■	–	■	■	■	–	■	–

*The lower case letter identifies the replica when more than one replica per specimen was analysed; ** tools after Leakey (1) and Shipman (2); *** control sample; **** modification after Leakey and Shipman; (x) cut-mark-like grooves associated with punctures.

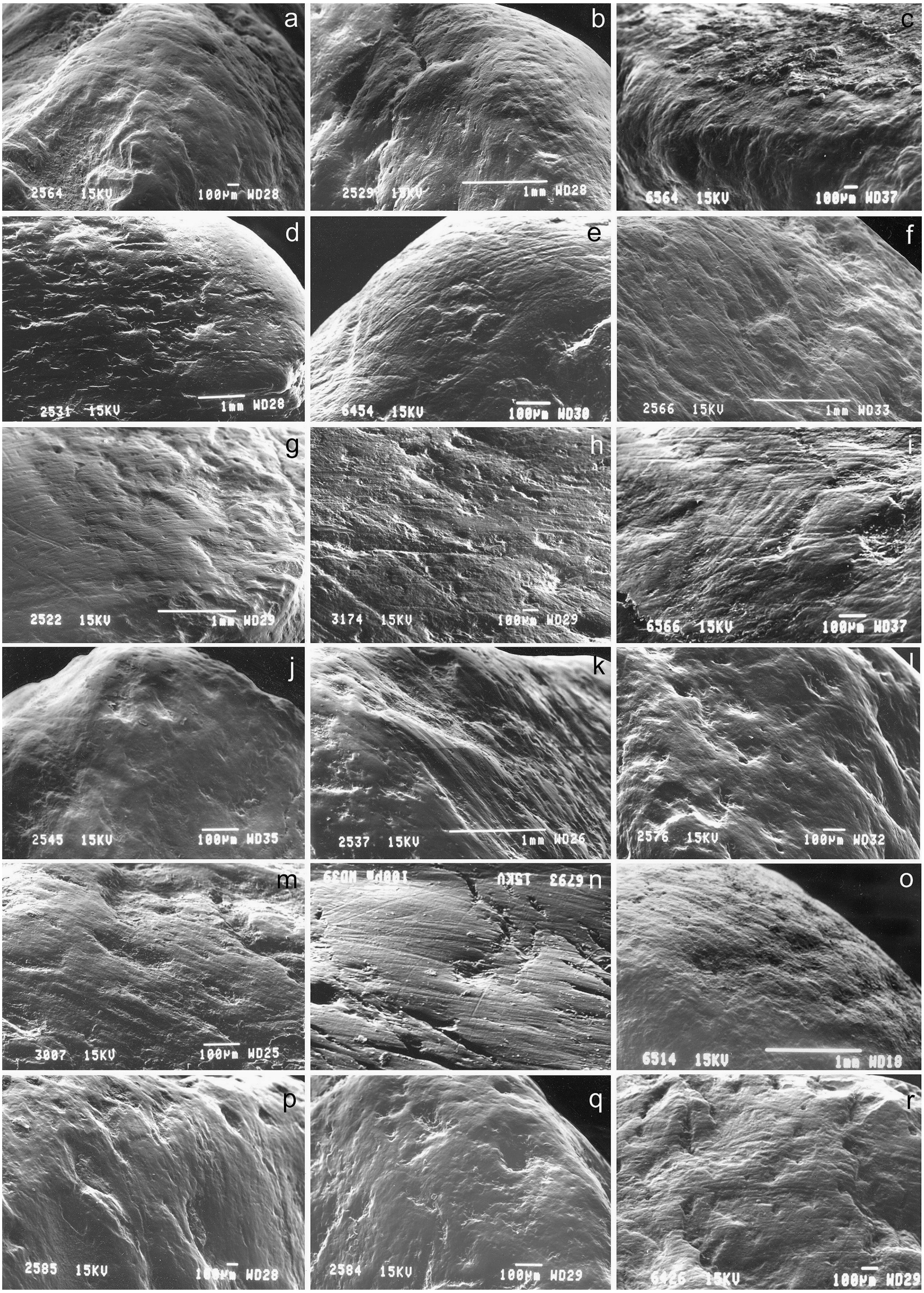

Figure 2. a–n, Wear pattern on bone fragments interpreted as tools by Shipman (**a–d**: smoothing; **e–f**: smoothing associated with sub-parallel striations; **g–h**: parallel striations; **i**: sets of intersecting parallel striations; **j–l**: polish with no striations); **m–n**: wear pattern on areas of the objects interpreted as tools, located away from the purported functional area (**m**: smoothing, **n**: sub–parallel striations on a smoothed area); **o–r**, pieces interpreted by Leakey as tools but rejected by Shipman (**o**: smoothing, **p–q**: polish, **r**: parallel striations). a: BKII 1938b, b: FCIIS 068–6679, c: HWKEII 068–6690, d: FLKII spit5+a, e: BKII 1938a, f: MNKII 1741c, g: FCII 068–6679, h: FLKII spit5+, i: HWKEII 6690, j: MNKII 1731a, k: FCIIS 068–6679, l: SHKII 068–6688, m: BKII 53–9b, n: BKII 1938c, o: BKII 201, p: BKII 1953b, q: BKII 1953b, r: BKII 3122b.

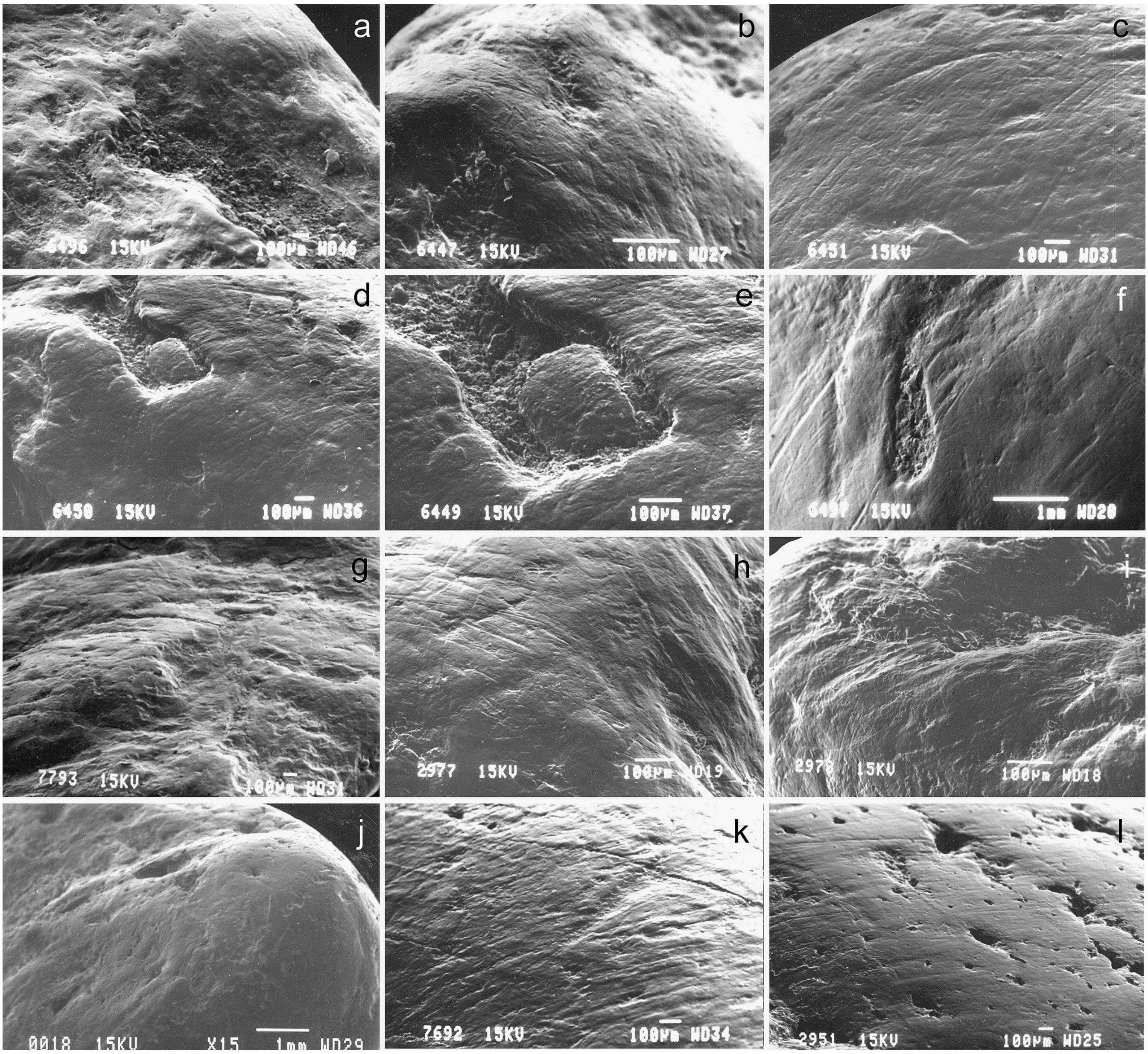

Figure 3. **a–f**, Edges and tips of shaft fragments from the remainder of the Olduvai Beds I–II assemblage not considered as tools by Shipman and by Leakey, and bearing no apparent anthropic traces (**a**: smoothing of elevated areas, **b**: smoothing with randomly oriented striations, **c–e**: smoothing with sets of parallel striations. **e**: close–up view of (d) showing a bone islet resulting from abrasion; **f**: polished area crossed by individual striations); **g–i**, edges of bone pieces from the Homeb Hottentot water hole bearing traces of smoothing and striations; **j–l**, edges of bone pieces from the Bacon Hole hyaena den showing smoothing and areas covered by parallel striations.

Comparative collections

Damage inflicted on bones by non-human agents may also closely match, at microscopic scale, the surface features observed on the edges of the purported tools. Comparable features are observed on bones collected by Brain at the Homeb Hottentot water hole in Namibia, where they were subjected to trampling by goats (Fig. 3g–i). The edges of these pieces record significant smoothing of the more elevated regions often associated with individual and sets of parallel striations. Bone pseudo-tools from the Bacon Hole fossil hyaena den cave site (Stringer 1977) also record comparable modifications, including smoothing of elevated areas (Fig. 3j) and zones covered with broad or fine parallel striations (Fig. 3k–l). In both comparative collections, where these modifications affect the bone surface to a lesser degree, only more exposed areas such as ridges, edges and tips develop a detectable wear pattern that may not appear on the remainder of the object, thus producing a pattern that might be erroneously interpreted as differential wear due to anthropic use.

Wear patterns on experimentally used bone tools

Experimental use of unmodified shaft fragments applied to different tasks produced distinct wear patterns that, in part, overlap with those described by other authors (MacGregor 1975; Campana 1980; Peltier 1986; Shipman 1988, 1989; Brain & Shipman 1993; d'Errico 1993b; Lemoine 1997; Backwell & d'Errico 2001). The working of fresh hides with sand by maintaining the tool perpendicular to the hide, flattens the edge and smoothes a 2–3 mm wide adjacent band (Fig. 5a–e). The edge is

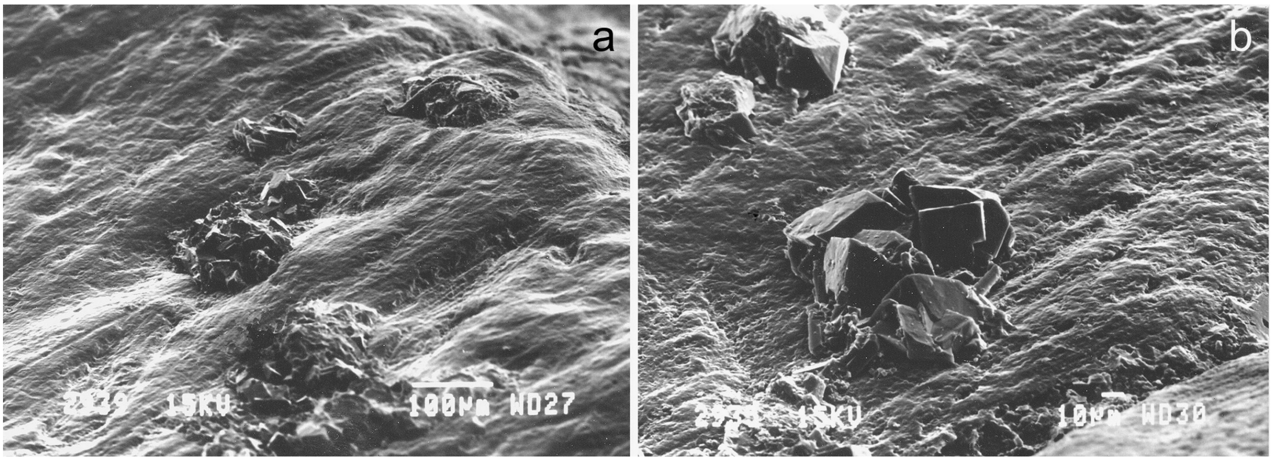

Figure 4. **a–b**, Examples of micro-crystals that developed on an already abraded bone surface (specimen MNKII 2474). Notice the rhombohedral cleavage of the crystal at top left in (b) demonstrating the calcitic nature of the crystals.

intersected by relatively broad superficial striations, and the adjacent band by narrow parallel striations perpendicular to the tool edge. Flaying with a bone tool produces a smoothing of the edge associated with polishing of prominent areas (Fig. 5f). Individual sub-parallel grooves develop on flat underside areas (Fig. 5g). This activity also chemically alters the bone surface, differentially etching the bone structure (Fig. 5h). Bark removal creates a smoothed surface covered by individual sub-parallel striations. Digging in soil produces an association of single and bar-code-like composite broad striations, oblique or parallel to the main axis of the tool (Fig. 5k–l).

Punctured bones

Only two of the four pieces interpreted by Leakey and by Shipman as anvils, a giraffe astragalus (BKII 2933, Fig. 7) and an elephant patella (FLKII 884, Fig. 8), were located in the National Museums of Kenya. Our reappraisal of these pieces has taken into account criteria proposed by other authors for identifying the causes of impressions on bone, as well as observations made on our experimentally broken elephant limb bones. Tooth pits, crushes and punctures produced by carnivores are well known features commonly described in the taphonomic literature (Binford 1981; Haynes 1983; Lyman 1994; Fisher 1995). Tooth pits are superficial, roughly circular markings producing no inward crushing of the bone cortex. Crushes are roughly circular depressions of cortical bone nested in underlying cancellous bone, often in the vicinity of epiphyses. Punctures are roughly circular holes in cortical bone with irregular edges, depressed margins and flaking of the outer wall of the bone pushed into the depression. More regular edges are seen on punctures made on thin cortical bone.

Percussion pits, impact marks, chop-marks, crushing and percussion striae are terms used to describe the alterations created by a hammer-stone striking a bone surface (Binford 1981; Blumenshine & Selvaggio 1988; White 1992; Oliver 1994; Fisher 1995). Though referring to the same phenomenon – the mark inflicted on a bone by a hammer – the first three terms indicate impact marks of variable shape. This shape is determined by the morphology of the contact area of the stone hammer. Tools with knapped edges typically produce deep v-shaped marks (chop-marks), while angular-edged hammer-stones produce irregularly shaped depressions with complex internal morphologies, and fine-grained pebbles result in more uniform superficial depressions. Crushing caused by stone tools is defined as the result of an impact in which thin cortical bone is nested in underlying cancellous bone. These features are often associated with micro-striations resulting from the contact of the hammer-stone tip with the bone surface before or after the impact.

It may be difficult distinguishing between carnivore- and hominid-induced punctures when micro-striations are absent, and the mark produced by the hammer-stone is circular, rounded, and does not display internal features reflecting the irregular morphology of the hammer-stone tip. These features may be mistaken for carnivore activity. Poor surface preservation can also mask diagnostic characters and make the identification of the agent problematic.

Our bone breakage experiments, conducted using dolomite and quartzite blocks as hammers or anvils, confirm the criteria described in the literature for stone tool-generated puncture marks. In our experiments, this activity produced three main features that may or may not be found together (Fig. 6). These are irregular depressions, the morphology of which is determined by the shape of the tool tip penetrating the bone (Fig. 6a), the lifting or detachment of micro-flakes adjacent to the impression (Fig. 6a,c), and the production of broad composite striations visible inside or close to the puncture (Fig. 6b).

The astragalus from Olduvai (Fig. 7) bears on its dorsal face a cluster of overlapping punctures of consistent triangular shape and orientation. Apart from the features already described by Shipman, indicating that these punctures were made by the same stone tip repeatedly striking the object, we have identified striations within two peripheral punctures (Fig. 7c–d), as well as inside the main area of percussion. Although calculating the precise number of punctures is difficult due to overprinting, microscopic analysis suggests that at least 14 blows were inflicted.

The patella records, on the left half of the articular

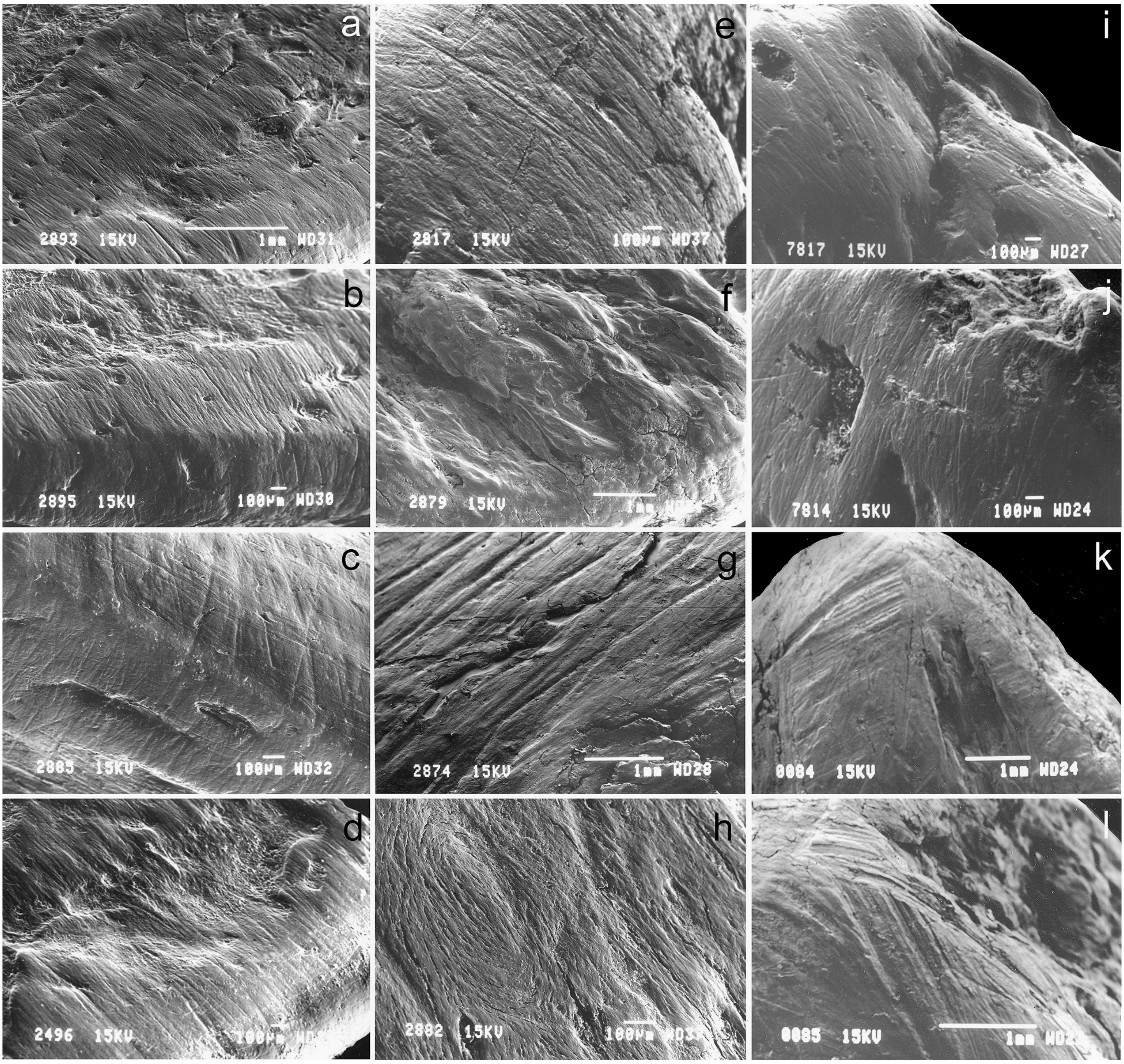

Figure 5. SEM micrographs of the edges of modern elephant bone shaft fragments used to work hide with sand (**a–e**), flay an eland carcass (**f–h**), remove bark from trees (**i–j**), and dig in soil in search of grubs and tubers (**k–l**).

surface, nine scattered punctures (Fig. 8) bearing ambiguous features. Our analysis of these marks (Fig. 8a–i) indicates that in spite of some degree of morphological variability, these punctures were probably made by the same agent striking the surface in a single session, as demonstrated by their similar internal morphology and the consistent orientation of their spindle-like shape. The rounded/oval morphology of a number of them, macroscopically similar to carnivore punctures, and the absence of clean angular edges, makes it difficult to securely attribute them to hominin agency. Macroscopic analysis of marks made on a similar bone by various carnivore taxa, and use of this bone as a hammer on material such as wood, is necessary before reaching a definite conclusion. This experiment might also explain, if the carnivore hypothesis is retained, why no other carnivore damage is present on the specimen, as would be expected if all these marks were made by a large carnivore.

In sum, our analysis confirms Leakey's and Shipman's diagnosis of these bones as anthropically modified. We believe, however, that an interpretation of these objects as hammers used on intermediate stone tools, rather than anvils on which to pierce skins, fits the evidence better. Experimental piercing of leather (d'Errico *et al.* 2003) shows that a rotating motion is needed to effectively perforate this material and leave a suitable non-tearing hole. If exerted against a bone surface, this motion results in circular or semicircular impressions with curved internal striations, not seen on the Olduvai specimens. Also, striking motions are unsuitable for piercing skin at precise locations, as generally required by this activity. Piercing a skin by striking a pointed stone tool against a bone anvil requires a relatively large and stable bone. Neither of the bones appears large enough, and the patella is very unsta-

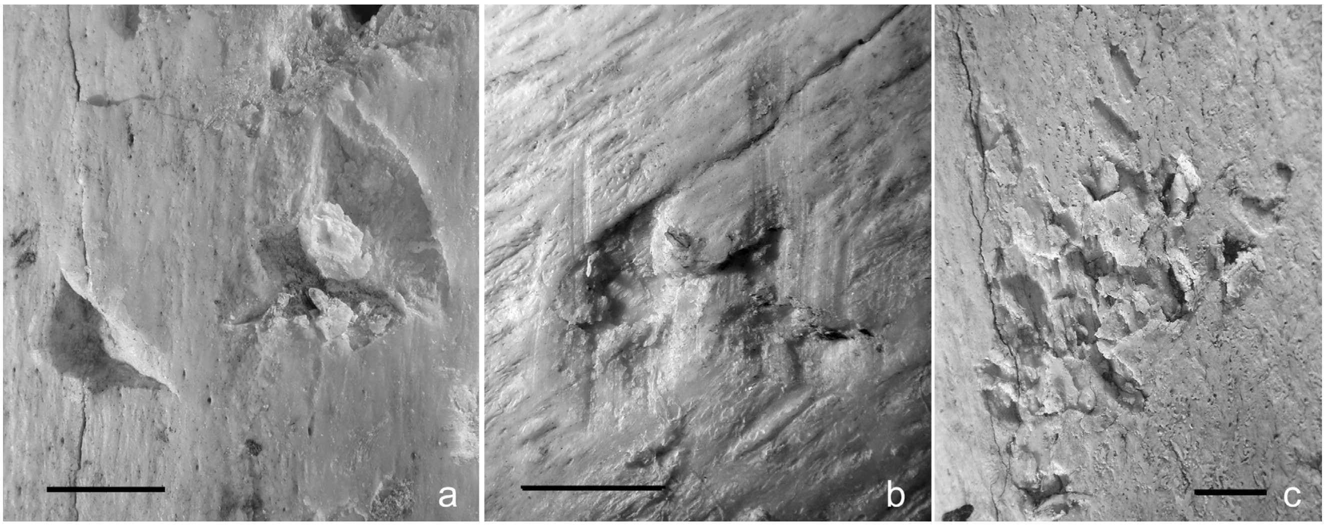

Figure 6. Puncture marks produced experimentally on fresh elephant bone; **a**, impressions of the stone tool tip associated (right) with chipping of the outer bone surface; **b**, impressions with composite striations; **c**, concentration of punctures with lifting of primary bone lamellae. Scale bars = 1 cm.

ble. The dispersed location of the punctures on the patella and the location of some impressions near the edge also cast doubt on the anvil interpretation, since the bone would have been destabilized by the striking force. We argue for now that the astragalus, and perhaps the patella, were instead used in single-session hammering tasks, most likely on intermediate stone wedges used to split bones, fruit or wood. Future research will include a wider range of actualistic studies, including observations of carnivore-generated bite marks and the impressions produced by a number of stone types and tip shapes.

The presence of crude choppers used as hammerstones and evidence of cut-marks and hammerstone-induced fractures on bones from the oldest levels of Bed I (DK), and their persistence through Bed II evidence the regular use of hammers in the subsistence activities carried out at Olduvai. In contrast, anvils occur only in Bed I (DK, FLK, FKLK North), while awls are recorded only in Bed II, appearing first in level 2 at HWK East, and later at SHK and BK, the reworked stream channel deposit.

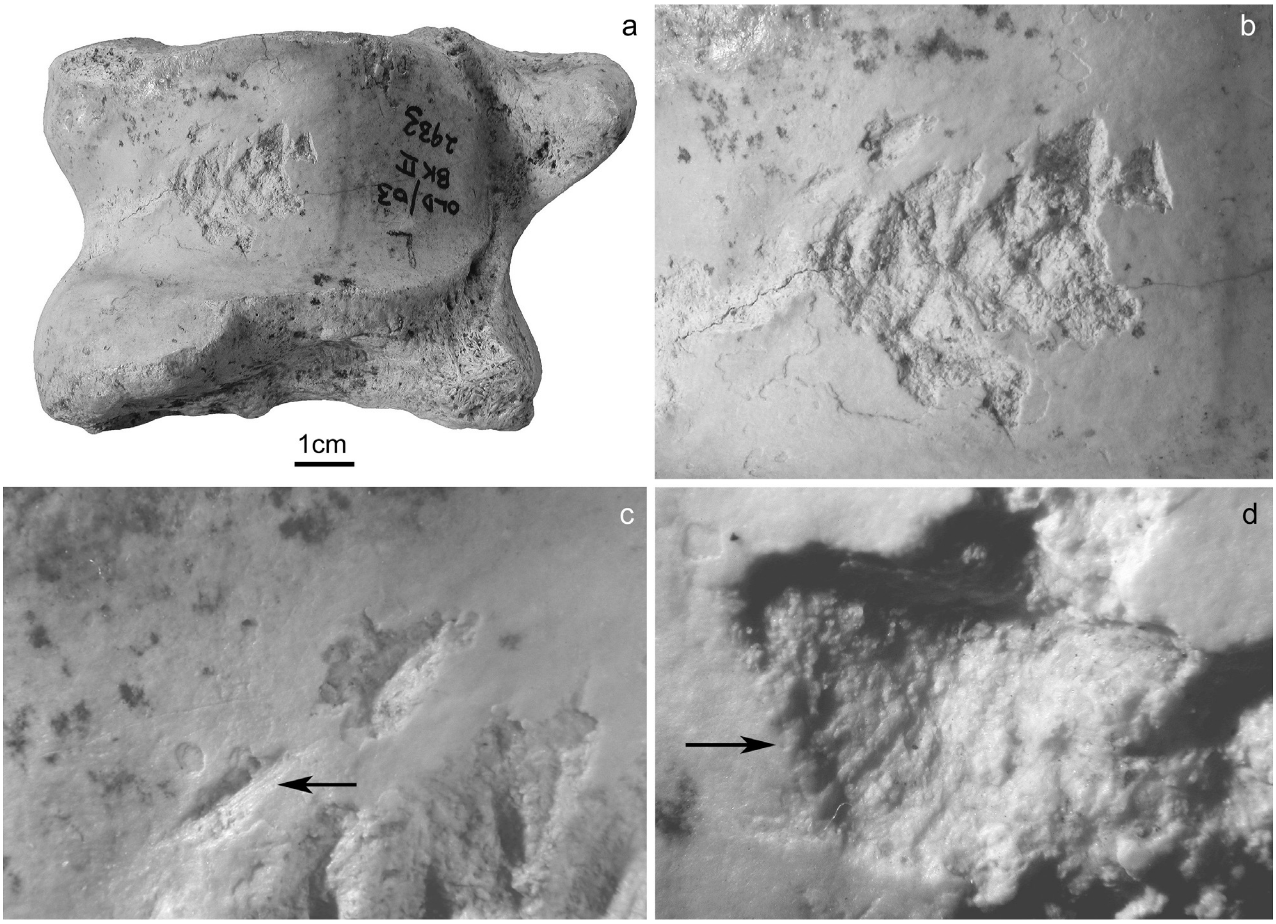

Figure 7. **a–b**, Astragalus from Olduvai (BKII 2933) with puncture marks, **c–d**, close up view showing striations associated with punctures (arrows).

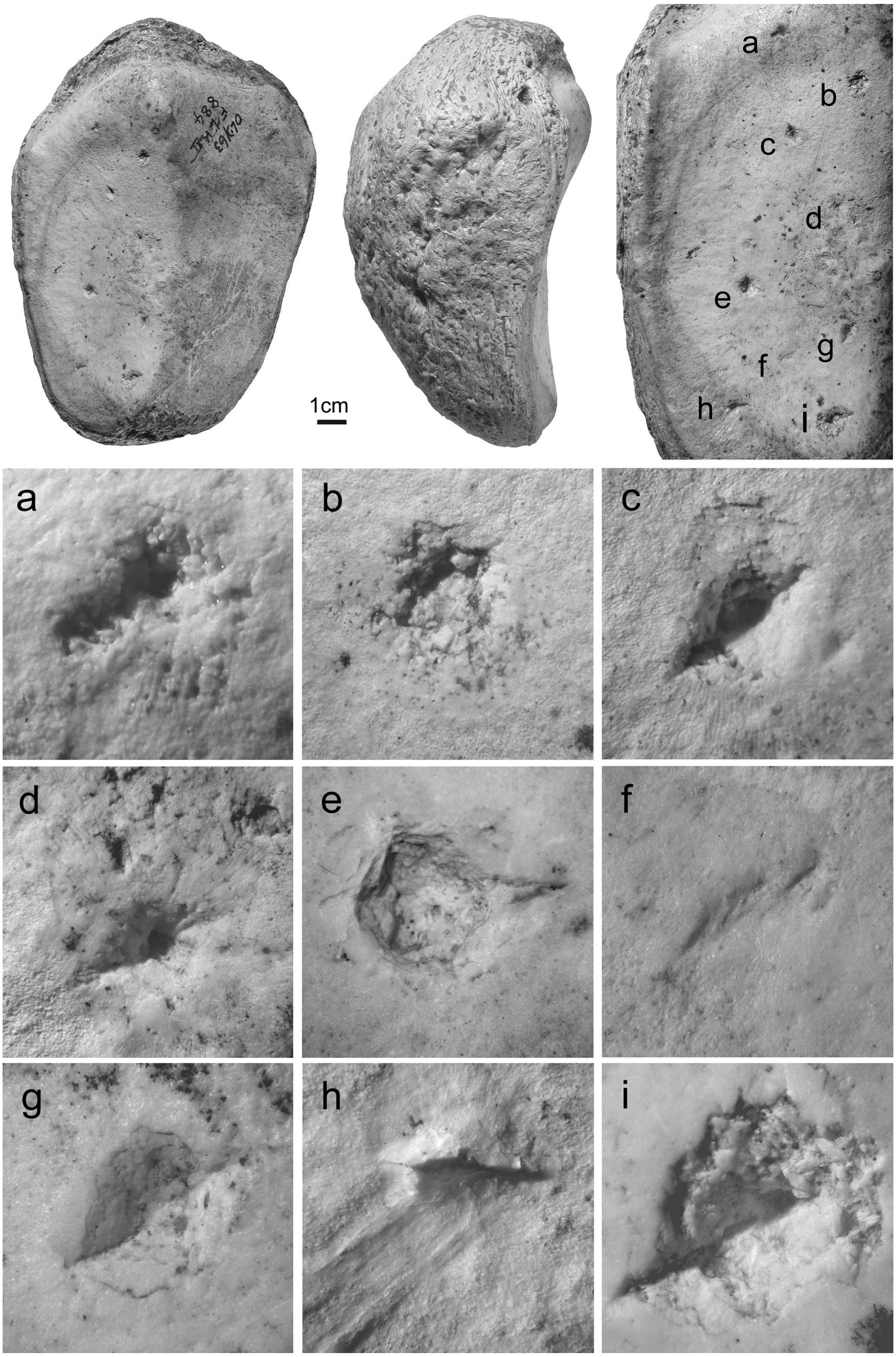

Figure 8. Elephant patella from Olduvai (FLKII 884) with punctures on the articular surface.; **a–i**, close up views of the puncture morphology.

Taphonomic and morphometric analysis

Experimental results

Four techniques were used by the students to break the bones (Table 3). The first involved lifting the bone while holding one epiphysis and repeatedly striking the opposite epiphysis against a rock. This produced in one case a mid-shaft break with no flakes, and in three other cases, breakage with numerous flakes. The second technique entailed throwing the bone repeatedly against a rock. This was used for two bones, which both produced flakes. The third, employed by females, involved throwing a rock at the bone. To avoid the absorption of the striking force by the ground, two bones were stabilized between two rock outcrops, and another inclined against a separate rock. The break of the former produced no flakes in one case and many in the other, while that of the latter resulted in numerous flakes. The fourth technique, attempted by females, consisting of striking the bone with a hand-held rock, was unsuccessful in bone breakage. Once the bones

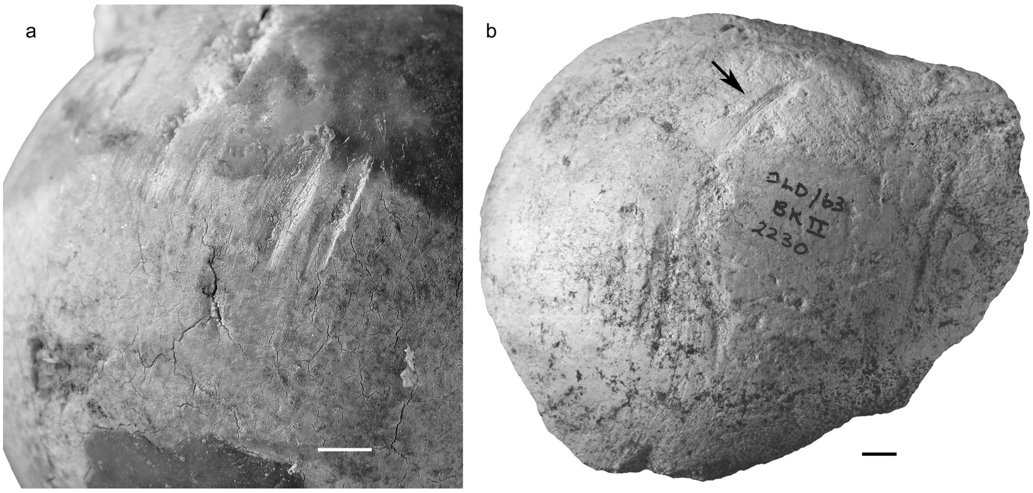

Figure 9. **a**, Head of a modern elephant femur showing scrape marks produced by striking the epiphysis against a rock; **b**, femoral head from Olduvai specimen BKII 2230 bearing weathered carnivore tooth notches, scores and pits as well as a modern scrape mark (arrow).

were broken, students attempted to detach more flakes from the epiphyses by throwing the bones against rocks, rocks against the bones or by using stone wedges. This, however, resulted in the production of very few additional flakes. Shaping the flakes by knapping was also attempted.

Percussion and scrape marks

Half of the flakes bear multiple large percussion marks (Fig. 6), and 23% bear chop marks. Virtually all the pieces with chop marks also have punctures, while only a third of the punctured flakes are associated with chop marks. The epiphyses of the bones struck against rocks show distinct parallel scrape marks resulting from their tangential impact caused by unskilled striking motions (Fig. 9a). The experimentally-produced scrape mark is characterized by parallel grooves with a spindle-like shape, and clear internal striations. A number of Olduvai epiphyses show traces of carnivore scoring which may be confused with strike marks (Fig. 9b). Carnivore marks, however, are seldom parallel, may be curved, do not have clear internal striations, and generally terminate abruptly at one end.

Flake analysis

Breakage of the nine elephant limb bones produced 134 flakes. Data were recorded on 107 of these pieces. Two bones produced no flakes, while the remainder produced between six and 29 flakes each, the highest figure deriving from the weathered bone.

Flakes can be divided into two broad categories; those made exclusively of compact bone (Fig. 10) and those retaining spongy bone (Figs 11 & 12). The compact bone includes slivers resulting from the detachment of primary cortical bone (Fig. 10: Nos 6–10, 14), spindle-like thicker splinters (Fig. 10: Nos 4–5), and rectangular blanks that are flat on the ventral and dorsal aspects (Fig. 10: Nos 2, 3, 11,12). One sliver-like flake is noteworthy (Fig. 10: No. 7) in that it demonstrates that very large blanks made of compact bone (26 × 10 cm) can result from the breakage of very large mammal bone when struck against rocks for the exclusive purpose of marrow extraction. The flakes with spongy bone include large elongated shaft fragments with rounded or pointed ends that retain between half and one third of the shaft section (Fig. 11), and irregularly-shaped chunks with a considerable proportion of cancellous bone (Fig. 12).

Table 5. Dimensions of flakes produced during the experimental breakage of elephant limb bones.

Flake dimensions	Mean $n = 107$	S.D. mm	Minimum mm	Maximum mm
Length	139	76.6	23	385
Width	50	25.5	10	125
Maximum thickness	21	12.1	2	52
Compact bone thickness	16.5	9.2	2	44

Data on the dimensions of the flakes are given in Tables 5 & 6 and Fig. 13. Results indicate that the frequency of flakes in the different size classes remains constant in all bones, with the exception of the weathered bone (Table 6, no. 5), which shows an over-representation of elongated flakes. This difference does not correspond to a change in the general size of the flakes, as demonstrated by the scattergram (Fig. 14) correlating the flake width and length. This scattergram also shows that the size of the flakes is not determined by the bone type or by the breakage technique.

Pseudo-retouch

Fifteen flakes (14%) show removals/flake scars that may be taken as evidence for deliberate shaping (Table 7). Six bear a single removal, seven bear between two and five removals, and only two pieces have eight removals. Removals occur more often on the periosteal surface (eight cases) than on the medullar (three cases). Four pieces have removals on both periosteal and medullar surfaces. Isolated removals generally do not exceed one per specimen, while multiple removals are in almost all cases found in association. Results also show that removals occur more often on the ends of flakes than on their sides. At close inspection, however, only a few of these removals may be taken as negatives of flakes produced by knapping. This is because they lack features that would indicate that percussion was applied. One piece, for example, presents a

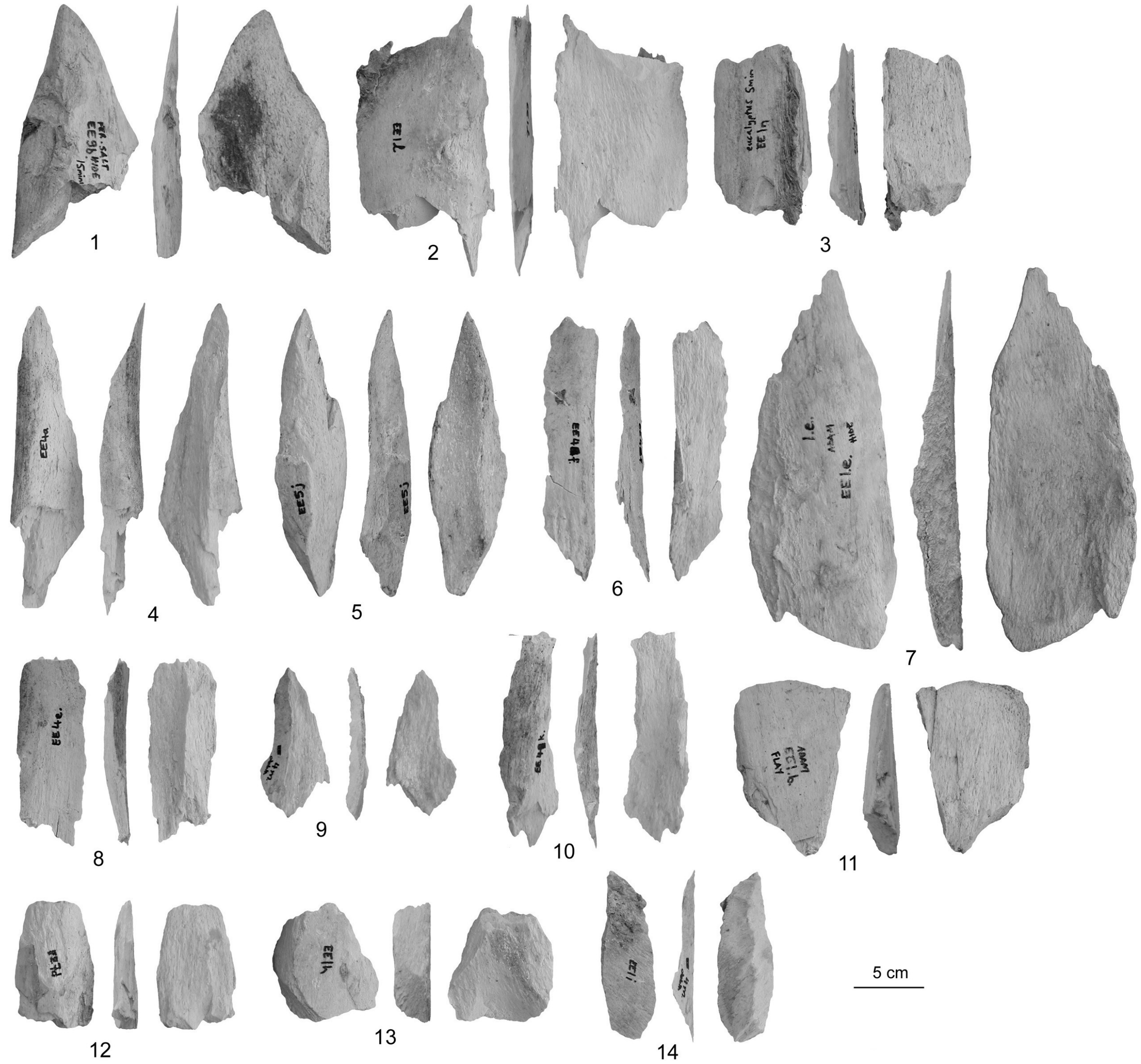

Figure 10. Cortical bone flakes produced by the experimental breakage of elephant limb bones.

wedge-like breakage with opposing flat scars that lack a negative bulb of percussion (Fig. 15a). Another, resulting from the breakage of the weathered bone, has scars due to the lifting of primary bone lamellae opposite to irregularly shaped scars (Fig. 15b). This morphology, difficult to accept as evidence of purposeful modification, is as to be expected, the result of the state of preservation of the bone. Two pieces require special attention. One is a large flake with a pointed end bearing overlapping removals that mimic the tip of a dihedral burin (Fig. 15c). The other is a large flake with a remarkable hand axe-like morphology with contiguous pseudo-removals on both ends that

Table 6. Length of the flakes from experimentally broken elephant bones.

Bone No.	Flake length (cm)								
	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	Total
1	1	9	5	2	4	2	0	0	23
2	2	8	1	1	1	0	2	1	16
3	0	2	4	0	0	1	0	0	7
4	0	5	7	3	1	1	1	0	18
5	1	9	8	6	1	4	0	0	29
6	0	0	0	0	0	0	0	0	0
7	0	3	0	2	0	1	0	0	6
8	0	0	0	0	0	0	0	0	0
9	2	2	2	1	1	0	0	0	8
Total	6	38	27	15	8	9	3	1	107

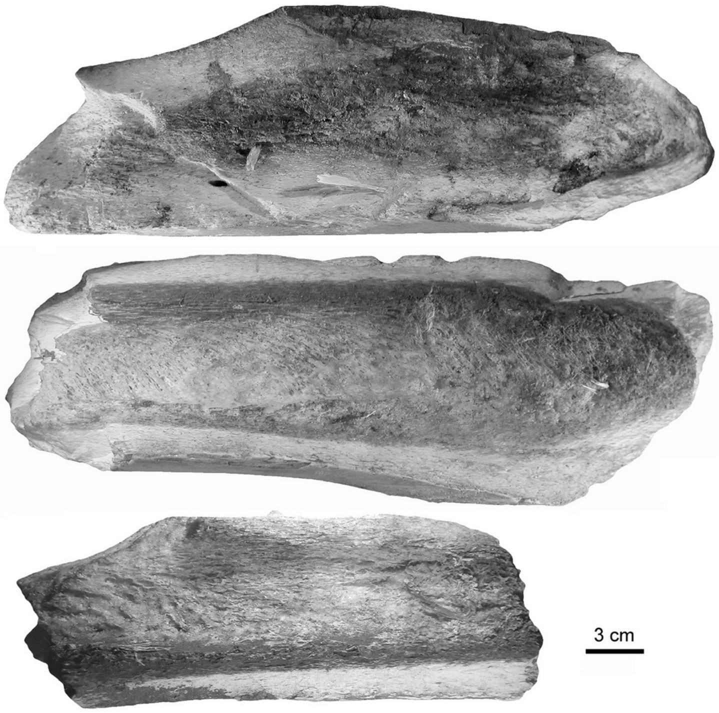

Figure 11. Large bone flakes produced by the experimental breakage of elephant limb bones with a large proportion of spongy bone.

mimic pseudo bifacial shaping at its base (Fig. 16). In spite of its general resemblance to an Acheulean stone hand axe or to one of the Acheulean elephant bone hand axes from the Italian sites (Radmilli 1985; Radmilli & Boschian 1996), this piece has no invasive contiguous bifacial scars.

Experimental shaping by knapping

Knapping of the elephant bone flakes using quartzite and dolomite blocks, attempted by the students shortly after the bone breakage, was unsuccessful. The students were, however, unskilled knappers and the available hammers seemed to be unsuitable for the task. Subsequent knapping, made by one of us (F.D.) using elongated quartzite pebbles weighing *c.* 500 g, took place one year after the breakage experiment, when the bone flakes had dried considerably. Flakes from bones fresh at the time of breakage experiments were difficult to knap, and split longitudinally. The results obtained after soaking them in water for two days were no better. Knapping was successful on shaft fragments resulting from bone weathered at

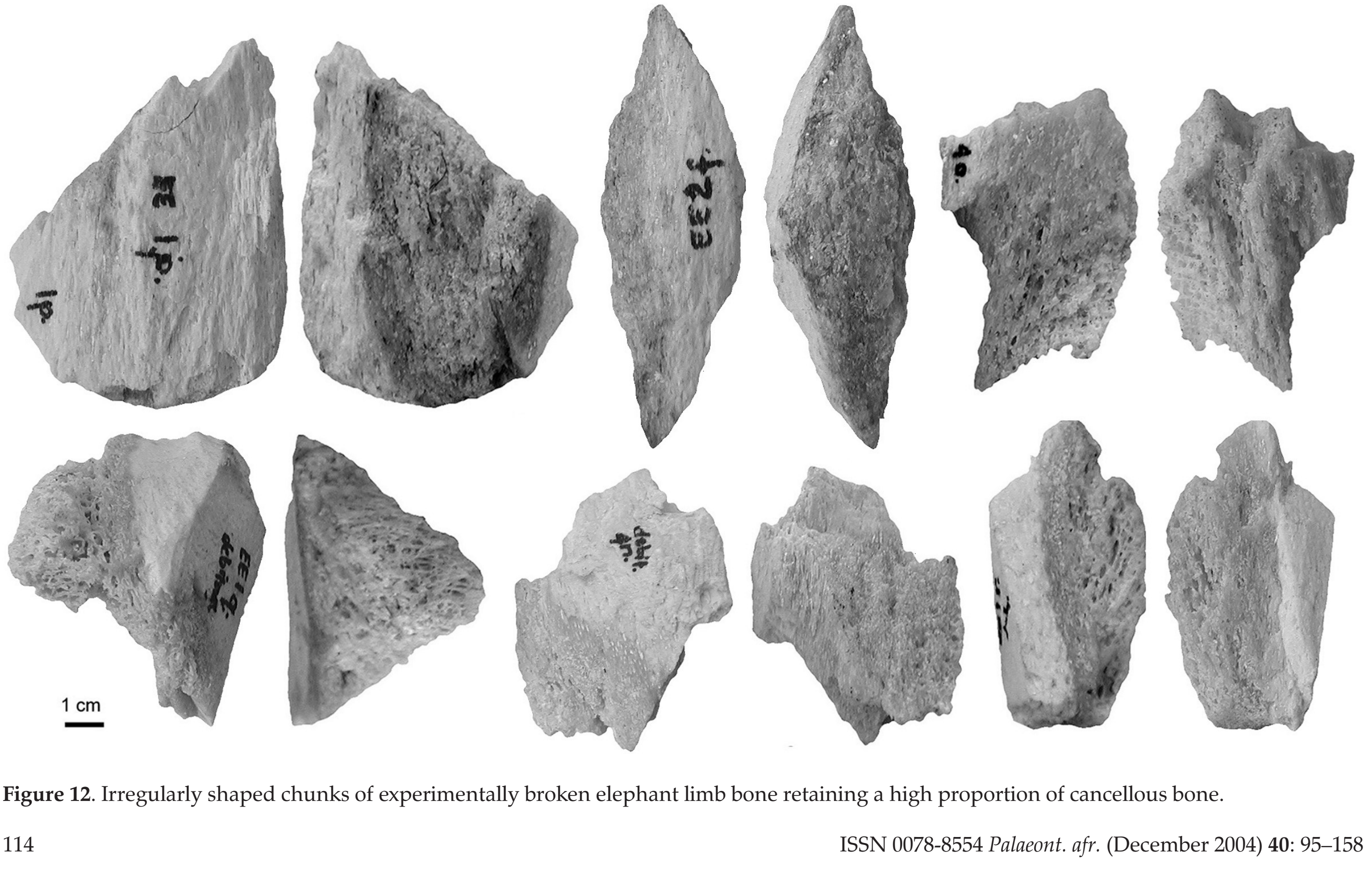

Figure 12. Irregularly shaped chunks of experimentally broken elephant limb bone retaining a high proportion of cancellous bone.

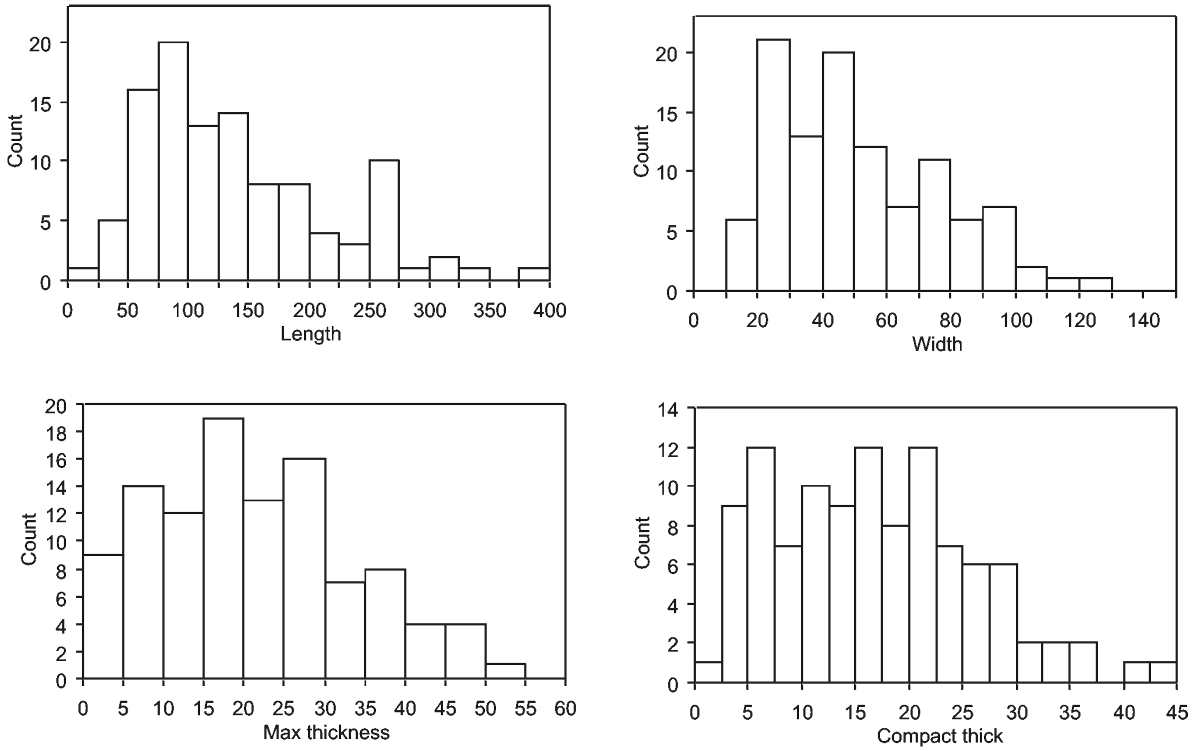

Figure 13. Histograms of the dimensions of flakes produced during the experimental breakage of elephant bone.

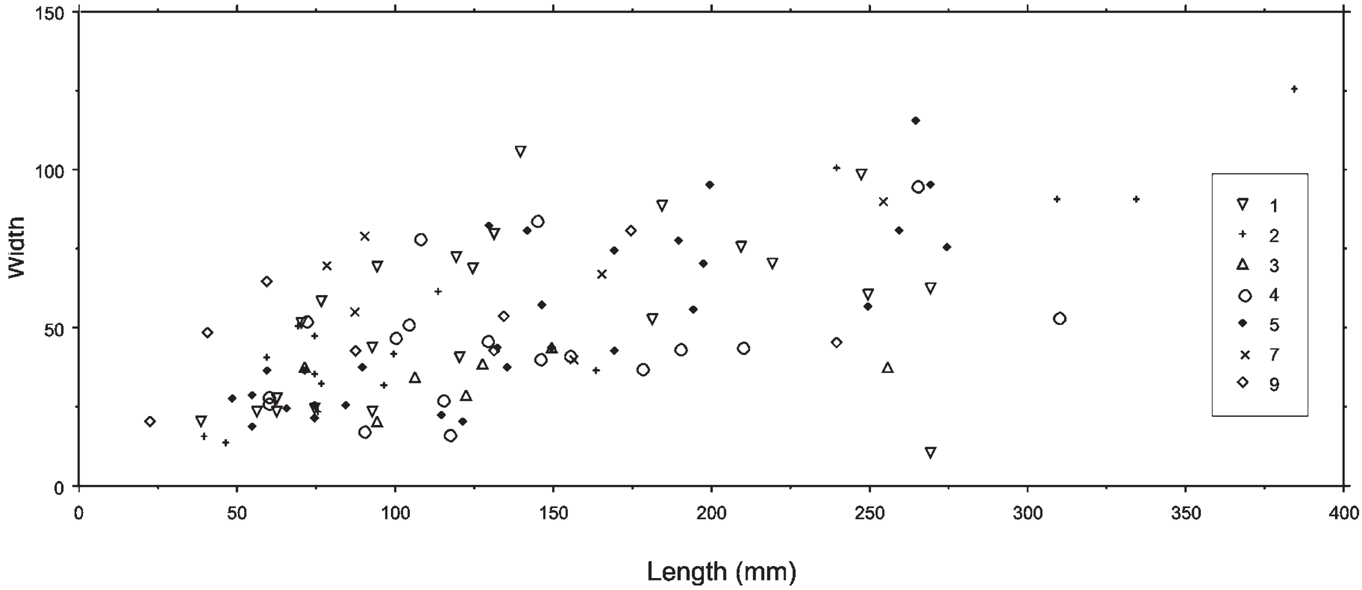

Figure 14. Length/width correlation of the flakes produced during the experimental breakage of elephant bone. Symbols indicate flakes from the same bone (see Table 3 for the bone type and the breakage technique used).

Table 7. Number, association and location of removals on the periosteal and medullar surfaces of flakes produced by the experimental breakage of elephant limb bones.

No. rem. per flake	No. of flakes with removals			Association				Location					
				Periosteal		Medullar		Periosteal			Medullar		
	Total	Peri.	Med.	Isolated	Cont.	Isolated	Cont.	End	End+side	Side	End	End+side	Side
0	92	95	100	103	99	101	106	97	105	106	103	106	105
1	6	4	5	4	0	5	0	3	0	1	3	0	2
2	2	3	0	0	3	0	0	2	1	0	0	0	0
3	1	0	1	0	0	1	0	0	0	0	0	1	0
4	2	3	1	0	3	0	1	2	1	0	1	0	0
5	2	1	0	0	1	0	0	1	0	0	0	0	0
8	2	1	0	0	1	0	0	1	0	0	0	0	0

rem: removals; Peri: periosteal; Med: medulla; Cont: contiguous.

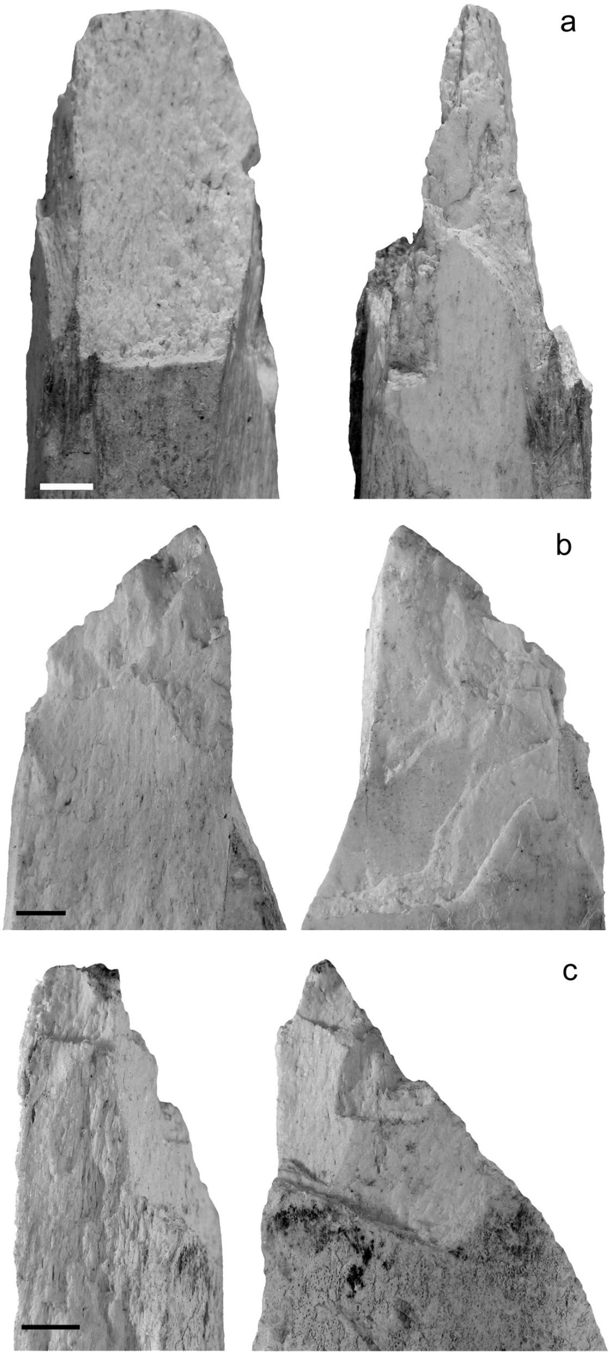

Figure 15. Pseudo-removals resulting from experimental breakage of elephant bones.

the time of the experimental breakage (Fig. 17). The large invasive removals obtained exhibit, however, a rough surface (Fig. 17b–c) different from the fine-grained texture recorded on the scars on many Olduvai purported bone tools. Also, the fracture surface is different, in that after producing a concoidal-like negative, it progresses inward, with its orientation determined by that of the bone lamellae. This gives a portion of the scar a flat appearance not seen at Olduvai.

Olduvai

Leakey bone tool collection and comparative sample composition

The purported bone tool collection we analyse here comprises 106 specimens. Teeth and tusks, as well as complete bones, are not the subject of this paper and complete bones bearing punctures have been analysed above. The photographs of the analysed material are presented in Figs 18–46, by site in alphabetical and numerical order. Most of the analysed pieces are limb bone flakes and shaft fragments (62%). The remainder consists of epiphyses with or without a portion of the diaphysis. Nearly 80% of the pieces come from large to very large mammals (Fig. 47). Owing to their fragmentary nature, most of them are difficult to identify to taxon level. The most commonly identified animals in order of abundance are giraffids, equids, bovids, elephantids, hippopotamids, and rhinocerotids. Our comparative sample is instead mostly composed of flakes and shaft fragments from medium-sized mammals, particularly bovids (Fig. 47). This is because outside of the bone tool collection, the Olduvai assemblage comprises very few large limb bone fragments, making impossible the construction of a more appropriate comparative sample.

Bone preservation and surface modifications

The bone tool collection is generally characterized by an excellent state of preservation. The large majority of the pieces (Table 8) are either fresh (44%) or slightly abraded (40%). Post-depositional breaks and scars, mostly due to excavation and handling, account for 23% and 13% of the collection, respectively. Almost all of the bones underwent a rapid burial process; 48% show no weathering, and 45% show a weathering stage 1 (Behrensmeyer 1978). A moderate degree of trampling and polishing affects *c.* 21% of the pieces. The majority of the pieces have spiral fractures, indicating that the bone was fresh when broken. Hominids are the agent most likely to have been responsible for the breakage, considering that 30% of the bone tool collection bears either cut-marks or clearly lithic-derived punctures (Fig. 48a–e), and an additional 3% bears a combination of both modifications (Table 9).

Carnivore marks, although occurring on 25% of the collection, only consist of superficial tooth scores and pits. No evidence of destruction of epiphyses by gnawing, crenulated edges or a combination of these features

Table 8. Bone surface modifications on Olduvai bones.

Collection	No. pieces	Surface modifications					Weathering stage			Degree of abrasion				Post deposition	
		Carn.	Cut-mark	Perc.	Tramp.	Polish	0	1	2	Fresh	Slight	Mod.	Heavy	Break	Rem.
Control	82	2	10	7	28	3	58	23	1	41	32	8	1	17	2
Leakey/Ship.	106	26	15	22	24	22	51	48	7	46	42	14	3	25	14

Ship: Shipman; Carn: carnivore tooth marks; Perc: percussion marks; Tramp: trampling: Mod: moderate; Rem: removal

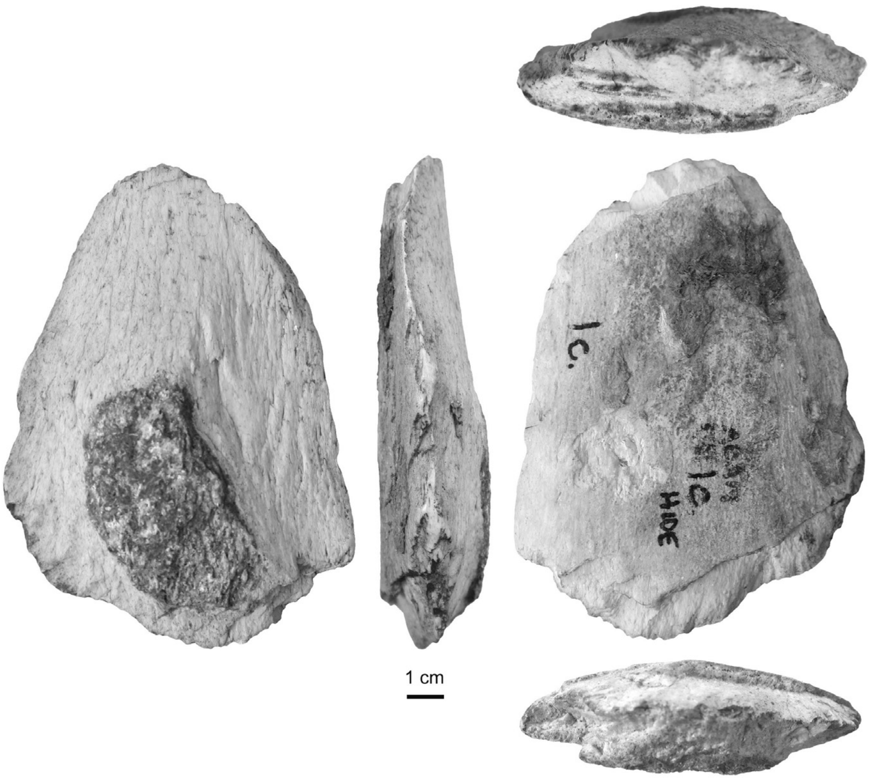

Figure 16. Bone flake resulting from experimental breakage of elephant limb bones with a hand axe-like morphology.

with impact notches is found, suggesting that carnivore involvement was limited and post-dated bone breakage. Figure 48f illustrates the most extreme example of carnivore damage recorded. Carnivore-, percussion-, and cut-marks occur on all bone types and mammal size classes. Their absence from the bones of small mammals is certainly due to the very low proportion of such bones in the sample.

The above surface modifications occur in the Olduvai control sample in proportions that are not significantly

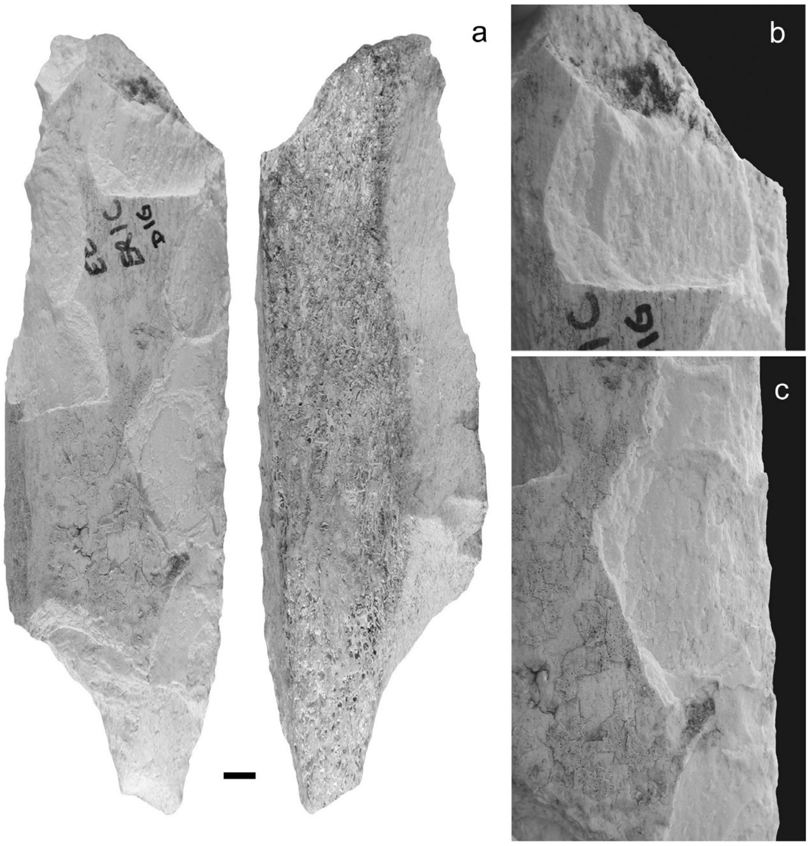

Figure 17. a, Experimental knapping of a shaft fragment from a weathered elephant bone; **b–c**, close up view of the scars.

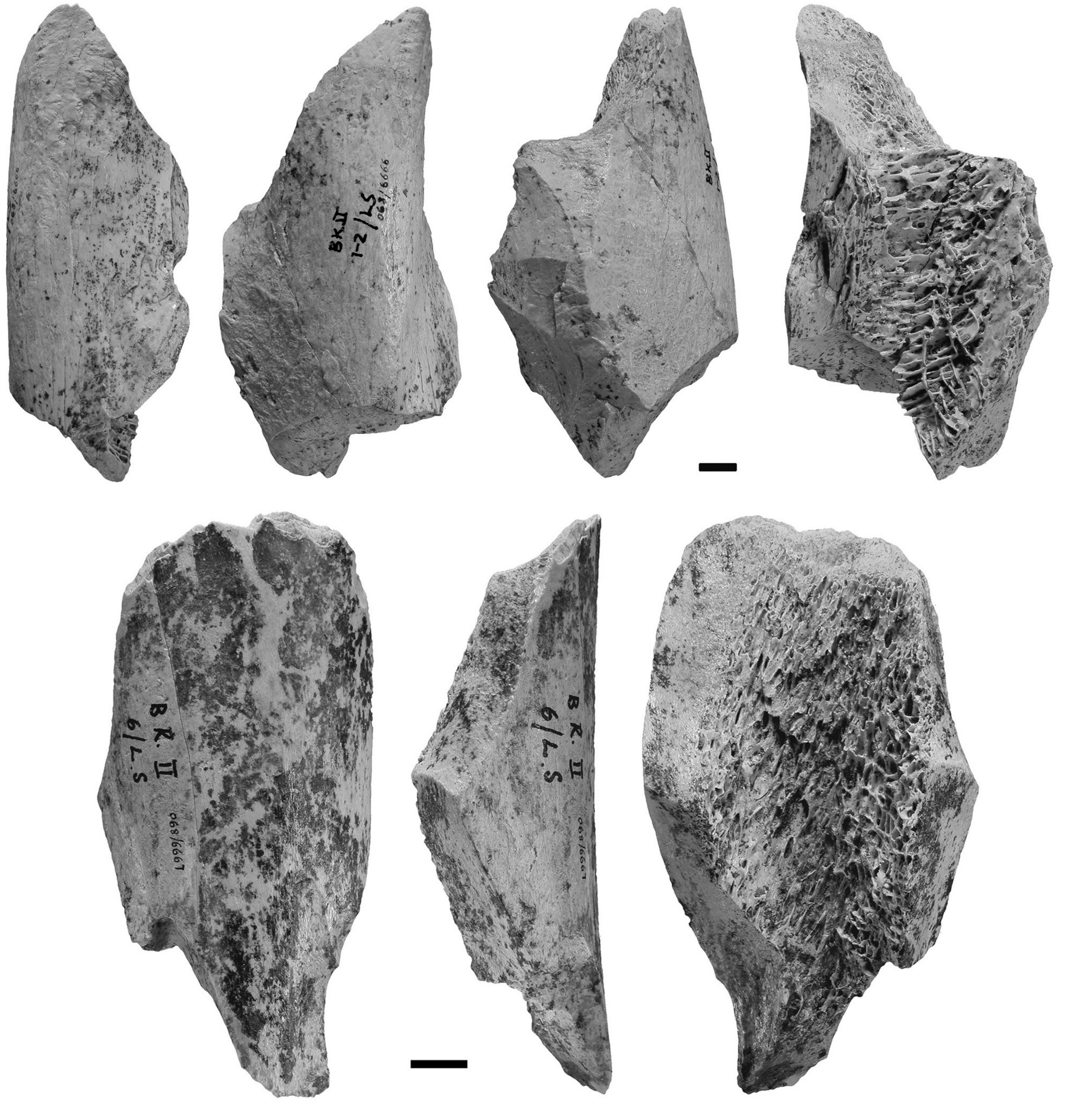

Figure 18. Olduvai bone tools proposed by Leakey. *BKII 068–6666 (**top**), BKII 068–6667 (**centre**) and *BKII 068–6668 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

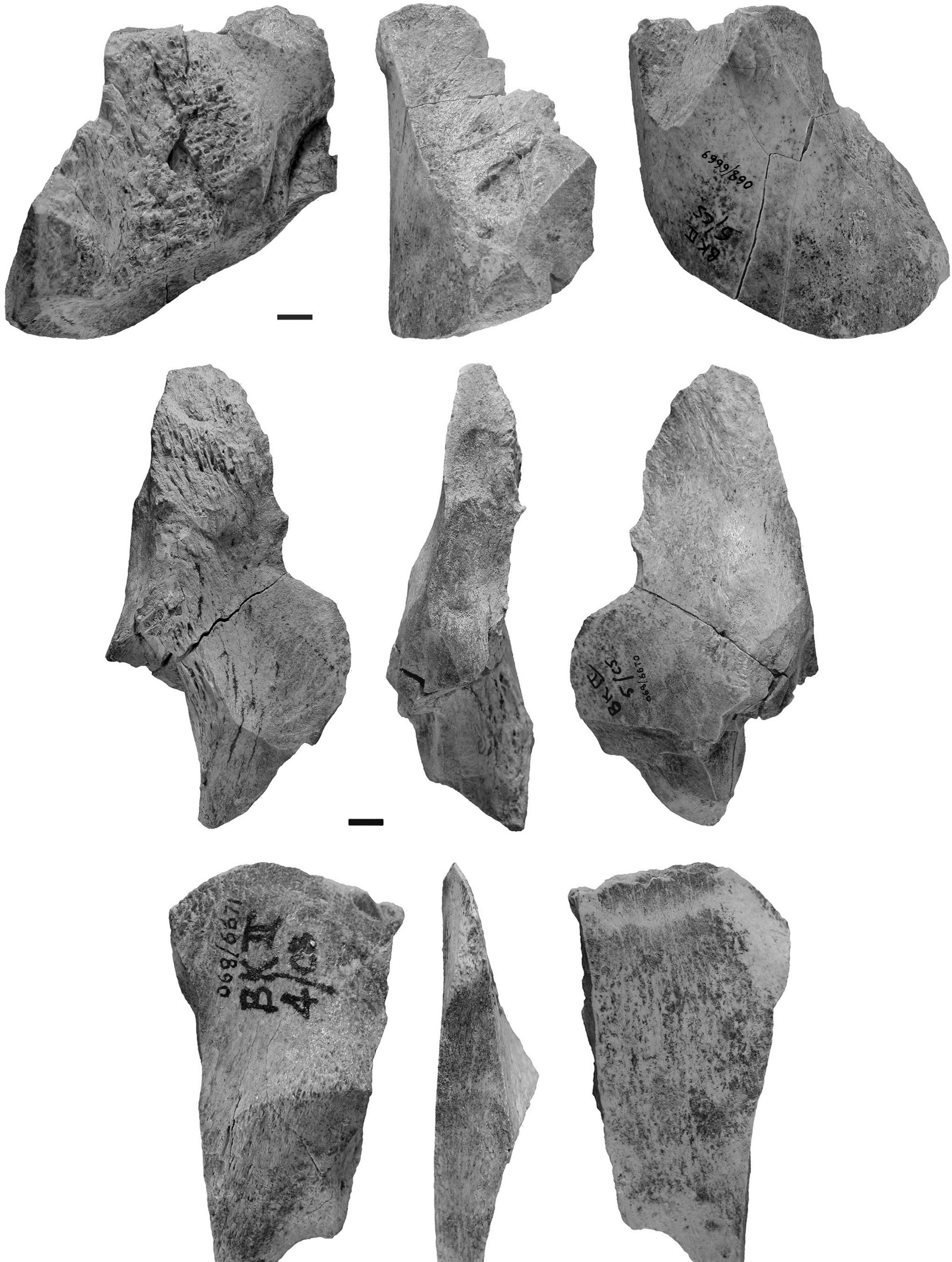

Figure 19. Olduvai bone tools proposed by Leakey. BKII 068–6669 (**top**), *BKII 068–6670 (**centre**) and BKII 068–6671 (**bottom**). Scale bars = 1cm. An asterisk indicates a bone tool according to this study.

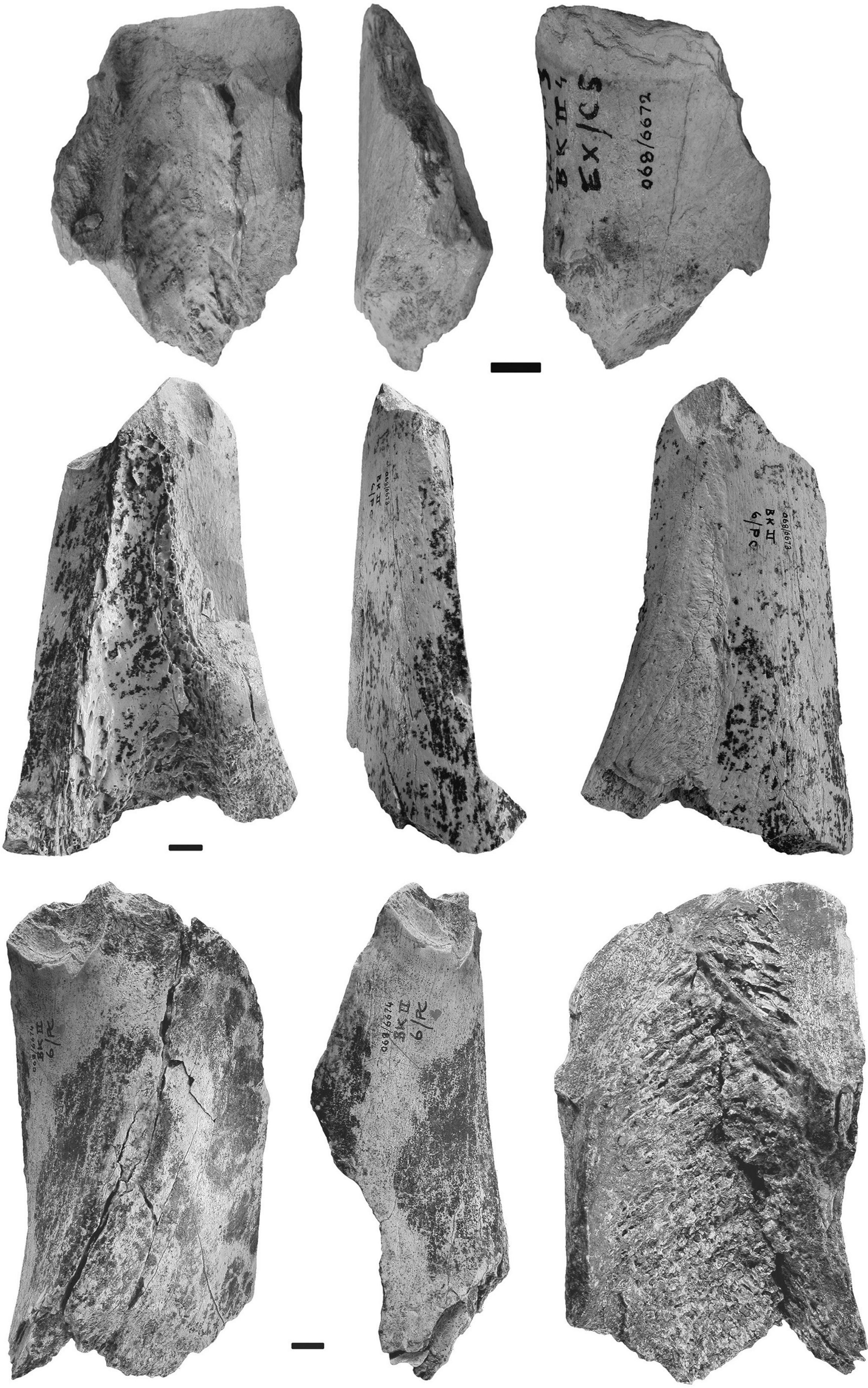

Figure 20. Olduvai bone tools proposed by Leakey. BKII 068–6672 (**top**), BKII 068–6673 (**centre**) and BKII 068–6674 (**bottom**). Scale bars = 1cm.

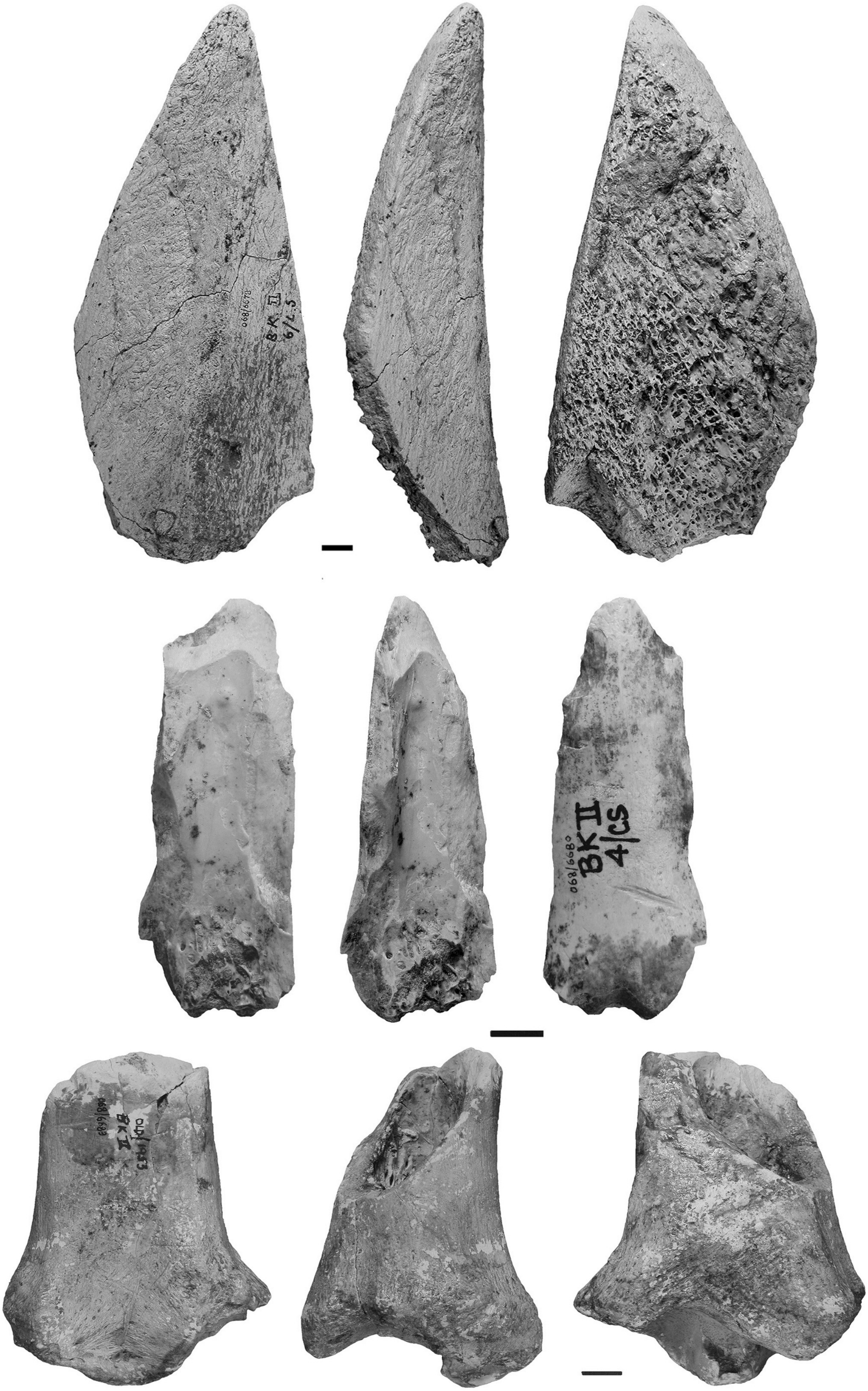

Figure 21. Olduvai bone tools proposed by Leakey, BKII 068–6678 (**top**), BKII 068–6674 (**bottom**), and by Leakey and by Shipman BKII 068–6673 (**centre**). Scale bars = 1 cm.

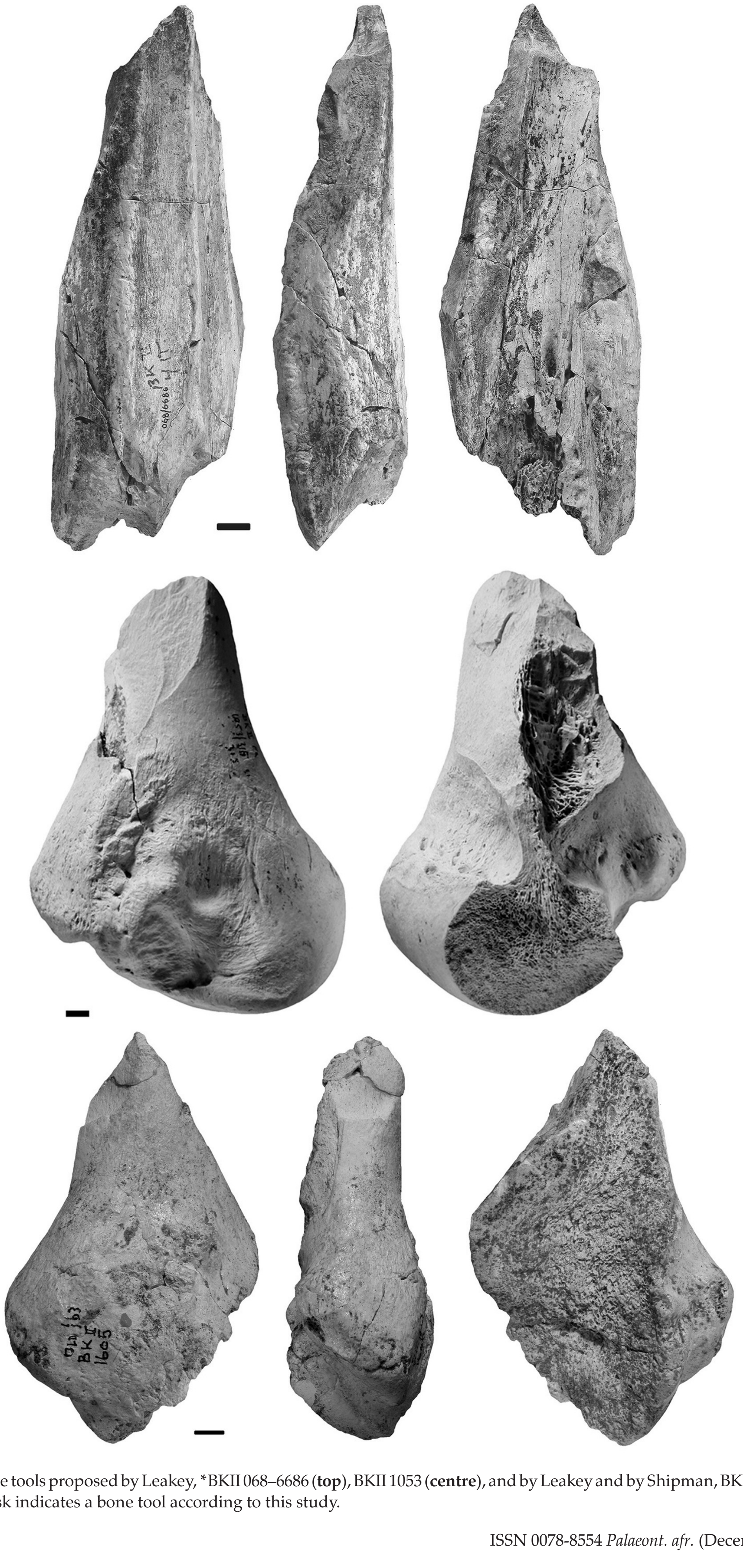

Figure 22. Olduvai bone tools proposed by Leakey, *BKII 068–6686 (**top**), BKII 1053 (**centre**), and by Leakey and by Shipman, BKII 1605 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

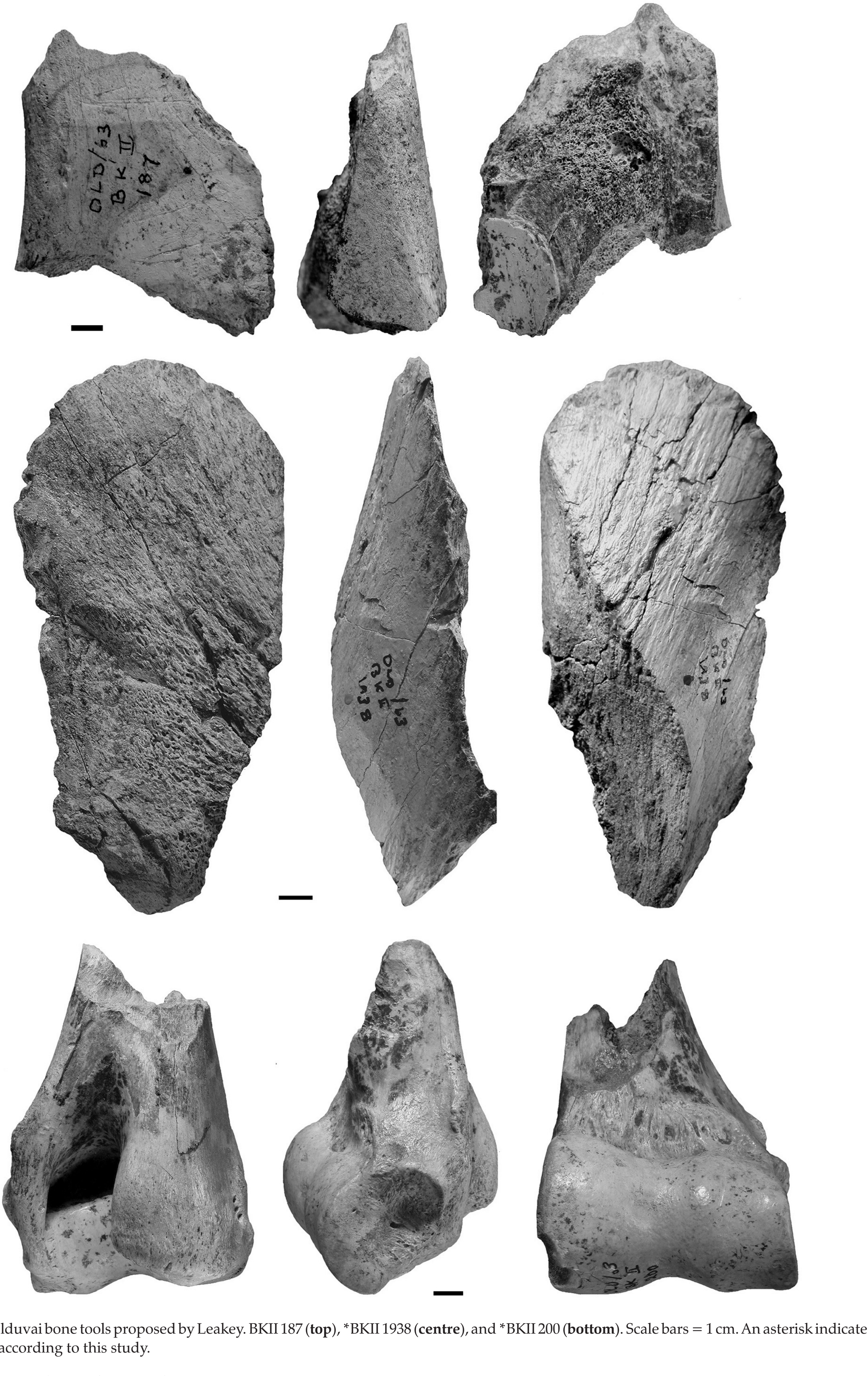

Figure 23. Olduvai bone tools proposed by Leakey. BKII 187 (**top**), *BKII 1938 (**centre**), and *BKII 200 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

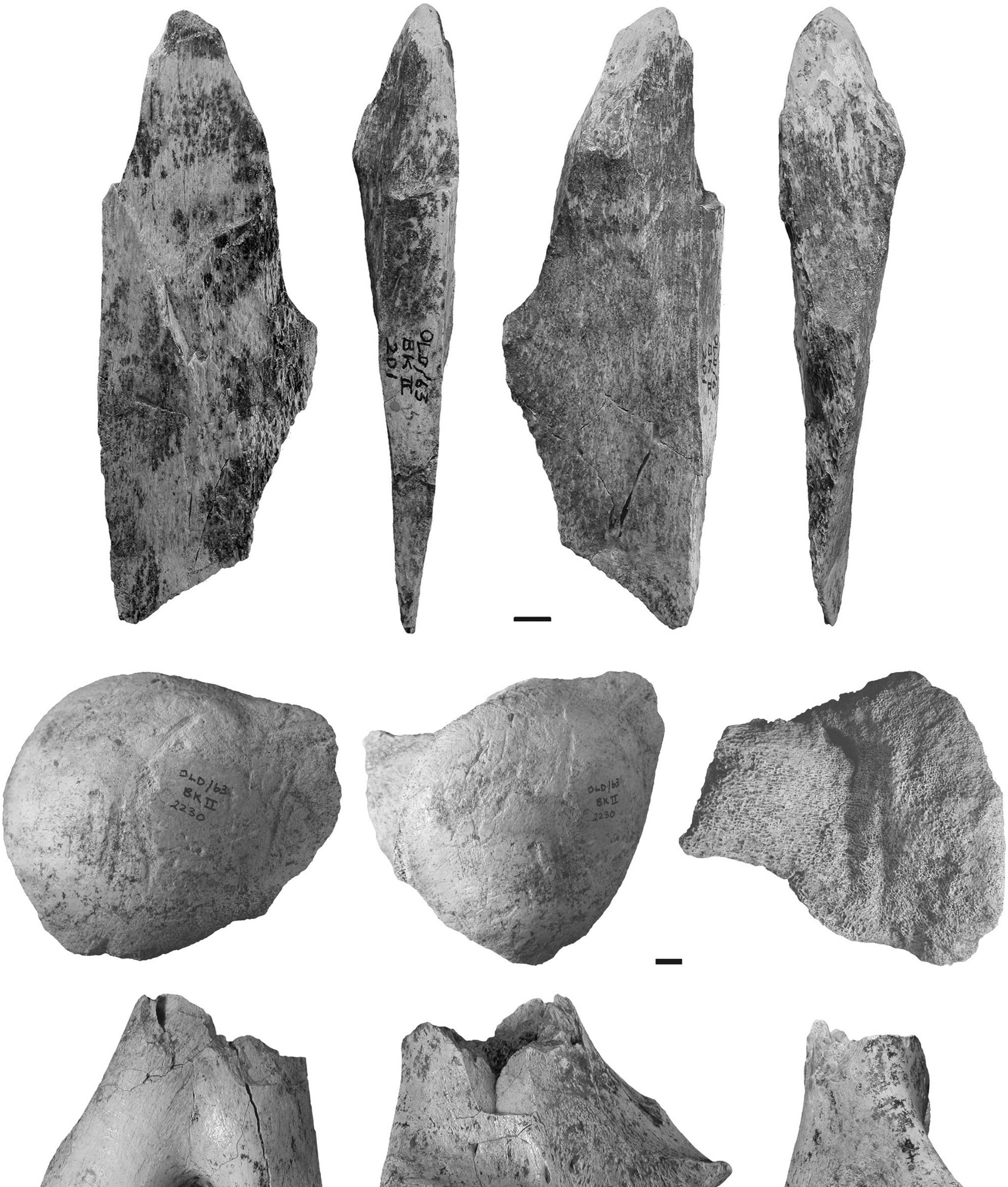

Figure 24. Olduvai bone tools proposed by Leakey. *BKII 201 (**top**), BKII 2230 (**centre**), and *BKII 2382 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

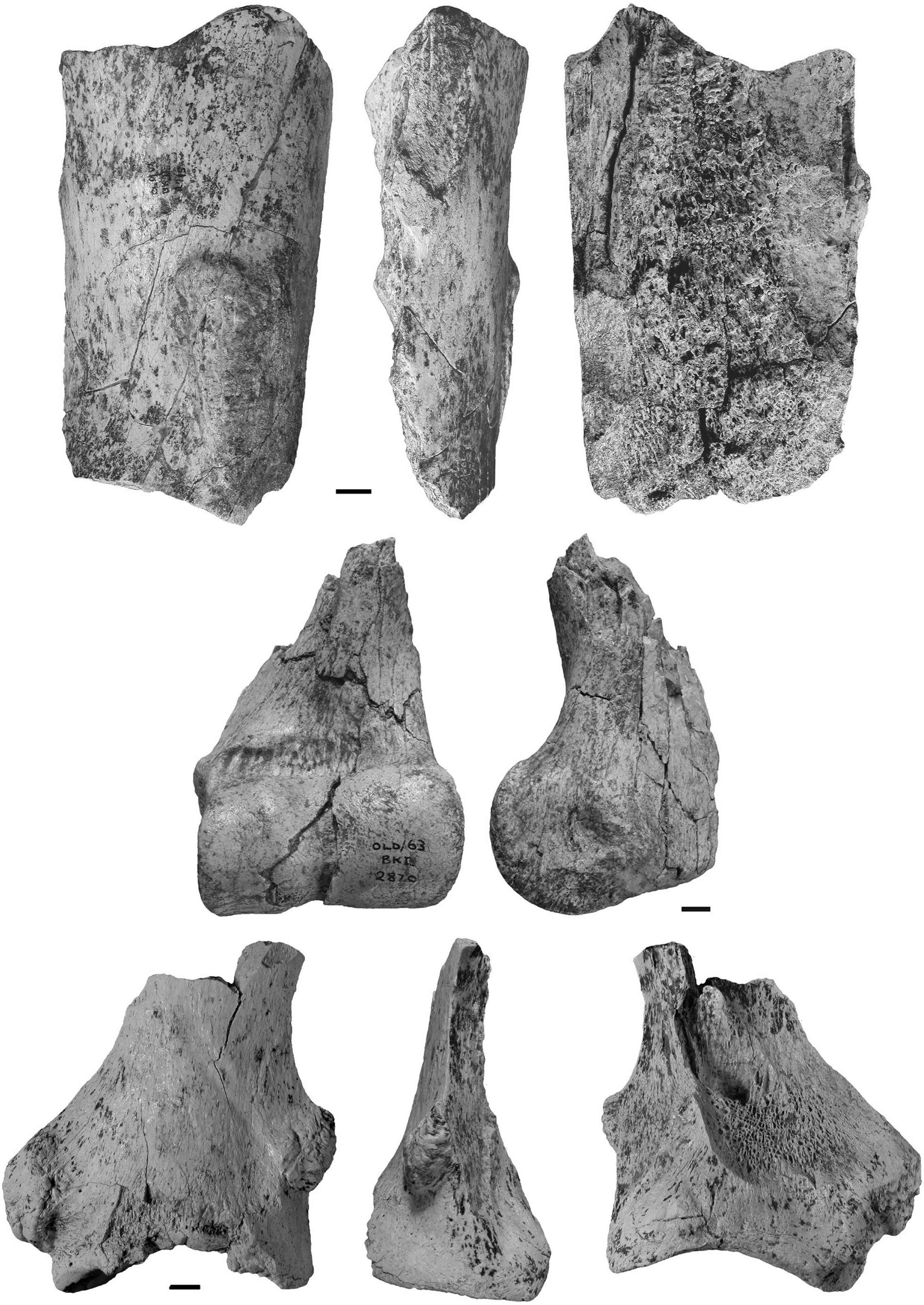

Figure 25. Olduvai bone tools proposed by Leakey, *BKII 2715 (**top**) and BKII 2959 (**bottom**), and by Leakey and by Shipman, BKII 2870 (**centre**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

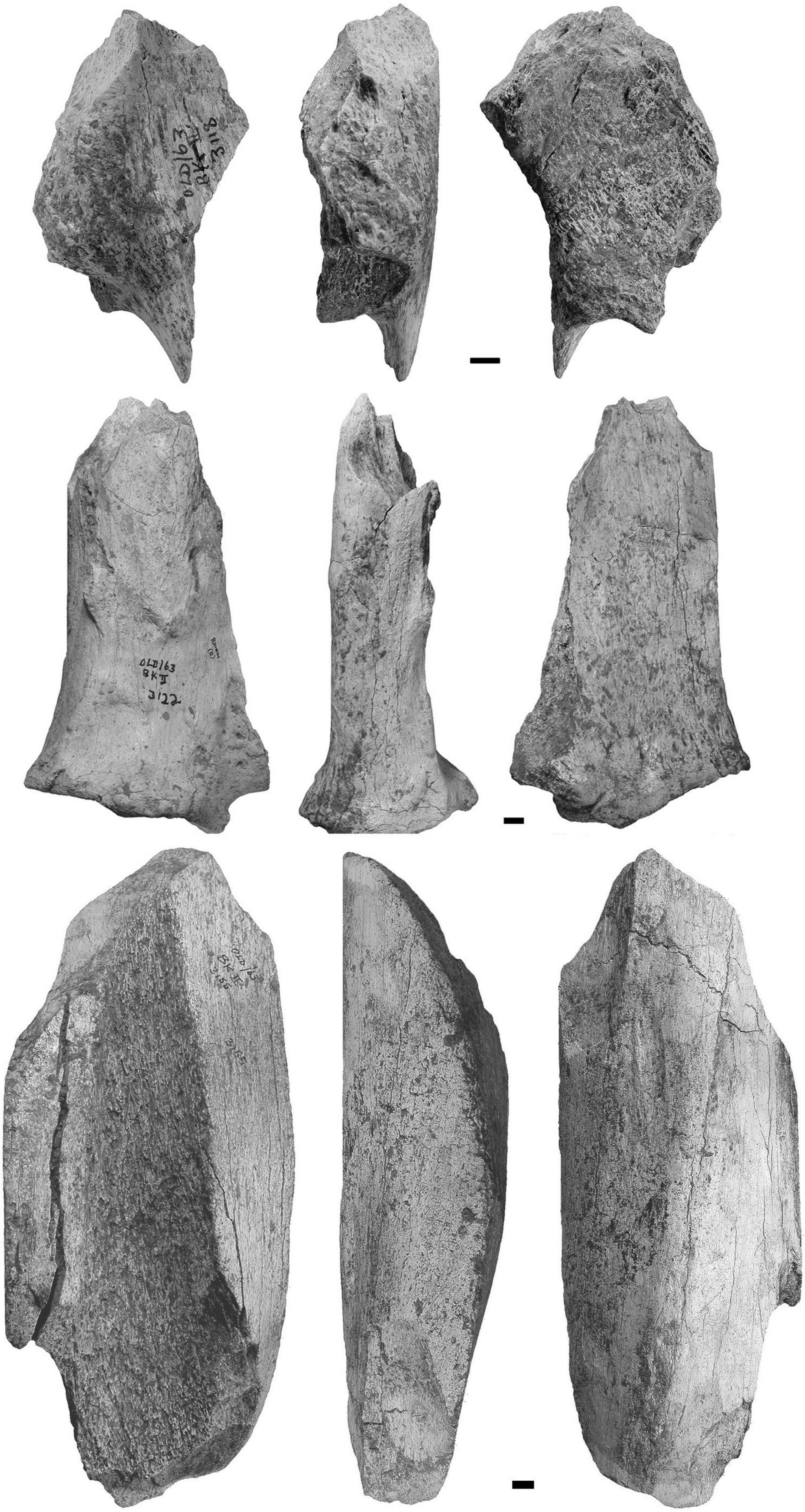

Figure 26. Olduvai bone tools proposed by Leakey, BKII 3118 (**top**) and BKII 3122 (**centre**), and by Leakey and by Shipman, *BKII 3155 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

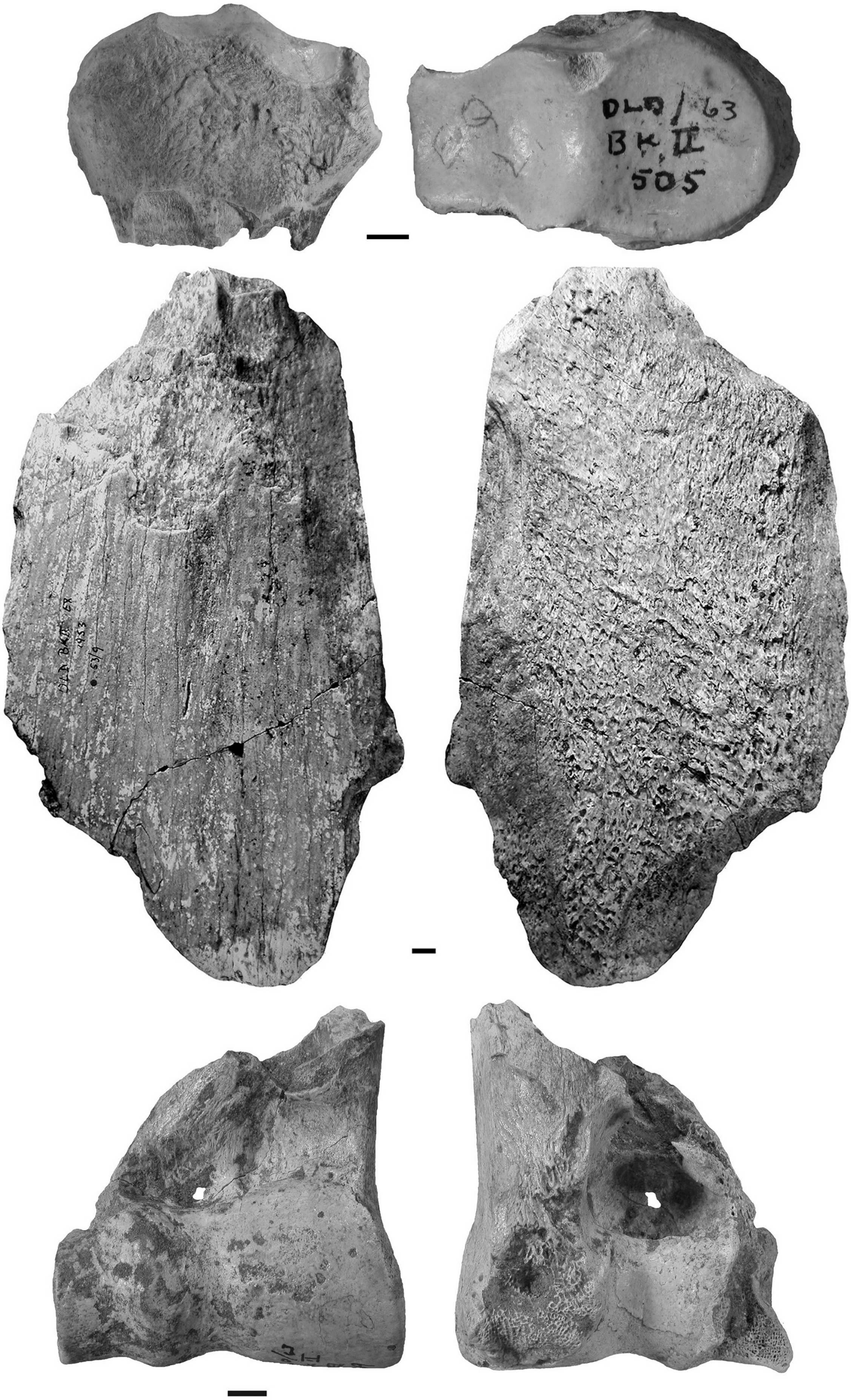

Figure 27. Olduvai bone tools proposed by Leakey, BKII 505 (**top**), *BKII 1953 or 53–9 (**centre**), and by Leakey and by Shipman, BKII 869 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

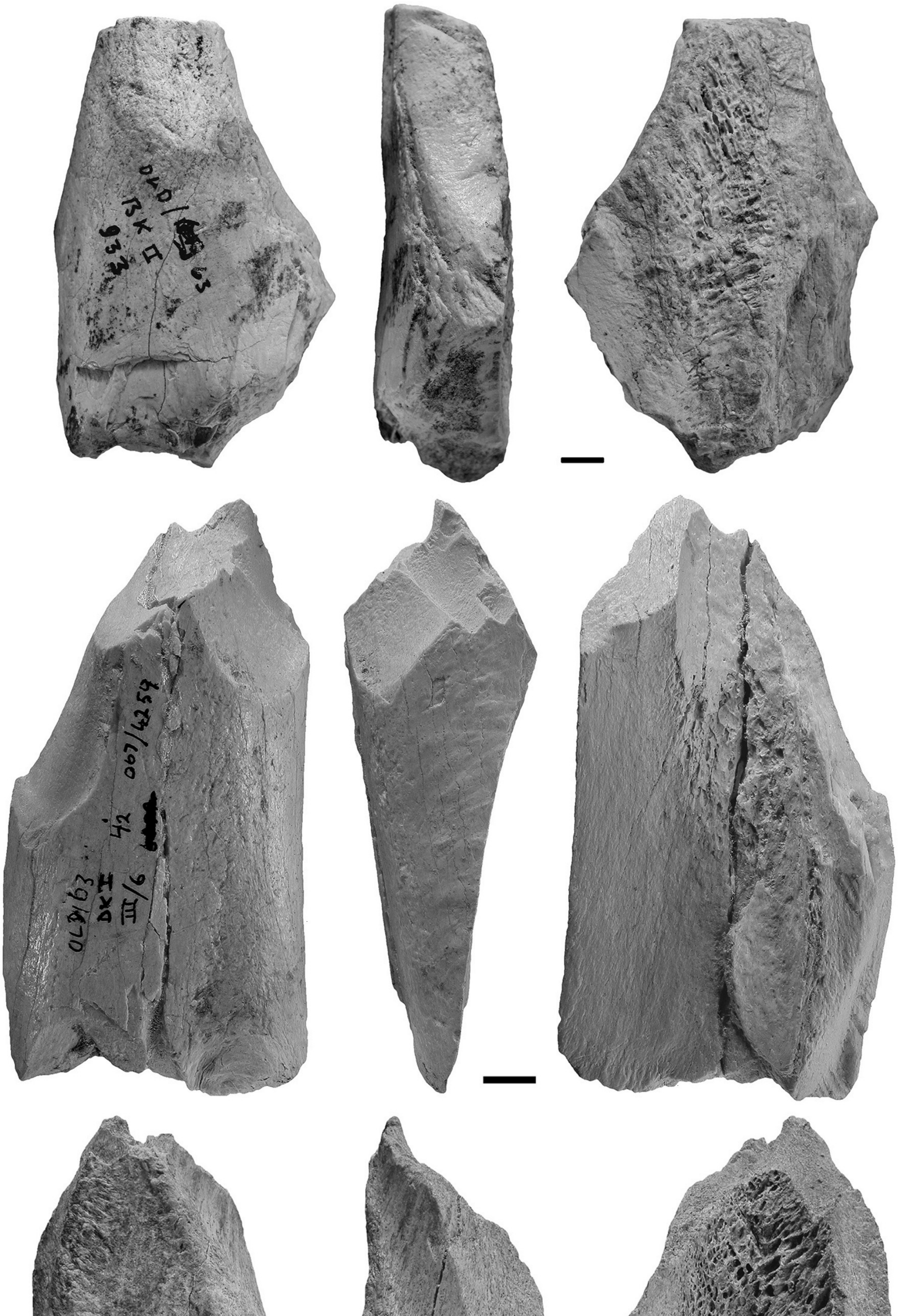

Figure 28. Olduvai bone tools proposed by Leakey, *BKII 933 (**top**), *DKI 067–4259 (**centre**), and by Leakey and by Shipman, DKI 4200 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

Figure 29. Olduvai bone tools proposed by Leakey, FCII 803 (**top**), FCII 068–6675 (**centre**), and by Leakey and by Shipman, *FCII 068–6679 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

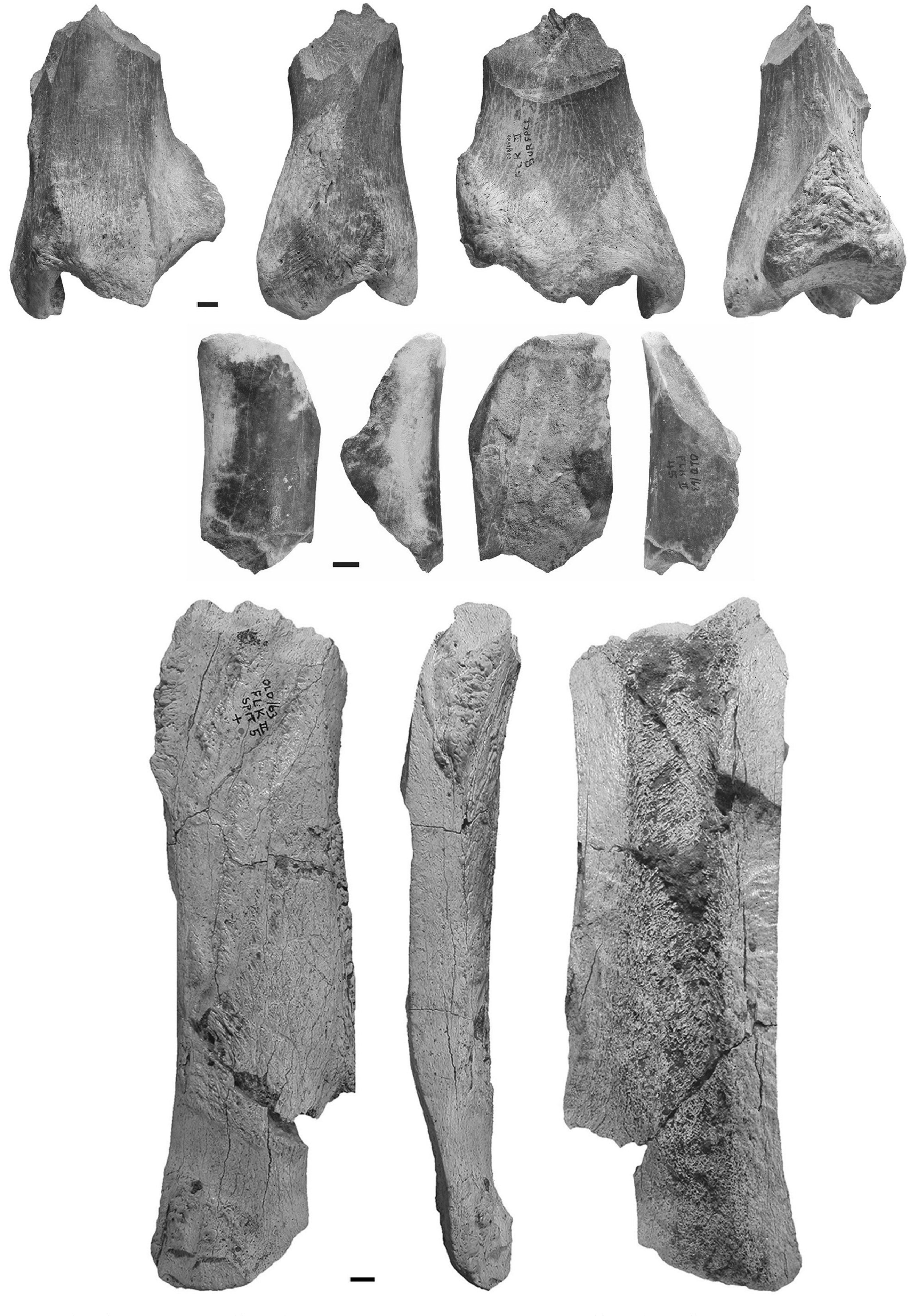

Figure 30. Olduvai bone tools proposed by Leakey, *FCKII 068–6682 (**top**), FLKII 45 (**centre**), and by Leakey and by Shipman, FLKII spit 5+ (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

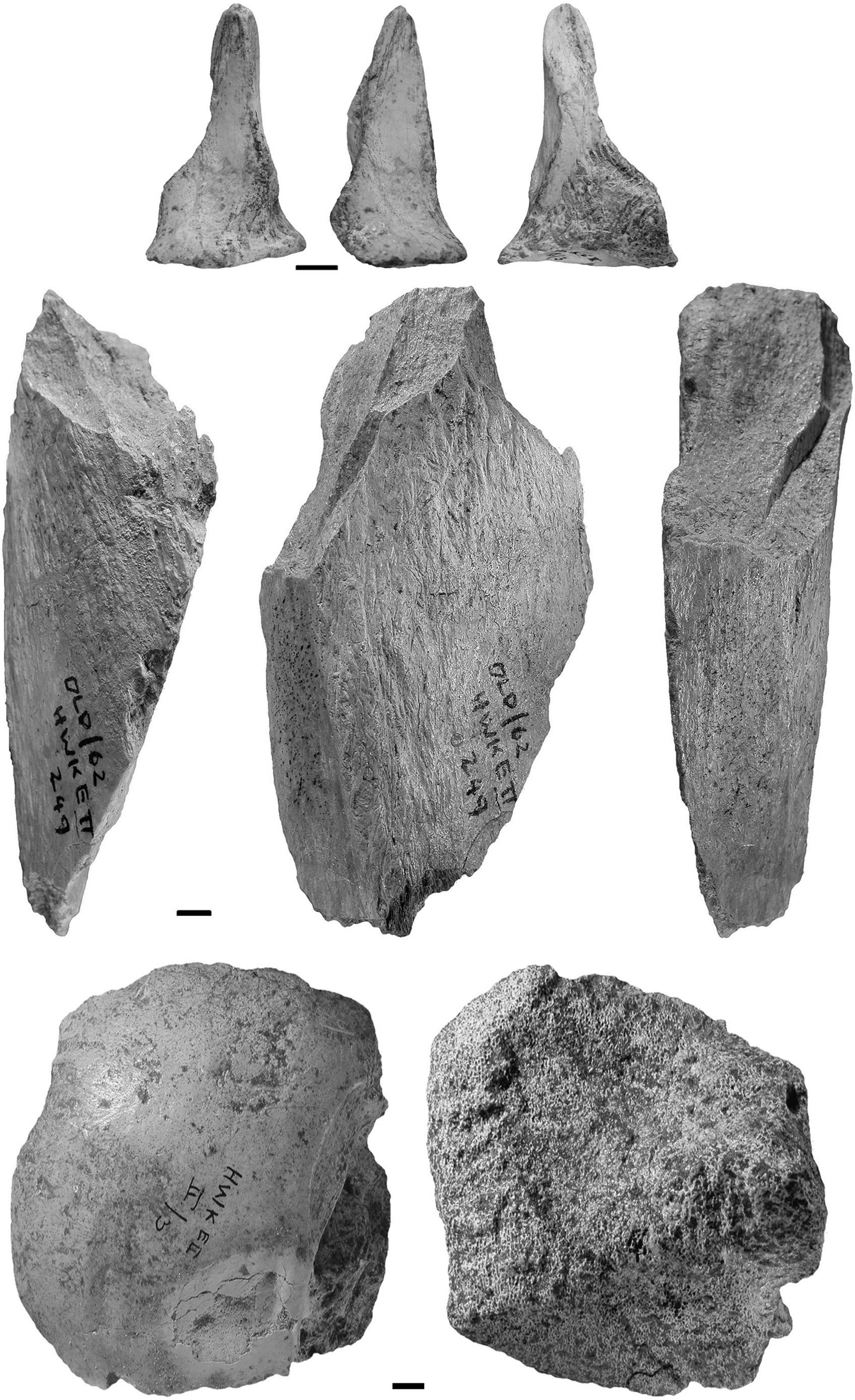

Figure 31. Olduvai bone tools proposed by Leakey and by Shipman, HWKEII 068–6690 (**top**), and by Leakey, *HWKEII 249 (**centre**), HWKEII 3a **(bottom)**. Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

Figure 32. Olduvai bone tools proposed by Leakey, HWKEII 3b (**top**), HWKEII 4021 (**centre**) and HWKEII 866 (**bottom**). Scale bars = 1 cm.

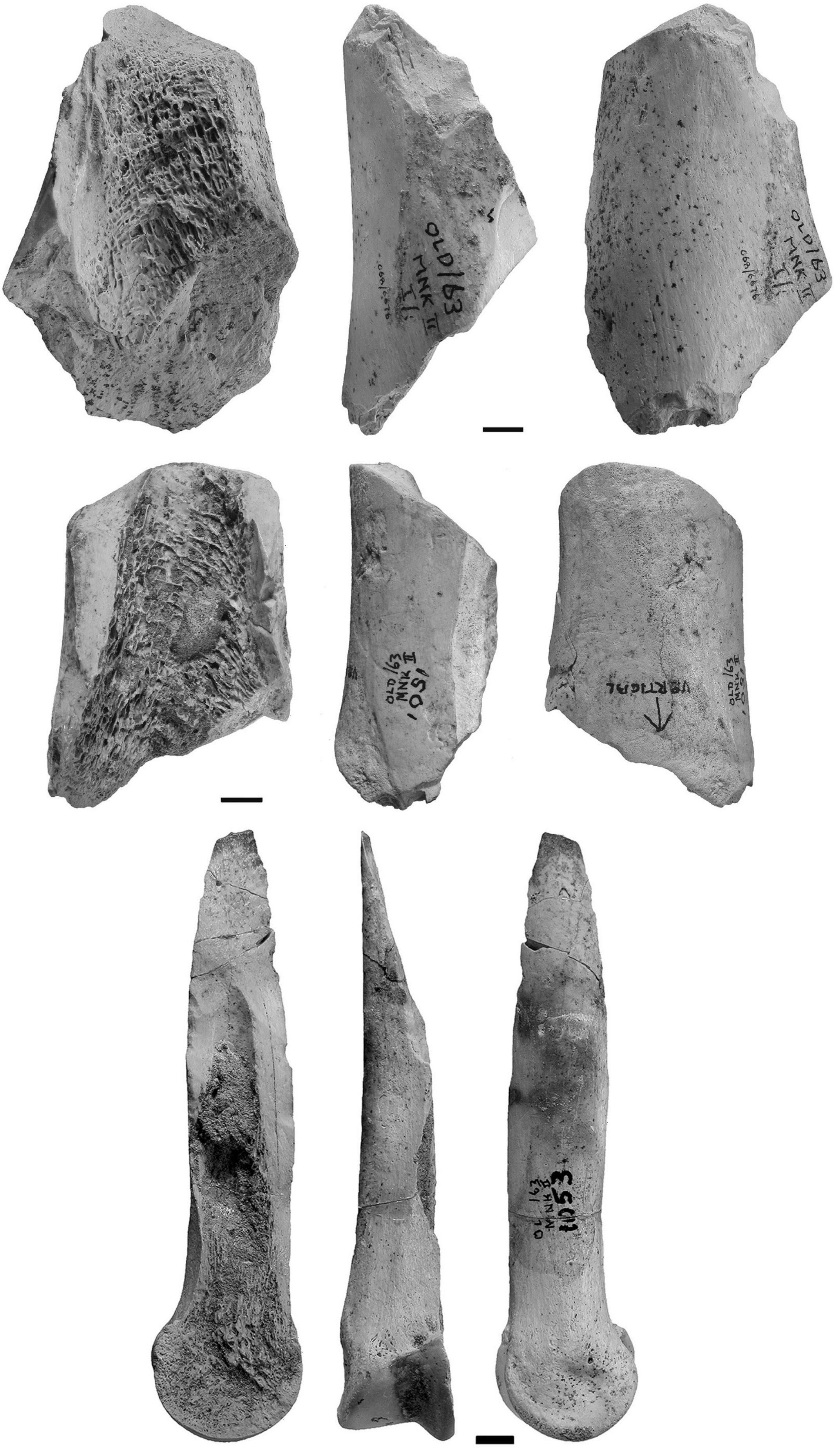

Figure 33. Olduvai bone tools proposed by Leakey and by Shipman, *MNKII 068–6676 (**top**), and by Leakey, MNKII 1051 (**centre**), MNKII 1053 **(bottom)**. Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

Figure 34. Olduvai bone tools proposed by Leakey, MNKII 1059 (**top**), MNKII 1090 (**centre**) and *MNKII 1116 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

Figure 35. Olduvai bone tools proposed by Leakey, *MNKII 1117 (**top**), *MNKII 1133 (**bottom**), and by Leakey and by Shipman, MNKII 1123 (**centre**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

Figure 36. Olduvai bone tools proposed by Leakey, MNKII 1269 (**top**), MNKII 1304 (**centre**), *MNKII 1496 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

Figure 37. Olduvai bone tools proposed by Leakey, MNKII 1563 (**top**), MNKII 1711 (**centre**), and by Leakey and by Shipman, *MNKII 1731 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

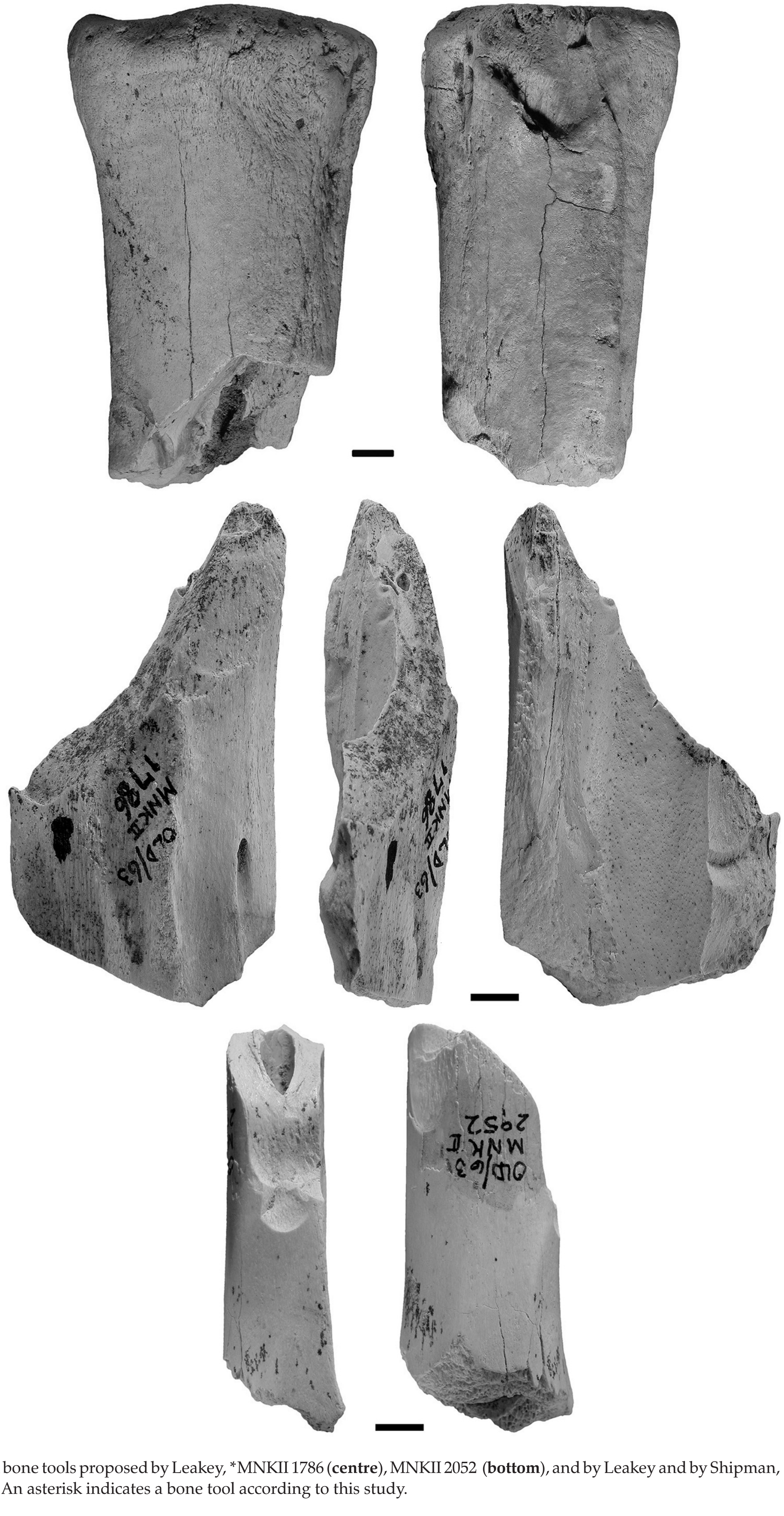

Figure 38. Olduvai bone tools proposed by Leakey, *MNKII 1786 (**centre**), MNKII 2052 (**bottom**), and by Leakey and by Shipman, *MNKII 1741 (**top**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

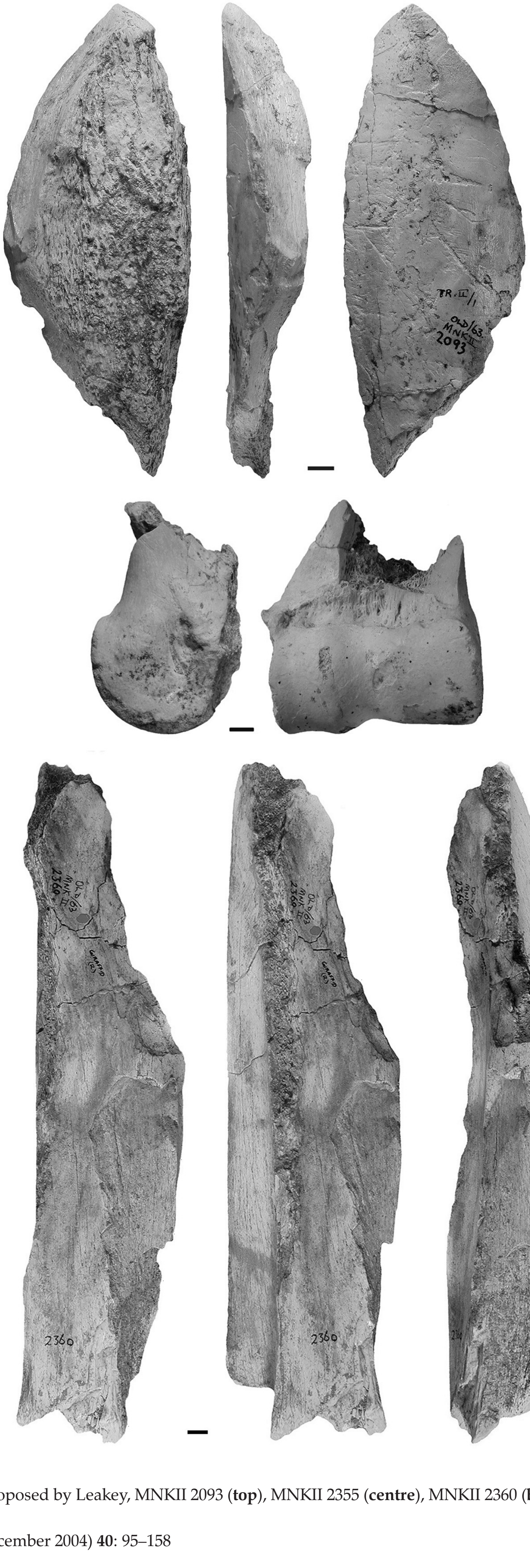

Figure 39. Olduvai bone tools proposed by Leakey, MNKII 2093 (**top**), MNKII 2355 (**centre**), MNKII 2360 (**bottom**). Scale bars = 1 cm.

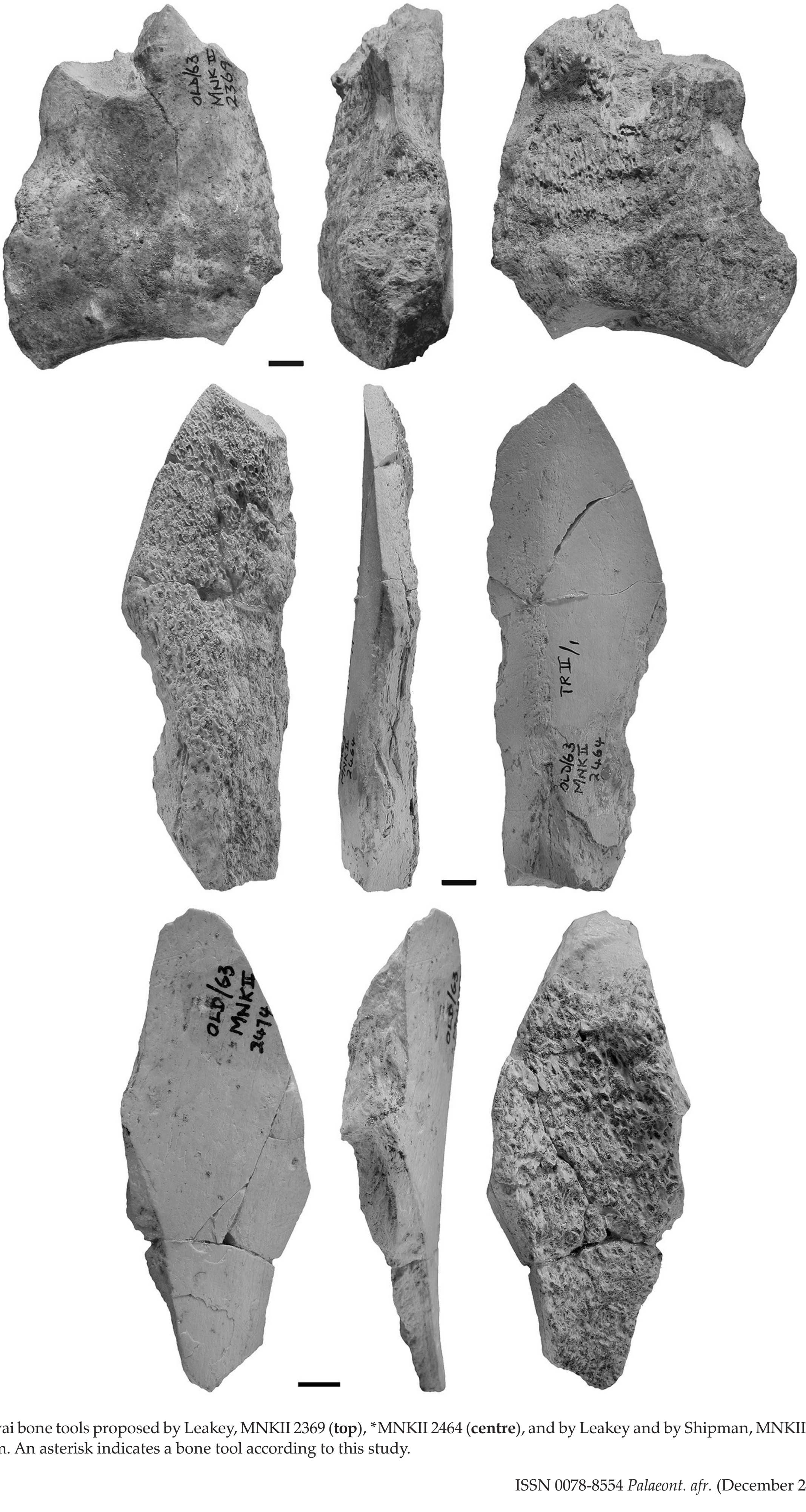

Figure 40. Olduvai bone tools proposed by Leakey, MNKII 2369 (**top**), *MNKII 2464 (**centre**), and by Leakey and by Shipman, MNKII 2474 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

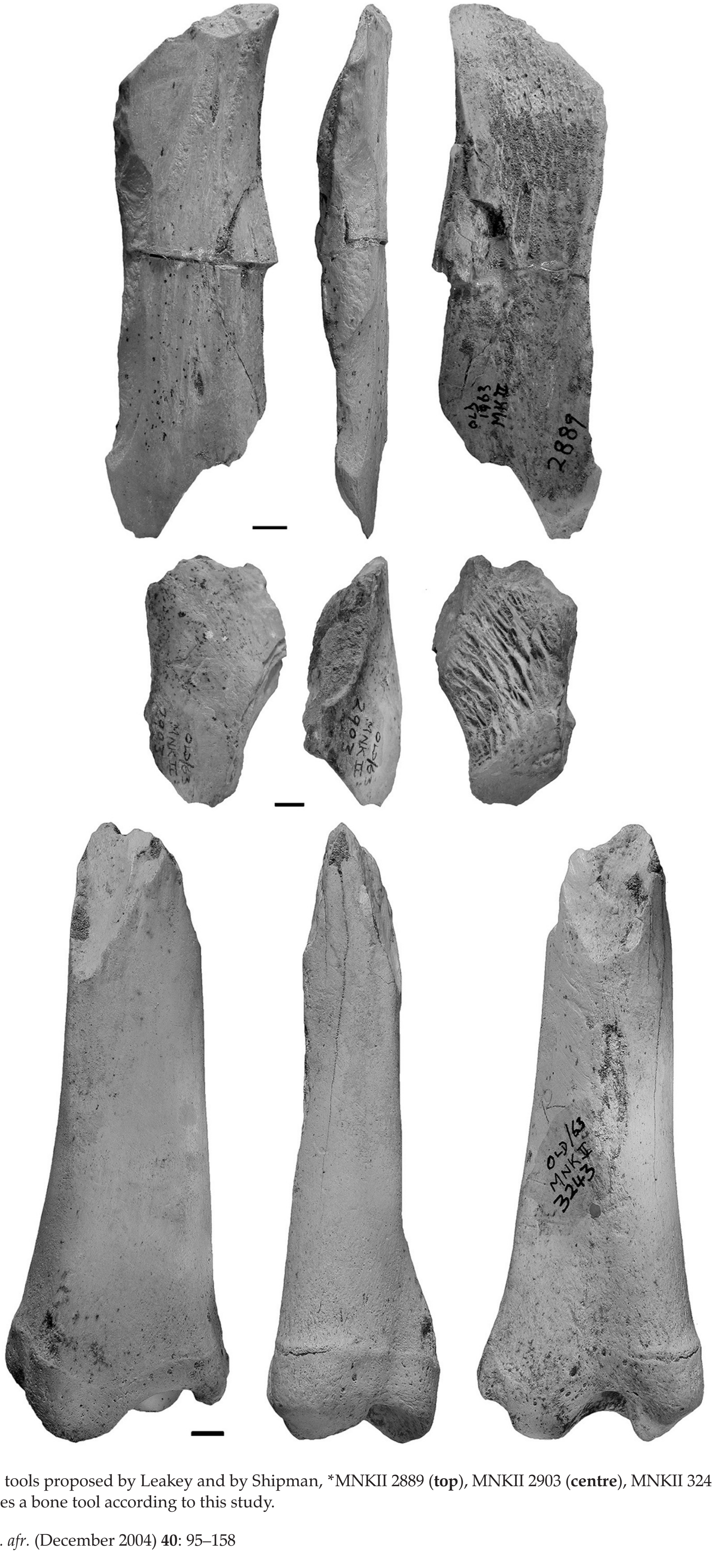

Figure 41. Olduvai bone tools proposed by Leakey and by Shipman, *MNKII 2889 (**top**), MNKII 2903 (**centre**), MNKII 3243 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

Figure 42. Olduvai bone tools proposed by Leakey, MNKII 3335 (**top**), *MNKII 471 (**centre**), and by Leakey and by Shipman *MNKII 475 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

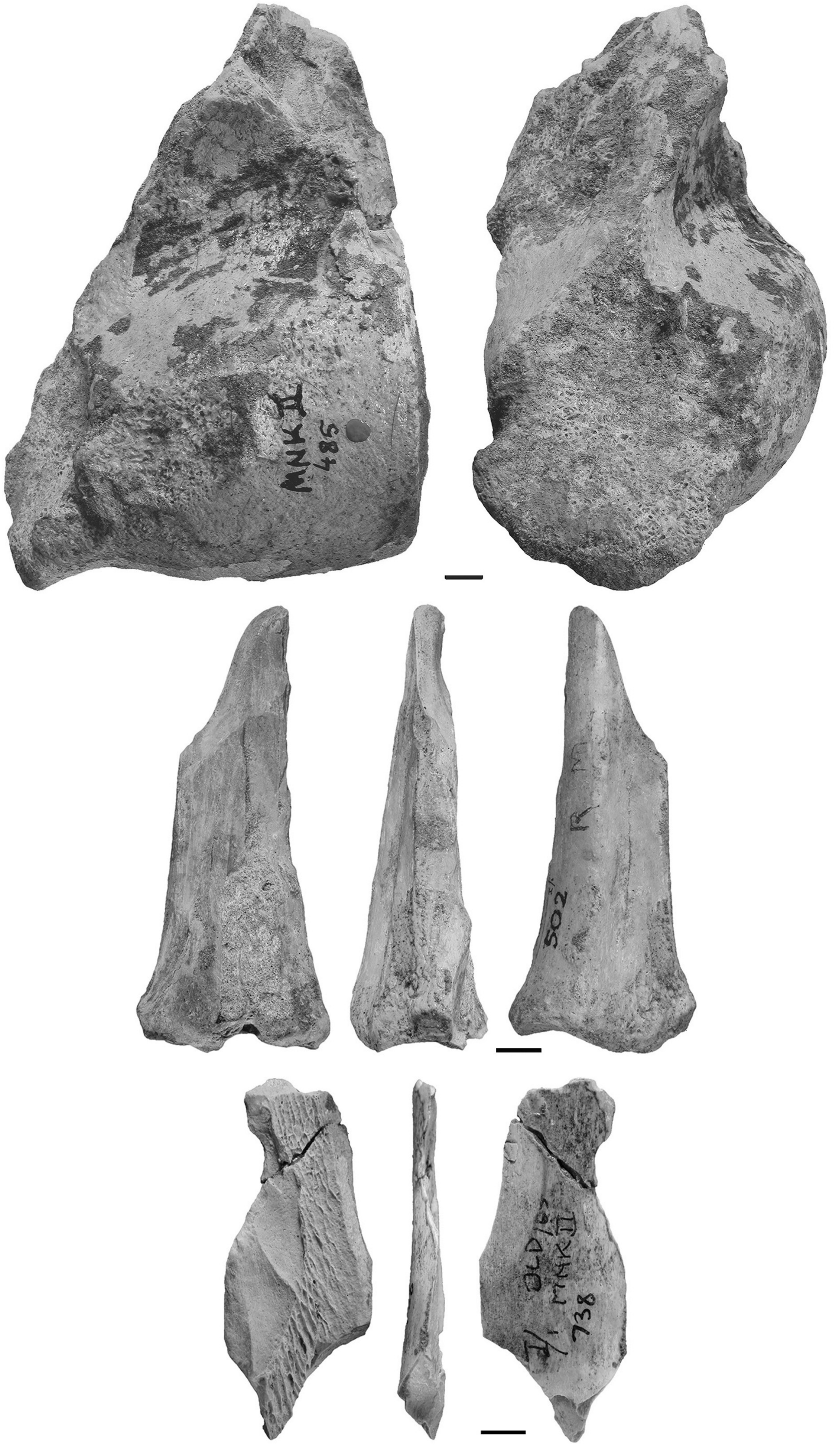

Figure 43. Olduvai bone tools proposed by Leakey, *MNKII 502 (**centre**), and by Leakey and by Shipman MNKII 485 (**top**), MNKII 738 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

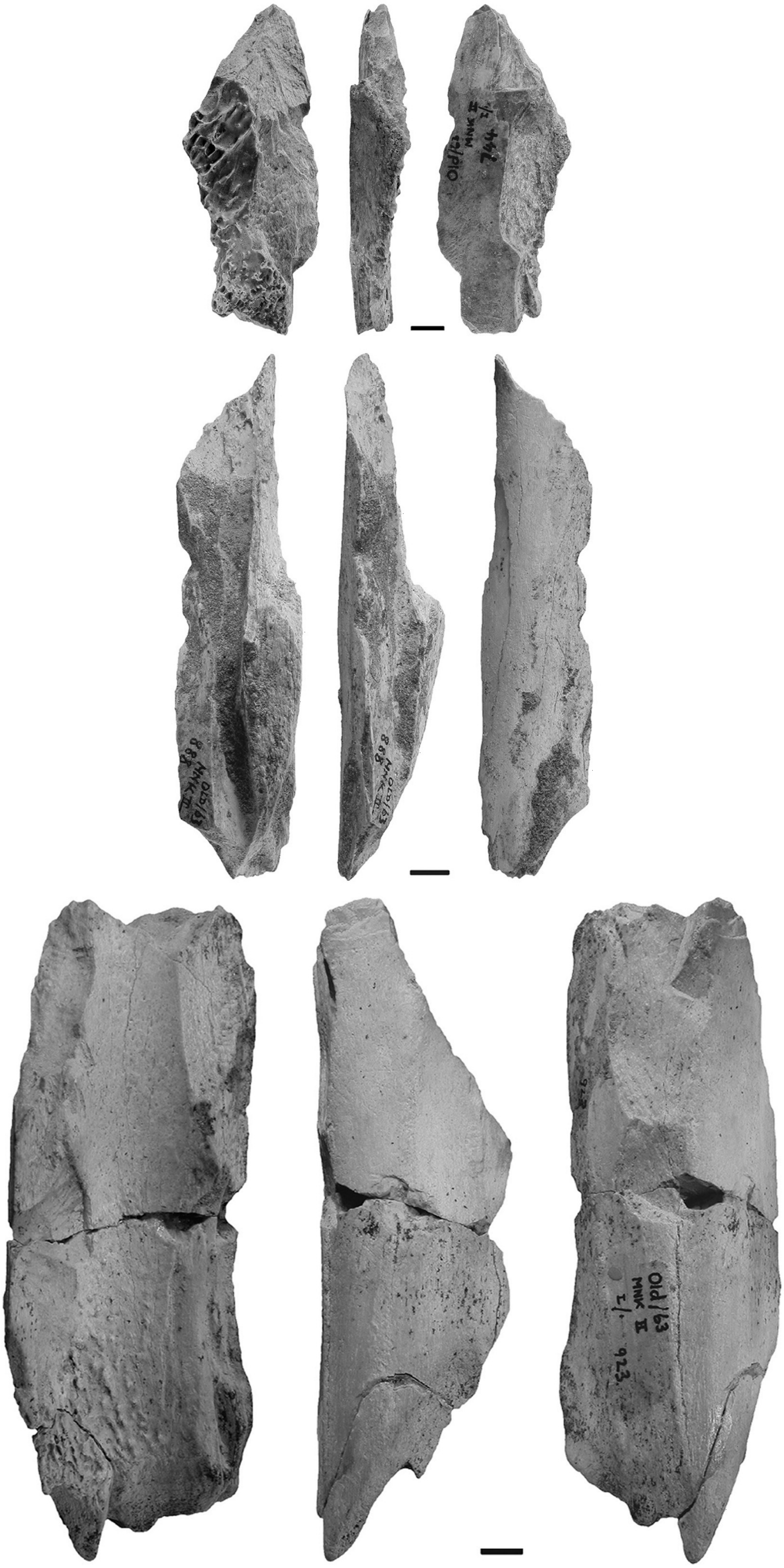

Figure 44. Olduvai bone tools proposed by Leakey, *MNKII 744 (**top**), MNKII 888 (**centre**), *MNKII 923 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

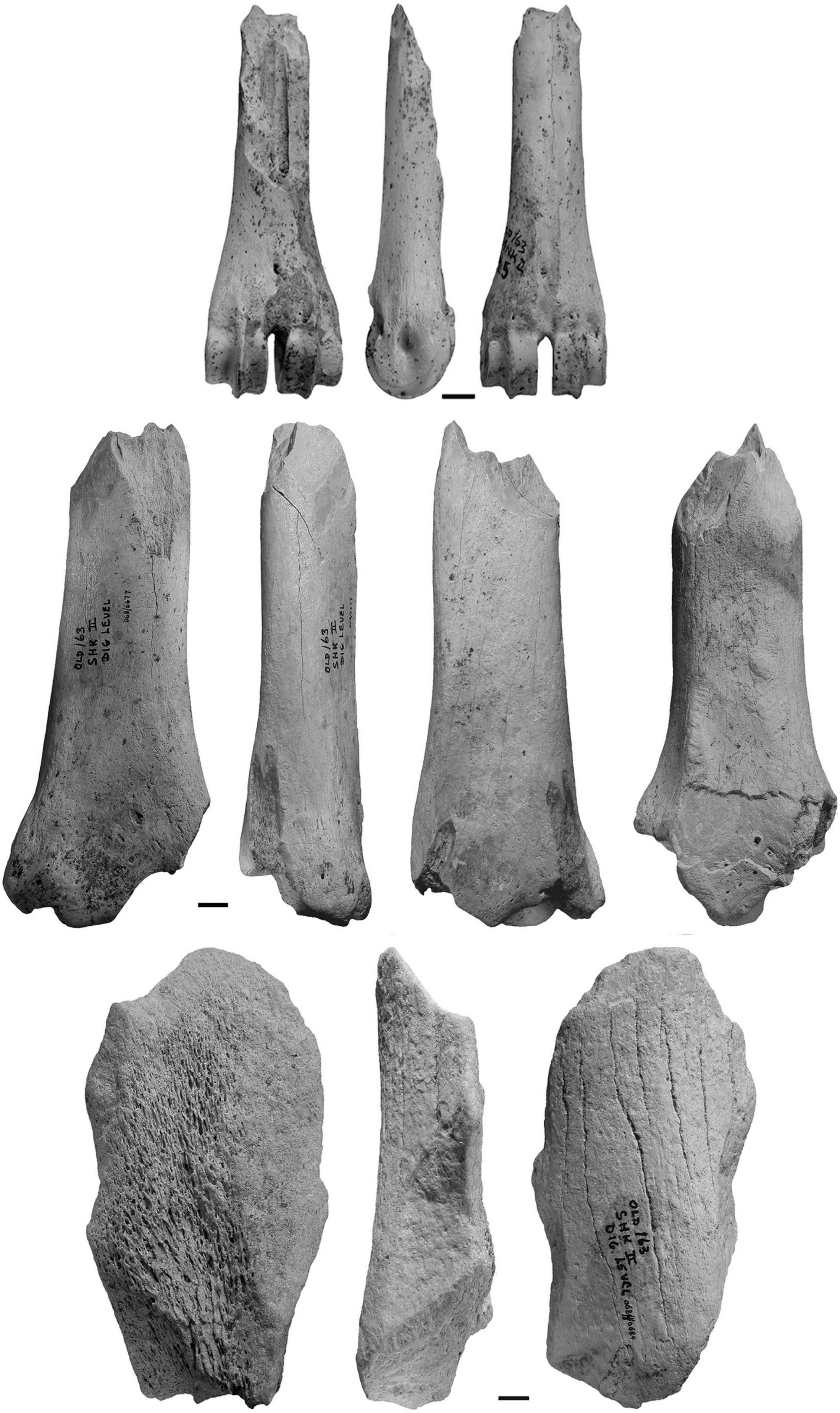

Figure 45. Olduvai bone tools proposed by Leakey, MNKII 925 (**top**), and by Leakey and by Shipman SHKII 068–6677 (**centre**), SHKII 068–6684 **(bottom)**. Scale bars = 1 cm.

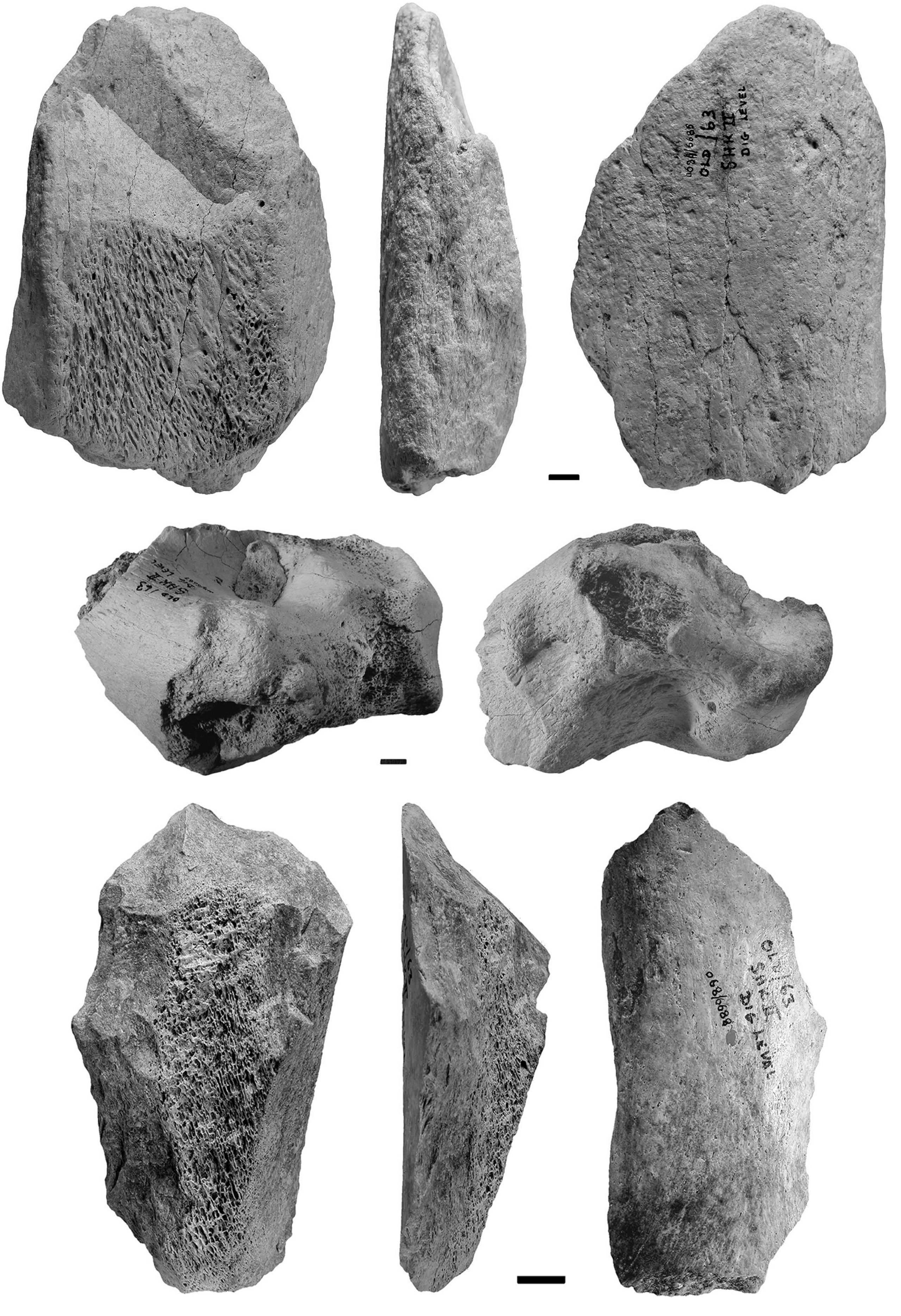

Figure 46. Olduvai bone tools proposed by Leakey, SHKII 068–6685 (**top**), and by Leakey and by Shipman SHKII 068–6687 (**centre**), *SHKII 068–6688 (**bottom**). Scale bars = 1 cm. An asterisk indicates a bone tool according to this study.

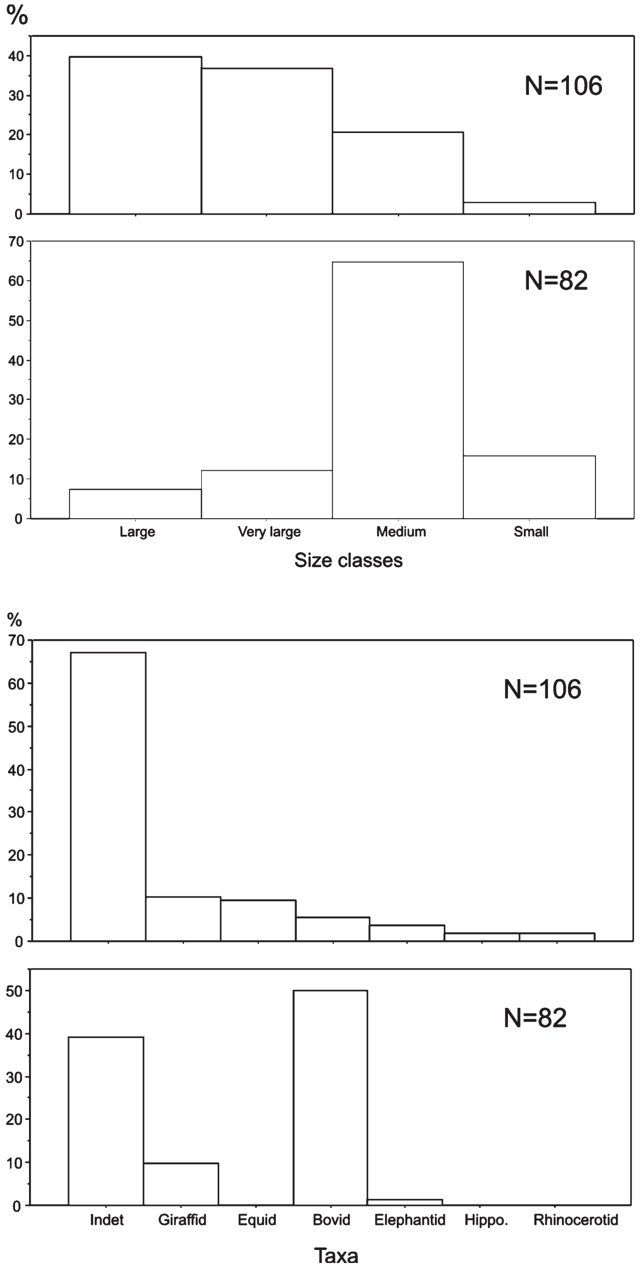

Figure 47. Proportions of mammal size classes (**top**) and taxa (**bottom**) represented in the Olduvai bone tool and comparative collections.

different from those observed on the Leakey collection, with the exception of carnivore traces and percussion marks less represented in the control sample (Table 8). The lower proportion of percussion marks in the control sample is to be expected, considering the smaller size and resistance of the original bones, which broke readily under percussion instead of recording the impact marks. The lower count for carnivore marks in the control sample may be due to specimen size, as smaller bones submitted to the action of carnivores have less chance of survival.

Removals

Bone flakes and shaft fragments described by Leakey and by Shipman as tools, record a significantly higher number of removals suggestive of intentional knapping, than do the Olduvai control sample and the experimental assemblage (Tables 7, 10 & 11). While the Leakey/Shipman collection may have up to 20 removals per piece, no more than four and eight flake scars were observed on the control sample and the experimental flakes, respectively. The Leakey/Shipman collection has an average of four removals per piece, the control sample has 1.2 removals and the experimental collection has only 0.4. In particular, the frequency distribution of the number of removals per piece reveals in the purported tools a marked bimodal trend absent in the other collections (Fig. 49). The second peak in the Leakey/Shipman distribution, composed of pieces having between five and 22 removals each, accounts for nearly half of the specimens. All these pieces come from large- to very large-sized mammals.

Removals do not occur with the same frequency on the periosteal and medullar surfaces of the pieces from the two Olduvai collections (Table 10–11). On specimens from the control sample, flake scars are four times more abundant on medullar than on periosteal surfaces, while on the Leakey/Shipman specimens, a significantly higher proportion of pieces with removals on the medullar surface are only observed on pieces with a single removal. An even more remarkable difference appears when comparing the occurrence of isolated and contiguous removals in the three collections. The Leakey/Shipman collection bears a consistent record of specimens with a considerable number of contiguous removals on both periosteal and medullar surfaces and very few pieces with multiple isolated flake scars. The other two collections have comparatively few pieces bearing contiguous removals, and in the case of the Olduvai control sample, a high proportion of pieces with single removals on the medullary aspect. The number of pieces presenting overlapping removals mimicking stepped retouch is also much higher in the Leakey/Shipman collection than in the other samples (Table 12). Interestingly, only in the Leakey/Shipman collection do a consistent number of flakes (17%) have removals on the same edge and on opposite aspects of the bone flake, creating a bifacial arrangement (Table 12). Moreover, all these pieces belong to large to very large mammal size classes. No such pieces were found in the control sample and only two (2%) among the experimen-

Table 9. Olduvai purported tools with carnivore and hominid modifications.

Carnivore traces	MNKII 1046, BKII 187, MNKII 3243, MNKII 1046, BKII 068/6680, HWKEII/3, MNKII 925, MNKII 2355, BKII 2959, MNKII 1053, BKII 068/6669, BKII 949, BKII 1053, SHKII 068/6677, MNKII 1059, FLKII 323
Cutmarks	BKII 949, BKII 068/6669, MNKII 1053, BKII 1053/315, FLKII 323, MNKII 1059, SHKII 068/6677, BKII 2959, MNKII 1046, MNKII 3243, BKII 187, BKII 068/6680, MNKII 2355, MNKII 925, HWKEII/3
Percussion marks	BKII 068/6683, BKII 949, BKII 1053/315, BKII 068/6678, BKII 068/6674, BKII 2715, BKII 1605, BKII 068/6666, FLKII 45, FLKII spit 5+, MNKII 1741, MNKII 1053, MNKII 475, MNKII 888, MNKII 1115, MNKII 1133, MNKII 1051, MNKII 1304, MNKII 1496, MNKII 502, HWKEII 4021, SHKEII 068/6681

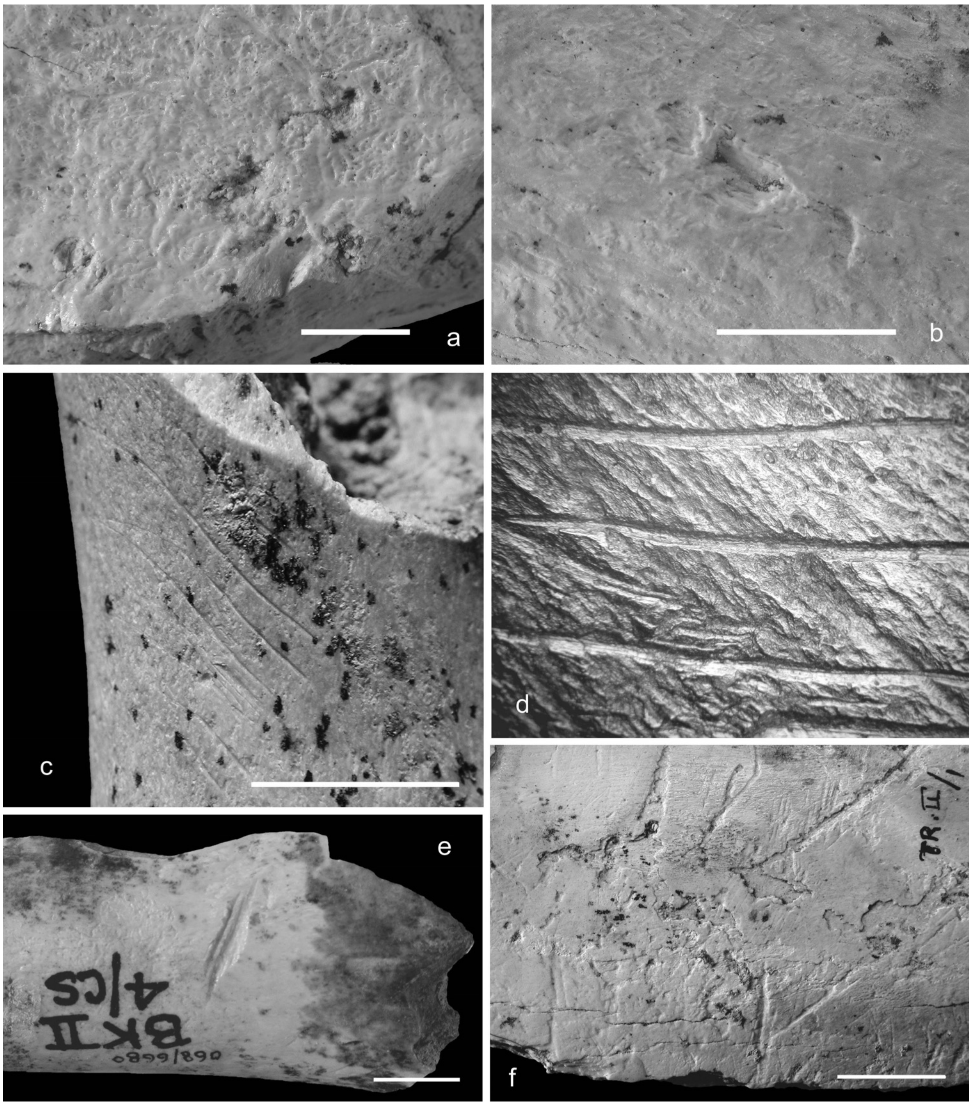

Figure 48. **a–b**, Percussion marks on Olduvai purported bone tools BKII 068/6666 (a) and MNKII 1133 (b); **c–d**, multiple cut-marks on specimen MNKII 925; **e**, cut-marks on specimen BKII 068/6680; **f**, scoring and pits on specimen MNKII 2093. Scale bars = 1 cm.

tal flakes. The location of the removals is not significantly different between the samples.

Additional noteworthy differences appear when analysing the length of the removals. Removals exceeding 40 mm are only present on the Leakey/Shipman and experimental flakes, and those of more than 80 mm occur only in the former sample (Fig. 50). Also, the large majority of the removals on the control sample are less than 10 mm in length (Fig. 50), while those of the same size constitute 40% in the Leakey/Shipman sample and less than 10%

Table 10. Number, association and location of removals on the periosteal and medullar surfaces of Olduvai shaft fragments described as tools.

No. rem.	No. flakes		Association				Location					
			Periosteal		Medullar		Periosteal			Medullar		
	Peri.	Med.	Isolated	Cont.	Isolated	Cont.	End	End + side	Side	End	End + side	Side
0	24	16	55	35	45	36	37	62	57	45	59	45
1	8	17	8	0	17	0	5	0	3	10	0	6
2	9	11	1	8	0	8	8	0	1	8	0	3
3	9	6	2	7	0	6	9	0	0	1	1	4
4	3	6	0	3	0	6	2	0	1	2	0	4
5	4	3	0	4	0	3	1	1	2	0	2	1
6	3	2	0	3	0	2	1	0	2	0	1	1
7	2	1	0	2	0	1	1	1	0	0	1	0
8	1	2	0	1	0	2	1	0	0	0	1	1
9	1	0	0	1	0	0	0	1	0	0	0	0
10	1	1	0	1	0	1	1	0	0	0	0	0
14	1	0	0	1	0	0	0	1	0	0	0	0
20	0	1	0	1	0	1	0	0	0	0	0	1

rem: removals; Peri.: periosteal; Med.: medullar; Cont: contiguous.

Table 11. Number, association and location of removals on the periosteal and medullar surfaces of a shaft fragment control sample from Olduvai.

No. rem.	No. flakes		Association				Location				
			Periosteal		Medullar		Periosteal		Medullar		
	Peri.	Med.	Isolated	Cont.	Isolated	Cont.	End	Side	End	End + side	Side
0	66	39	72	74	54	65	69	77	78	79	52
1	9	23	8	1	23	0	7	2	10	0	13
2	2	8	0	2	3	5	2	0	1	1	6
3	2	9	0	2	0	9	1	1	0	0	9
4	1	1	0	1	0	1	1	0	1	0	0

rem: removals; Peri.: periosteal; Med.: medullar; Cont: contiguous.

Table 12. Frequency of primary/secondary and monofacial/ bifacial removals on the three samples analysed.

Collection	Succession		Arrangement	
	First generation	Second generation	Monofacial	Bifacial
Experimental	34 (71%)	14 (29 %)	12	2
Olduvai control	86 (89%)	11 (11%)	81 (100%)	0
Leakey/Shipman	312 (59%)	216 (41%)	84 (83%)	17 (17%)

among the experimental flakes. One might argue from this evidence, considering the composition of the three collections, that the length of the removals is a function of the bone size. Analysis of removal size according to mammal size classes reveals, however, that those from the Leakey/Shipman collection are in all size classes significantly longer than those on the Olduvai control sample (Table 13). The high standard deviation observed on the purported tools from large and very large animals, in contrast with the low values in the control sample, is due to the fact that these pieces record a succession of large and small, often contiguous and overlapping flake scars. This is supported by the frequency distribution of the lengths of primary and secondary removals, indicating that the putative bone tools are the only sample that records a clear variation in size between first and second

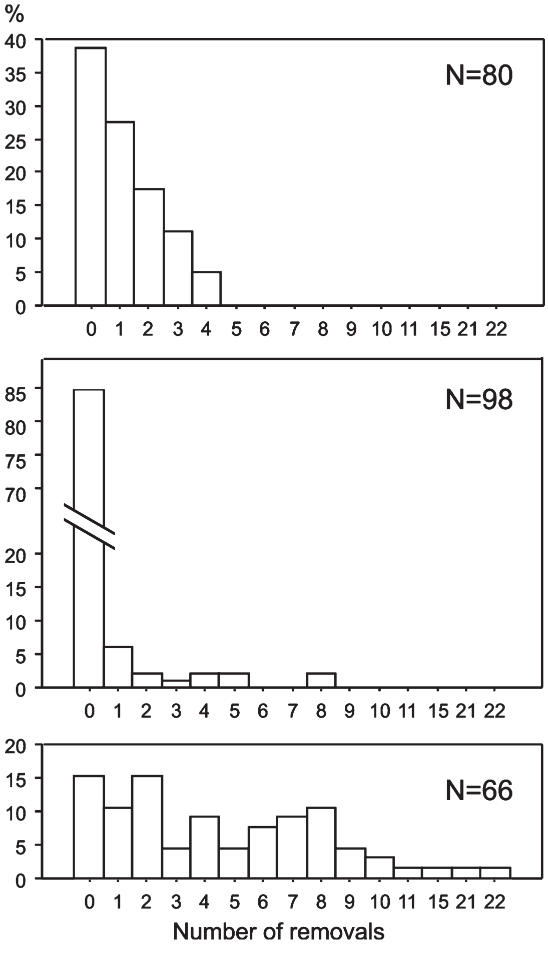

Figure 49. Frequency distribution of the number of removals per piece in the Olduvai control sample (**top**), flakes from the experimental breakage of elephant bones (**centre**), and Leakey/Shipman collection (**bottom**).

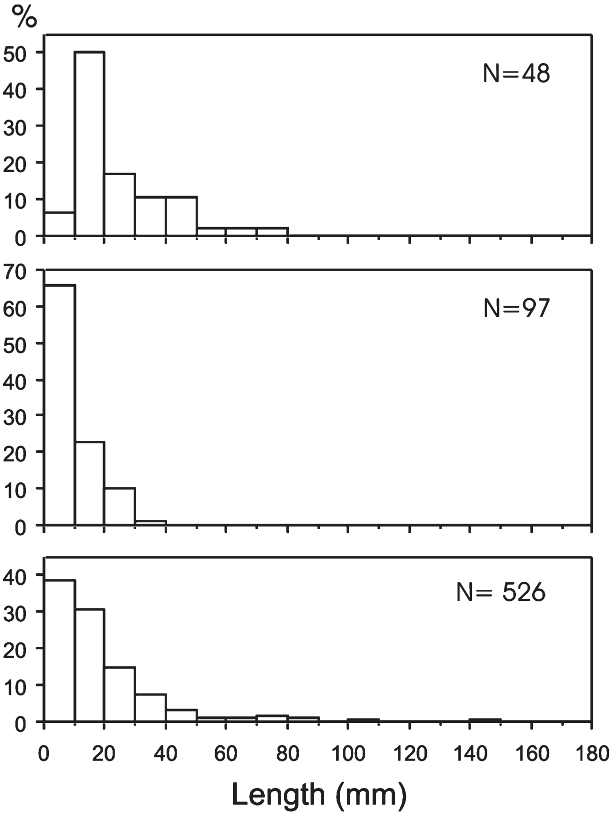

Figure 50. Length of the removals from the experimental flakes (**top**), the Olduvai control sample (**centre**), and the purported bone tools (**bottom**).

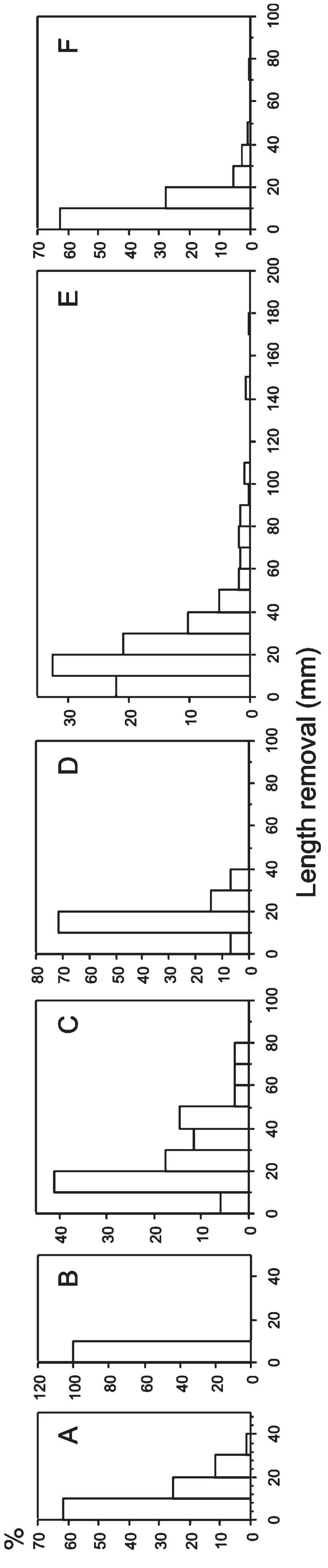

Figure 51. Length of the primary and secondary removals respectively, from the Olduvai control sample (**A–B**), experimental flakes (**C–D**), and the purported bone tools (**E–F**).

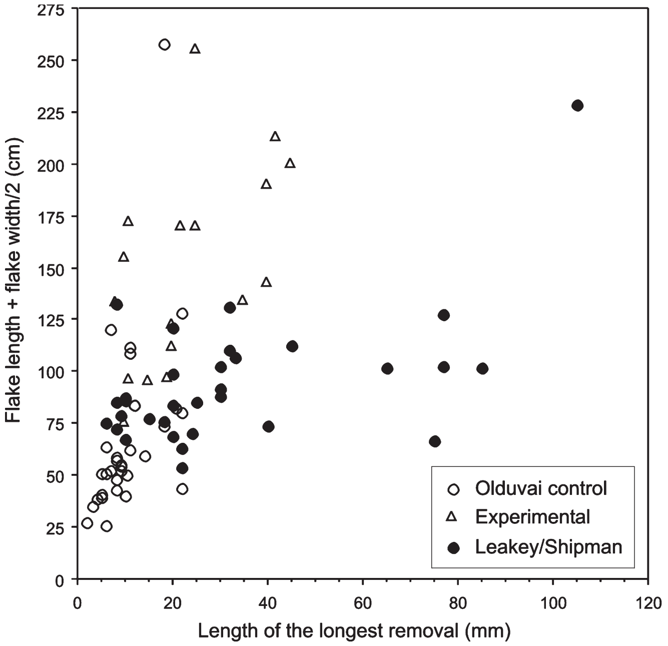

Figure 52. Correlation between the longest flake scar and the shaft fragment size index.

generation flake scars (Fig. 51). The anomalous size of the removals on the Leakey/Shipman sample is also indicated by the correlation of the longest removal with the flake size index, showing that a number of pieces from this collection have removals that exceed the size expected on the basis of the removal/size ratio observed in the other collections (Fig. 52).

According to flake removal data, we identify a reduced number of bone tools ($n = 36$) in Leakey's (1971) purported bone tool collection of 123 specimens. Shipman (1989) identified 41 of these as true bone tools, and even though we identify fewer, some of these pieces are interestingly not considered as tools by Shipman. Bone tools identified by us derive from seven sites (DK, MK, HWK East, SHK, MNK, FC West, BK and FCKII), though site FCKII is not recorded in Leakey's 1971 monograph. We concur that the majority of bone tools occur in MNK and BK, in middle-upper Bed II (Table 2).

In sum, our results seem to identify within the purported tools, a cluster of pieces that appear idiosyncratic when compared with the available non-artefactual analogues. They consist of fresh bone shaft fragments and epiphyseal pieces from large and very large mammals, bearing five or more flake scars, some of which are contiguous, with one or more anomalously invasive primary removals. Table 14 lists the 37 specimens from the Leakey collection that have more than five removals. Most of them share the features mentioned above and reveal a particularly high proportion of bifacially arranged removals, accounting for 14 of the 17 cases recorded in this collection. Importantly, they are virtually unaffected by carnivore damage. The anthropic origin of the removals on many of the specimens belonging to this sample is supported by the few pieces on which the removals are the likely result of carnivore activity because of their close proximity to typical carnivore damage (BKII 869, MNKII 2093, MNKII 2360, MNKII 2369, MNKII 3335, SHKII 068/6687). The removals on these

Table 13. Length of removals according to mammal size class.

	No. of removals			Leakey		Control sample		Experimental	
	Leakey	Control	Exp.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Very large	112	13	48	20.1	21.5	13.7	6.1	22.3	15.4
Large	111	14	0	15.8	15.8	7.7	4.7	–	–
Medium	62	28	0	11.6	9.3	7.1	3.2	–	–
Small	8	8	0	10.9	8.4	7.8	6.5	–	–

pieces may be contiguous but are rarely invasive.

Clearly, a number of these pieces are difficult to interpret as bone tools. This is certainly the case for the distal epiphyses of humeri (e.g. BKII 2382, BKII 200, MNKII 475) that do not seem to differ from similar fragments found at Olduvai and in numerous other collections.

Although bearing a striking amount of invasive contiguous removals, which could suggest their intentional shaping, some other pieces may also be explained as the outcome of bone breakage for marrow extraction (e.g. BKII 068-6668, MNKII 1133, DKI 067-4259 and perhaps HWKEII 249, MNKII 923, BKII 068-6674 and MNKII 1117, all from sites considered as occupation floors by Leakey). These flakes may have been detached as a consequence of repeated percussion made with a hammer or against an anvil, inflicted obliquely on the broken end of a shaft piece. In one specimen (MNKII 1133), these percussions were followed by a strike inflicted on the cortical bone close to the broken end, which was successful in the detachment of the flake and produced a characteristic impact notch on the medullar surface. A similar interpretation may also be proposed for a few other flakes (MNKII 1786, BKII 068-6686, MNKII 1116, MNKII 744) that present a pointed end with adjacent burin-like removals that may

Table 14. Olduvai specimens with five or more removals and a suite of features that appear to differentiate them from the remainder of the Leakey collection.

Site	Spec. No.	Size class	Body part	Bone region	Carn.	Perc.	Total rem.	Periosteal			Medullar			Bifacial	Tools after	Fig. No.
								No. rem.	Type	Loc.	No. rem.	Type	Loc.			
BKII	068/6666	VL	Humerus	Shaft	n	y	8	5	Cont.	Side	3	Cont.	Side	No	1	18
BKII	068/6668	VL	Humerus	Shaft	n	n	6	5	Cont.	E+S	1	Isol.	End	Yes	1	18
BKII	068/6670	VL	Indet.	Shaft	n	n	5	3	Cont.	End	2	Cont.	Side	No	1	19
BKII	068/6686	L	Tibia	Shaft	n	n	9	1	Isol.	End	8	Cont.	E+S	No	1	22
BKII	1938	VL	Humerus	Shaft	n	n	6	3	Cont.	End	3	Cont.	Side	No	1.2	23
BKII	200	M	Humerus	Epi.	n	n	9	4	Cont.	End	5	Cont.	End	No	1	23
BKII	201	L	Indet.	Shaft	n	n	5	3	Cont.	End	2	Cont.	End	Yes	1	24
BKII	2382	VL	Humerus	Epi.	n	n	10	1	Isol.	End	9	Cont.	End	No	1	24
BKII	2715	L	Humerus	Shaft	n	y	22	2	Isol.	Side	20	Cont.	Side	No	1	25
BKII	3155	VL	Indet.	Shaft	n	n	7	3	Con+Is.	End	4	Cont.	End	Yes	1.2	26
BKII	3385	VL	Humerus	Epi.	y	n	5	1	Isol.	End	4	Cont.	End	No	1	–
BKII	53/9 1953	VL	Indet.	Shaft	n	n	15	9	Cont.	E+S	6	Cont.	E+S	Yes	1.2	27
BKII	6674	VL	Humerus	Shaft	n	n	8	3	Cont.	End	5	Cont.	Side	No	1	–
BKII	933	VL	Indet.	Shaft	n	n	8	6	Cont.	Side	2	Isol.	Side	No	1	28
DKI	067/4259	L	Indet.	Shaft	y	n	7	7	Cont.	End	0	–	–	No	1.2	28
FCII	068/6679	VL	Indet.	Shaft	n	n	8	5	Cont.	Side	3	Cont.	E+S	Yes	1.2	29
FCKII	068/6682	L	Femur	Epi.	n	n	7	5	Cont.	End	2	Cont.	End	Yes	1	30
HWKEII	249	VL	Pelvis	Shaft	n	n	7	6	Cont.	End	1	Isol.	End	Yes	1	31
MNKII	068/6676	L	Indet.	Shaft	n	n	8	5	Cont.	End	3	Cont.	Side	Yes	1.2	33
MNKII	1116	L	Indet.	Shaft	n	n	7	3	Isol.	End	4	Cont.	Side	Yes	1	34
MNKII	1117	VL	Humerus	Shaft	n	n	6	3	Cont.	End	3	Cont.	End	No	1	35
MNKII	1133	L	Humerus	Shaft	n	y	11	10	Cont.	End	1	Isol.	End	Yes	1	35
MNKII	1140	M	Tibia	Epi.	n	n	5	3	Cont.	End	2	Cont.	End	No	1	–
MNKII	1496	M	Humerus	Shaft	n	y	5	2	Cont.	End	3	Cont.	Side	No	1	36
MNKII	1731	VL	Femur	Shaft	n	n	7	1	Isol.	End	6	Cont.	Side	No	1.2	37
MNKII	1741	VL	Metatar.	Epi.	n	y	7	4	Cont.	End	3	–	–	No	1.2	38
MNKII	1786	L	Tibia	Shaft	n	n	6	4	Cont.	End	2	Cont.	End	Yes	1	38
MNKII	2360	VL	Scapula	Blade	y	n	8	8	Con+Is.	E+S	0	–	–	No	1	–
MNKII	2464	VL	Indet.	Shaft	n	n	8	4	Cont.	Side	4	Cont.	Side	Yes	1	40
MNKII	2889	M	Tibia	Shaft	n	n	7	7	Cont.	E+S	0	–	–	No	1.2	41
MNKII	471	VL	Humerus	Shaft	n	n	8	0	–	–	8	Cont.	Side	No	1	42
MNKII	475	VL	Humerus	Shaft	n	y	9	8	Cont.	End	1	Isol.	End	No	1.2	42
MNKII	502	M	Metapod.	Shaft	n	y	6	1	Isol.	Side	5	Cont.	E+S	No	1	43
MNKII	744	L	Indet.	Shaft	n	n	10	6	Cont.	Side	4	Cont.	Side	No	1	44
MNKII	923	L	Tibia	Shaft	n	n	9	4	Cont.	End	5	Cont.	E+S	Yes	1	44
SHKII	068/6688	L	Indet.	Shaft	n	n	10	0	–	–	10	Cont.	E+S	No	1.2	46

Tools after Leakey (1) and Shipman (2).
Spec. no: specimen number; Carn: carnivore; Perc: percussion marks; rem: removals; No. rem: number of removals; Loc: location; Fig. no: figure number; VL: very large; L: large; M: medium; Indet: indeterminate; Epi: epiphysis n: no; y: yes; Cont: contiguous; Isol: isolated; Con + Is: contiguous and isolated; E + S: end and side.

Figure 53. Distal tibiae (SHKII 068–6677, MNKII 3243, HWKEII 4021, FCII 803, FCKII 068–6682) interpreted by Leakey as tools, showing centripetal removals at the broken end of the shaft.

result from repeated strikes to the broken end of a shaft, as with the pieces mentioned above.

That this technique was employed at Olduvai is evidenced by the presence of several distal tibiae (SHKII 068-6677, MNKII 3243, HWKEII 4021, FCII 803, FCKII 068-6682 and perhaps BKII 068-6670) interpreted by Leakey as tools, which show centripetal removals on fresh bone at the broken end of the shaft, with the likely intention of reducing the shaft length to access the marrow (Fig. 53). It is also noteworthy that the single piece (Fig. 14c) from the experimental breakage of elephant bone, which has a pointed tip with similar removals, derives from a limb bone struck against a rock. This seems to confirm the kinetic mechanism we have proposed for the detachment of these flakes. One may argue that marrow could be extracted with less effort by using a probe, and that both the distal tibiae and the flakes described above must have been knapped with the intention of using them as tools. This explanation fits particularly well the distal epiphysis of a giraffid tibia showing a large number of invasive centripetal removals around an exceedingly small marrow cavity (Fig. 54). Although we have no basis on which to favour one of these two hypotheses, which moreover, are not mutually exclusive, it would appear that this flaking technique is peculiar to bone from large animals at Olduvai, as no flakes with similar adjacent removals are found in the control sample, mostly composed of bones from smaller animals.

A flake with a pointed end and burin-like removals (BKII 201, Fig. 24), although similar to those discussed above, represents a special case in that its tip shows a marked macroscopic rounding in contrast to the unaltered

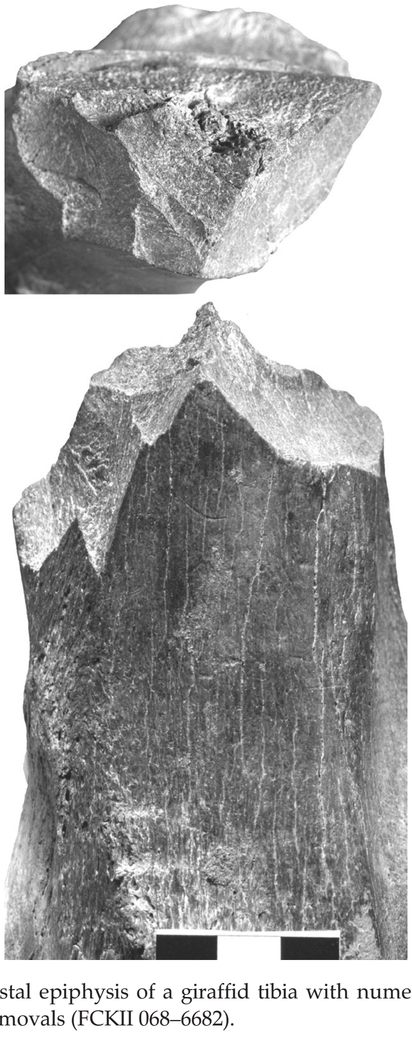

Figure 54. Distal epiphysis of a giraffid tibia with numerous invasive centripetal removals (FCKII 068–6682).

appearance of the remainder of the piece. This is the only specimen in the Leakey collection presenting a clear association of localized rounding with removals. This wear could not have been produced by percussion of the tip, as no evidence of battering is seen at microscopic scale in this area (Fig. 2o), making this piece a good candidate for having been used as a tool. The BKII site is however a reworked channel stream deposit, which may account for the anomalous rounding of the tip.

Other pieces are difficult to interpret as the mere by-product of butchering activities. In some specimens (MNKII 1731, MNKII 471, BKII 2715, the two sites with the highest concentration of bone tools according to Leakey, Shipman and this study), contiguous removals occur along both edges of the shaft fragment on the medullar aspect. The detachment of these flake scars seems to have taken place subsequent to the detachment of the shaft piece from the bone, which is inconsistent with marrow extraction. A large elephant flake (BKII 1938, Fig. 23) shows a continuous sequence of removals on its medullar side, which postdates the detachment of the flake; this continuous sequence is not seen on our experimental breakage pieces. A stronger case can be made for a smaller piece (SHKII 068-6688, Fig. 46) presenting a multiple-stepped, markedly invasive suite of removals on one side of the medullar edge, which postdates the detachment of the flake. Invasive bifacial removals associated with diagnostic percussion marks and a percussion notch are recorded on specimen BKII 068-6666 (Fig. 18). While the flake scars on the medullar aspect, near to the percussion notch, may be a function of the blow, those on the opposite edge, occurring bifacially, and made after the detachment of the piece, can hardly be explained in these terms. Two large elephant flakes deserve special attention; FCII 068-6679 (Fig. 29) and BKII 1953 or 53-9 (Fig. 27). The first, described by Leakey and by Shipman as a biface, bears on the periosteal aspect five contiguous removals that occur on a surface fracture, which indicates that the resulting flakes must have been removed after the detachment of the blank from the elephant bone. The second piece presents on both faces contiguous bifacial removals that appear particularly invasive on the periosteal surface at one end. Removals on the last two pieces are of dimensions considerably longer than those on elephant flakes resulting from experimental breakage. A proximal epiphysis of a giraffid metatarsal (MNKII 1741, Fig. 38) shows on its medial aspect along the edge of the articular surface, contiguous removals resulting from percussions applied to the articular surface, as evidenced by percussion marks close to the margin. The opposite end has a smoothed edge and one removal. The location of these modifications is compatible with an interpretation of this piece as a wedge.

DISCUSSION

There are two means by which to establish the artefactual nature of potential bone tools showing ambiguous traces of manufacture and use. The first entails the documentation of possible evidence of utilization and the demonstration that the recorded modifications, if interpreted as resulting from use, cannot be the outcome of other taphonomic processes. Apart from two pieces bearing traces of use as hammers, and a probable wedge, as well as a flake with a macroscopically worn tip, the remainder of the Olduvai purported bone tools do not seem to provide unambiguous evidence of utilization. Comparative microscopic analysis of different areas of the purported Olduvai tools, and of the edges of bone pieces from the rest of the bone assemblage (control sample), suggests that possible modifications due to utilization are indistinguishable from features attributed to post-depositional abrasion. This conclusion is reached after a systematic microscopic survey of the purported bone tools and control sample from Olduvai. Experimental and comparative non-human modified bone collections involving optical and scanning electron microscopic inspection of hundreds of specimens were similarly surveyed. Additionally, further visual comparison and the recording of features on a comparable amount of SEM micrographs were conducted. We cannot exclude the possibility that similar research by Shipman has made her more adept than we are in the identification of anthropic use-wear, as distinct from other causes. If this is the case, however, one has to acknowledge that her criteria for making this distinction and differentiating between task-specific tools are not clear-cut. Robust criteria are essential if inferences from this type of archaeological evidence are to be made, accepted by a scientific community, and become shared knowledge reinforced by repeatable results. Future analyses of the identification of anthropic use-wear should include the quantification of possible worn areas and the development of appropriate analogues. At present, the SEM is perfectly suited to documenting microscopic features; however, if it is the only diagnostic tool used, it may provide deceptive results for this site, in that gentle, mechanical sedimentary abrasion appears to have affected most of, if not the entire Olduvai assemblage, overprinting potential evidence of use-wear.

It is noteworthy that experimentally used bone tools show that tasks involving a high degree of mechanical abrasion, such as digging in soil or working hide with sand, produce distinct localized macroscopic modifications on the active zone of the tool. Considering the excellent state of preservation of the more probable Olduvai tools, one would expect that the presence of use-wear generated by these aggressive tasks should be easily detectable on the edges of tools. With the possible exception of two pieces (BKII 201, Fig. 24; MNKII 1741, Fig. 38), no evidence of localized macro-wear is observed on the probable tools. This suggests that they may have been used in activities such as butchering, which does not significantly alter the tool edge.

The second means by which to identify ambiguous bone tools is through the recognition of intentional modifications for the purpose of shaping the artefact, and the demonstration that such modifications cannot be ascribed to natural agents, or be the by-product of other subsistence activities. The purpose of Shipman's comparison between possible bone tools and the remainder of the Olduvai assemblage, was not to identify bone tools, but to identify differences between pieces she had previously selected as bone tools, based on the presence or absence of microscopic traces of utilization. Her objective was to characterize hominid preferences for certain bone types. Since our microscopic results challenged her findings, our comparison between purported tools and non-tools had a different objective, namely to contrast the occurrence of taphonomic features and potential traces of manufacture in the Leakey bone tool collection, the Olduvai control sample, and the experimental bone breakage collection, with the objective of isolating an idiosyncratic population of specimens, for which a robust argument could be made for their identification as tools.

Although it is difficult to formally demonstrate that some of the bones from the Leakey collection were intentionally flaked, we believe that our results strengthen this interpretation for a number of the specimens. For the first time, their artefactual nature was assessed using a step-by-step analysis involving different types of variables. This highlighted to what degree each of these pieces bears features interpretable as evidence of intentional shaping.

Villa & Bartram (1996) report on bones of medium- to large-size herbivores from the Pleistocene hyaena den of Bois Roche in France, bearing continuous scars that in some cases mimic scaling retouch. They correctly caution against the interpretation of flaked bones as evidence of bone shaping without the support of contextual and taphonomic analysis of the bone assemblage. A carnivore origin for the flake scars on the more convincing Olduvai bone tools cannot be advocated for a number of reasons. Almost all of the Bois Roche 'flaked' bones show clear signs of hyaena damage in the form of heavy gnawing of articular ends, and pitting and scoring on shafts, features that are rare at Olduvai and virtually absent on the specimens interpreted as tools. Instead, the majority of these pieces record diagnostic stone-induced percussion marks, in a number of cases clearly associated with flake scars. Additionally, pseudo-retouch at Bois Roche is small relative to bone size and does not invade the surface of bones from large mammals by more than 15 mm on the pieces illustrated by Villa and Bartram. This is in stark contrast to the more invasive removals recorded on the Olduvai bone tools. Finally, if carnivores were responsible for the production of flake scars at Olduvai, we should find the same number and proportion of contiguous removals in the Olduvai control sample pertaining to bone from medium- to large-size mammals, as those recorded on the bone tool collection, which is not the case.

In sum, our results indicate that Mary Leakey was correct in isolating a collection of bones, that in her opinion, looked different from the others emerging at Olduvai, and in proposing their interpretation as tools. This was mainly intuitive, relying on morphological similarities between flake scars on stone and putative bone tools. Our results show that many pieces comprising her original collection do not differ significantly from the control sample, or may be similarly interpreted as intentionally-shaped tools, or the result of marrow extraction. We also identify a reduced number of specimens, based on flake removal data (Table 14) that confirm her contention that the bones were tools used by hominids. In order to differentiate between marrow extraction and intentional shaping, future research will focus on the experimental breakage and knapping of extremely fresh bone from very large mammals. Recorded differences in the morphology of the flake scars produced on experimentally-broken elephant bones suggest that those on Olduvai specimens were produced immediately after the animals' death. The breakage of large bone in the same condition can provide an appropriate analogue by which to gather more informed inferences on early bone tool use by East African hominids. A reassessment of the tusk fragments interpreted as tools also needs to be conducted, and analogues compiled to verify the anthropic nature of potential signs of use and manufacture.

An interesting aspect of our results lies in the stratigraphic occurrence of the pieces we are inclined to interpret as bone tools. While for Leakey and Shipman bone tools are present in all beds, we identify, with one possible exception, bone tools only in Bed II (Table 2). This suggests modification of bone fragments by knapping is not a behaviour associated with the Oldowan, but with the more developed phases of this technological tradition (Developed Oldowan B) and/or the Early Acheulean. This observation may have implications for the identification of the maker of these tools. Knapped bone tools appear more systematically, according to our results, in coincidence with the appearance of remains of *H. erectus* in middle and upper Bed II. The presence in a Bed II site of an intentionally knapped bone hand axe (FCII 068-6679, Fig. 29) constitutes supplementary evidence that *H. erectus* was responsible for at least a part of these bone tools.

The alternative hypothesis is that the use of this raw material represents an innovation within a cultural tradition, developed by one or more pre-existing hominin taxa. We favour for a number of reasons the first hypothesis. The relatively low number of bone tools found at Olduvai compared to stone tools is not due to taphonomic reasons, which indicates that modification by knapping of this raw material was occasional and can be interpreted as an extension of motions applied to stone. The size of the mammals involved, and the freshness of the bone used, suggests this extension may have been practiced to facilitate the butchering of large animals, perhaps on occasions when suitable raw material was not immediately available, or could not be transported to the butchering site before the arrival of competitors. Since the production of this type of tool pertains more to the domain of expedient adaptation than to technological innovation (*sensu stricto*), and considering that instances of large mammal butchering are recorded at Bed I sites, one may expect to find occurrences of the same practice in the lower levels, but this is not the case.

The reason may lie in the neuro-motor abilities of various East Africa hominin taxa, enabling some or all of them to knap stone, but only few to effectively knap bone, or do it in a way that has left detectable removals. Though limited, and not made on very fresh bone, knapping experiments conducted in the framework of this study confirm what was known from previous experiments (Bonnichsen 1979; Stanford *et al.* 1981; Haynes 1991; Vincent 1993; Peretto *et al.* 1996), that particular skills are required to produce contiguous invasive removals on long bone shaft fragments. This is due to the elastic and anisotropic nature of bone matter, which obliges the knapper to develop specific adaptations in the strength and control of the blow.

Hovers (2001), notes that both physical and mental capacities are factors that must be considered when inferring knapping skills from archaeological finds. On the one hand, anatomical characteristics dictate the dexterity of a stone tool maker and the ability to manipulate various raw materials in applying the correct force and direction of blows during the reduction process. On the other hand, technical knowledge, or the cognition necessary to implement a mode of tool production (Roche 2000), sets the objectives of the action. Knapping skills may therefore be hampered by limitations in one or both of these broadly defined domains.

Chimps in the wild do not knap stone. Cracking nuts can occasionally produce irregular flakes due to the breakage of the stone hammers (Mercader *et al.* 2002) but the resulting blanks are significantly different from those found at Oldowan sites. Although showing some skills in knapping activities, bonobos trained in captivity do not seem to be able to reach the level of control required to produce Oldowan tools, and even less so Developed Oldowan or Early Acheulean tools (Toth *et al.* 1993). In light of the cognitive competence shown by these animals in other domains, and the well-known strength of their muscles, these restrictions must be attributed to differences in neuro-physiology and anatomy, rather than cognition or strength.

Whether australopithecines were anatomically capable of stone knapping, and if so, which species had these abilities, is debatable (e.g. Susman 1991, 1998; Marzke 1997). The date for the oldest occurrence of stone tools in East Africa (2.6 Mya), which slightly predates the oldest evidence for early *Homo* (Semaw *et al.* 2003), indicates australopithecines could have been be the authors of these early knapping traditions. It does not demonstrate, if this was indeed the case, that australopithecines could extend such abilities to bone matter. Early *Homo* instead appears to have had many, if not all the specific elements of precision grip necessary for habitual tool-making (Marzke 1997). It is possible that these features enabled this hominid to efficiently (albeit occasionally) knap bone, a material that for others was difficult to modify using these motions.

Our identification of ground horn cores at southern African sites shows that the barrier was not a cognitive one, as we see these hominids develop techniques specifically conceived to modify bone in a different cultural and environmental context.

CONCLUSION

We do not consider the results presented here as the last word on the early use of bone tools. In spite of our efforts to tackle the problem from a multi-angled perspective, the definitive identification of flaked bone tools remains a tricky endeavour for a number of specimens. However, evidence gathered in the framework of this study, indicates that bone tool use is attested at different Olduvai localities between 2.1 and 1.15 Mya. It consists of complete bones used as hammers, long bone shaft fragments intentionally shaped by knapping, and possible wedges. This evidence contrasts sharply with findings from a number of contemporaneous South African sites. The use of bone at Olduvai involves large to very large mammals, is confined to limb elements that include an astragalus and patella, applies to very fresh pieces, adopts motions similar to those used for knapping stone, appears to be expedient and occasional, concerns multiple tasks, and is probably restricted to large mammal carcass processing. South African bone tools found at early hominid sites derive from medium-size bovids, are made almost exclusively of weathered limb bone shaft fragments and horn cores, are occasionally shaped by grinding – a technique peculiar to this raw material, and were systematically used in digging activities that probably involved termite or tuber extraction.

One may argue that these discrepancies are due to the different nature of the sites preserving the faunal remains, and that bone tools similar to those from Olduvai may have been used by South African hominids at sites located far from the catchment basins that preserve the bone digging tools. However, this hypothesis is contradicted for Olduvai, considering the good state of preservation of the faunal assemblage and the absence of bone digging implements at this site. We therefore conclude that the remarkable behavioural differences recorded between these two regions indicate that we are dealing with different subsistence strategies, suggesting distinct cultural traditions. Whether these can be interpreted as the expression of regional variants in the adaptation of a single hominid species, or the product of different species, if not genera, is hard to tell at this stage. The emergence of bone tool utilization in both regions is not coincidental with the emergence of the genus *Homo,* and the time span for which bone tools were used, ends with the extinction of the robust australopithecines. This suggests, in light of the virtual absence of bone tools in the African Acheulean and early Middle Stone Age, that early bone tool industries do not represent, as often postulated in the past, a first step in a process of increasing sophistication, the beginning of which has been seen as the behavioural counterpart of the emergence of our genus. The hand axe morphology of one of the flaked bone tools from Olduvai (FCII 068-6679, Fig. 29) may be taken as an indication that bone shaping by knapping is associated with an Early Acheulean industry traditionally assigned to *Homo erectus.* Broken stone bifaces are reported from the same Olduvai locality where the hand axe-like bone tool was found, but this does not exclude other hominids such as *Australopithecus boisei* or *Homo habilis* as the potential makers and users of these tools.

We dedicate this paper to the memory of Mary Leakey, who first identified the Olduvai Gorge bone tools and recognized the significance of this discovery. We thank P. Bushozi of the Ministry of Natural Resources and Tourism in Tanzania and

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REFERENCES

AGUIRRE, E. 1986. Format et techniques dans la fracturation d'ossements à Torralba (Soria, Espagne). **In**: Patou-Mathis, M. (ed.), *Artefacts 3. Outillage Peu elaboré en Os et en Bois de Cervidé,* 81–89. Treignes, CEDARC.

ANDREWS, P. 1990. *Owls, Caves and Fossils.* Chicago, University of Chicago Press.

ANZIDEI, A.P., ARNOLDUS-HUYZENVELD, A., CALOI, L., LEMORINI, C. & PALOMBO, M.R. 1999. Two Middle Pleistocene sites near Rome (Italy): La Polledrara di Cecanibbio and Rebibbia-Casal de' Pazzi, **In:** Gaudzinski, S. & Turner, E (eds), *The Role of Early Humans in the Accumulation of European Lower and Middle Paleolithic Bone Assemblages,* 173–195. Mainz, Monographien des Römisch-Germanischen Zentralmuseums 42.

BACKWELL, L.R. 2000. *A Critical assessment of southern african early hominid bone tools.* Unpublished M.Sc. dissertation, University of the Witwatersrand, Johannesburg.

BACKWELL, L.R. & D'ERRICO, F. 1999. The application of SEM, confocal microscopy and image analysis to assess the first use of bone by early hominids. *Microscopy Society of Southern Africa 38th Annual Conference,* 1–3 December 1999, University of the Free State, Bloemfontein, South Africa.

BACKWELL, L.R. & D'ERRICO, F. 2001. First evidence of termite-foraging by Swartkrans early hominids. *Proceedings of the National Academy of Sciences* **98**(4), 1358–1363.

BACKWELL, L.R. & D'ERRICO F. 2003. Additional evidence on the early hominid bone tools from Swartkrans with reference to spatial distribution of lithic and organic artefacts. *South African Journal of Science* **99**, 259–267.

BASTIN, A.H. 1932. Nouvelle contribution à l'étude de l'utilisation de l'os au Paléolithique inférieur. 1. L'épieu acheuléen de Saint-Mard (Aisne). 2. L'humérus débité de Saratov (U.R.S.S.). *Bulletin de la Société Préhistorique Française* **29**, 458–65.

BEHRENSMEYER, A.K. 1978. Taphonomic and ecological information from bone weathering. *Paleobiology* **4**, 150–162.

BIBERSON P. & AGUIRRE, E. 1965. Expériences de taille d'outils préhistoriques dans des os d'éléphant. *Quaternaria* **7**, 165–184.

BIDDITTU, L. & BRUNI, L. 1987. Il Rinvenimento di Una Amigdala in Osso del Paleolitico Inferiore a Fontana Ranuccio (Anagni). *Latium* **4**, 3–9.

BIDDITTU, L. & SEGRE, A.G. 1982a. Utilizzazione dell'osso nel Paleolitico inferiore Italiano. *Atti della XXIII Riunione Scientifica dell'Istituto Italiano di Preistoria e Protost,* 89–105.

BIDDITTU, L. & SEGRE, A.G. 1982b. Industria su Scheggia e Bifacciali: Nuovi Reperti Del Paleolitico Inferiore ad Anagni-Fontana Ranuccio, Frosinone. *Atti 24a Riunione Scientifica Instituto Italiano di Preistoria e Protostoria,* 105–112.

BIDDITTU, L., CASSOLI, P.F., RADICATI DI BROZOLO, F., SEGRE, A.G., SEGRE NALDINI, E. & VILLA, I. 1979. Anagni, a K-Ar dated Early and Middle Pleistocene Site, Central Italy: preliminary report. *Quaternaria* **XXI**, 53–71.

BINFORD, L.R. 1981. *Bones, Ancient Men and Modern Myths.* New York, Academic Press.

BLUMENSCHINE, R.J. 1987. Characteristics of an early hominid scavenging niche. *Current Anthropology* **28**, 383–407.

BLUMENSCHINE, R.J. 1995. Percussion marks, tooth marks, and experimental determinations of the timing of hominid and carnivore access to long bones at FLK *Zinjanthropus,* Olduvai Gorge, Tanzania. *Journal of Human Evolution* **29**, 21–51.

BLUMENSCHINE, R.J. & MASAO, F.T. 1991. Living sites at Olduvai Gorge, Tanzania?: preliminary landscape archaeology results in the basal Bed II lake margin zone. *Journal of Human Evolution* **21**(6), 451–462.

BLUMENSCHINE, R.J. & SELVAGGIO, M.M. 1988. Percussion marks on bone surfaces as a new diagnostic of hominid behaviour. *Nature* **333**, 763–765.

BLUMENSCHINE, R.J., MAREAN, C. & CAPALDO, S.D. 1996. Blind tests of inter-analyst correspondence and accuracy in identification of cut marks, percussion marks, and carnivore tooth marks on bone surfaces. *Journal of Archaeological Science* **23**, 493–507.

BONNEFILLE, R.J. & RIOLLET, G. 1984. Palynological research at Olduvai Gorge. Research Reports No. 17, 227–243. Washington, D.C., National Geographic Society.

BONIFAY, E. 1974. Outils en os et os utilisés dans le Paléolithique ancien du Mas des Caves à Lunel-Viel (Hérault) (Note préliminaire), *L'industrie de l'os dans la Préhistoire,* sous la direction de H. Camps-Fabrer, pp. 157–167. Aix-en-Provence, Université de Provence.

BONIFAY M-F. 1986. Le matériel osseux fragmenté déterminable au Paléolithique ancien: mise en évidence, catégories, histogramme. *Artefacts 3,* Outillage en os peu élaboré en os et en bois de Cervidés II, Ed. du C.E.D.A., pp. 11–14. Belgique.

BONNICHSEN, R. 1979. Pleistocene bone technology in the Beringian refugium. *National Museum of Man Mercury Series Archaeological Survey of Canada Paper 89*. National Museum of Man, Ottawa.

BONNICHSEN, R. & SORG, M.H. 1989. *Bone Modification.* Orono, University of Maine.

BONNICHSEN, R. & WILL, R.T. 1980. Cultural modification of bone: the experimental approach in faunal analysis. **In**: Gilbert, B.M. (ed.), *Mammalian Osteology,* 7–30. Wyoming, United States of America, B. Miles Gilbert Publisher.

BRAIN, C.K. 1967. Bone weathering and the problem of bone pseudo-tools. *South African Journal of Science* **63**, 97–99.

BRAIN, C.K. 1981. *The Hunters or The Hunted? An Introduction to African Cave Taphonomy.* Chicago, University of Chicago Press.

BRAIN, C.K. 1989. The evidence of bone modification by early hominids in southern Africa. **In**: Bonnichsen, R. & Sorg, M.H. (eds), *Bone Modification,* 291–297. Orono, University of Maine.

BRAIN, C.K. 1993. *Swartkrans. A Cave's Chronicle of Early Man.* Transvaal Museum Monograph No. 8. Pretoria, Transvaal Museum.

BRAIN, C.K. & SHIPMAN, P. 1993. The Swartkrans bone tools. **In**: Brain, C.K. (ed.), *Swartkrans. A Cave's Chronicle of Early Man,* 195–215. Transvaal Museum Monograph No. 8. Pretoria, Transvaal Museum.

BRAIN, C.K., CHURCHER, C.S., CLARK, J.D., GRINE, F.E., SHIPMAN, P., SUSMAN, R.L., TURNER, A. & WATSON, V. 1988. New evidence of early hominids, their culture and environment from the Swartkrans cave, South Africa. *South African Journal of Science* **84**, 828–835.

BREUIL, H. 1932. Pointe d'épieu en os du Moustérien de la caverne du Castillo (Santander). *L'Anthropologie* **42**, 679–80.

BREUIL, H. 1938. Bone and antler industry of the Chou-Koutien *Sinanthropus* site. *Paleontologia Sinica* n.s. 6, Pékin.

BREUIL, H., & BARRAL, L. 1955. Bois de cervidés et autres os travaillés sommairement au Paléolithique ancien du vieux monde et au Mustérien des grottes de Grimaldi et de l'Observatoire de Monaco. *Bulletin du Musée d'Anthropologie et Préhistoire de Monaco* **2**, 3–34.

BROMAGE, T. 1987. The SEM/replica technique and recent applications to the study of fossil bone. *Scanning Electron Microscopy* **1987**, 607–613.

BUNN, H.T. 1981. Archaeological evidence for meat-eating by Plio-Pleistocene hominids from Koobi Fora and Olduvai Gorge. *Nature* **291**, 574–577.

BUNN, H.T. 1986. Patterns of skeletal representation and hominid activities at Olduvai Gorge, Tanzania, and Koobi Fora, Kenya. *Journal of Human Evolution* **15**, 673–690.

BUNN, H.T. & KROLL, E.M. 1986. Systematic butchery by Plio-Pleistocene hominids at Olduvai Gorge, Tanzania. *Current Anthropology* **27**(5), 431–452.

CAHEN, D., HAESAERT, P., VAN NEER, W. & VAN PAMEL, P. 1979. Un outil en os du Paléolithique inférieur dans la nappe alluviale de Mesvin. *Helinium* **19**, 105–127.

CAMPANA, D. 1980. *An Analysis of the Use-wear Patterns on Natufian and ProtoNeolithic Bone Implements.* Unpublished Ph.D. dissertation, Columbia University, Ann Arbor, New York.

CAMPETTI, S., D'ERRICO, F., GIACOBINI, G. & RADMILLI, A.M. 1989. Taphonomie, industrie osseuse et pseudo-instruments en os dans le site du Paléolithique inférieur de Castel di Guido (Rome). *Outillage peu élaboré en os et en bois de cérvides,* 21–23. Treignes, III, Edition du Centre d'Études et de Documentation Archéologique.

CAPALDO, S.D. 1998. Simulating the formation of dual-patterned archaeofaunal assemblages with experimental control samples. *Journal of Archaeological Science* **25**, 311–330.

CAPALDO, S.D. & BLUMENSCHINE, R.J. 1994. A quantitative diagnosis of notches made by hammerstone percussion and carnivore gnawing on bovid long bones. *American Antiquity* **59**, 724–748.

CERLING, T.E. 1986. An isotopic study of paleosol carbonates from Olduvai Gorge. *Quaternary Research* **25**, 63–78.

DART, R.A. 1957. The osteodontokeratic culture of *Australopithecus* *prometheus.* Transvaal Museum Memoir No. 10. Pretoria, Transvaal Museum.

DECHANT BOAZ, D. 1994. Taphonomy and the fluvial environment. Examples from Pliocene deposits of the Shungura Formation, Omo Basin, Ethiopia. **In**: Corruccini, R.S. & Ciochon, R.L. (eds), *Integrative Paths to the Past. Paleoanthropological Advances in Honor of F. Clark Howell,* 377–414. Englewood Cliffs, New Jersey, Prentice Hall .

DEINO, A.L. & HILL, A. 2002. 40Ar/39/Ar dating of the Chemeron Formation strata encompassing the site of hominid KNM-BC 1, Tugen Hills, Kenya. *Journal of Human Evolution* **42**, 141–151.

D'ERRICO, F. 1988a. Nouvelles observations sur deux pièces en silex et un objet en os de la Grotte du Vallonnet (Alpes-Maritimes). *L'Anthropologie* **92**(2), 615–628.

D'ERRICO, F. 1988b. The use of resin casts for the study of use-wear. **In**: Olsen, S.L. (ed.), *Scanning Electron Microscopy in Archaeology,* 155–167. Oxford, British Archaeological Report.

D'ERRICO, F. 1993a. Identification des traces de manipulation, suspension, polissage sur des objets d'art mobilier en os, bois de cervidés, ivoire. *Traces et fonction: les Gestes Retrouvés,* 177–188. Liège, Éditions ERAUL 50.

D'ERRICO, F. 1993b. Criteria for identifying utilised bone: the case of the Cantabrian 'Tensors'. *Current Anthropology* **34**(3), 298–311.

D'ERRICO F. 1996. Image analysis and 3-D optical surface profiling of Upper Palaeolithic mobiliary art. *Microscopy and Analysis* **39**, 27–29.

D'ERRICO, F. & VILLA, P. 1997. Holes and grooves. The contribution of microscopy and taphonomy to the problem of art origins. *Journal of Human Evolution* **33**, 1–31.

D'ERRICO, F. & BACKWELL, L.R. 2003. Possible evidence of bone tool shaping by Swartkrans early hominids. *Journal of Archaeological Science* **30**, 1559–1576.

D'ERRICO F., GIACOBINI, G. & PUECH P-F. 1984. Varnish replicas. A new method for studying worked bone surfaces. *OSSA, International Journal of Skeletal Research* **9/10**, 29–51.

D'ERRICO, F., BACKWELL, L.R. & BERGER L.R. 2001. Bone tool use in termite foraging by early hominids and its impact on understanding early hominid behaviour. *South African Journal of Science* **97**, 71–75.

D'ERRICO, F., JULIEN, M., LIOLIOS, M., VANHAEREN, M. & BAFFIER, D. 2003. Many awls in our argument. Bone tool manufacture and use from the Chatelperronian and Aurignacian layers of the Grotte du Renne at Arcy-sur-Cur. **In**: Zilhão, J. & d'Errico, F. (eds), *The Chronology of the Aurignacian and of the Transitional Technocomplexes. Dating, Stratigraphies, Cultural Implications*, 247–272. Lisbon, Instituto Português de Arqueologia.

FISHER, J.W. 1995. Bone surface modifications in zooarchaeology. *Journal of Archaeological Method and Theory* **2**(1), 7–69.

FREEMAN, L.G. 1978. 'Mousterian worked bones from Cueva Morin (Santander, Spain): A preliminary description'. **In**: Freeman, L.G. (ed.) *Views of the Past,* 29–51. The Hague, Mouton.

FREEMAN, L.G. 1983. More on the Mousterian flaked bone from Cueva Morin. *Current Anthropology* **24**, 366–77.

GAUTIER, A. 1986. Une histoire de dents: les soi-disant incisives travaillées du Paléolithique moyen de Sclayn. *Hélinium* **26**, 177–181.

GAUDZINSKI S. 1999. Middle Palaeolithic bone tools from the open-air site Salzgitter-Lebensted (Germany). *Journal of Archeological Science* **26**, 125–141.

GIFFORD-GONZALEZ, D. 1989. Ethnographic analogues for interpreting modified bones: some cases from East Africa. **In**: Bonnichsen, R. & Sorg, M.H. (eds), *Bone Modification,* 179–246. Orono, University of Maine Centre for the Study of the First Americans. U.S.A., Thompson-Shore Inc.

GIFFORD-GONZALEZ, D. 1991. Bones are not enough: analogues, knowledge, and interpretive strategies in zooarchaeology. *Journal of Anthropological Archaeology* **10**, 215–254

GONZÁLEZ-URQUIJO, J.E. & IBÁÑEZ-ESTÉVEZ, J.J. 2003. The quantification of use-wear polish using image analysis. First results. *Journal of Archaeological Science* **30**(4), 481–489.

HANNUS, L.A. 1990. The Lange-Ferguson site: a case for mammoth bone-butchering tools. Megafauna and man. **In**: Agenbroad, L., Mead, J. & Nelson, L. (eds), *Discovery of America's Heartland,* 86–99. Hot Springs, South Dakota.

HANNUS, L.A. 1997. Mammoth bone flake tools from the Lange-Ferguson site, South Dakota. **In**: Hannus, L.A., Rossum, L. & Winham, R.P. (eds), *Proceedings of the 1993 Bone Modification Conference, Hot Springs, South Dakota,* 220–235. Occassional Paper No. 1. Sioux Falls, Archeology Laboratory, Augustana College.

HAY, R.L. 1976. *Geology of the Olduvai Gorge.* Berkeley and Los Angeles, University of California Press.

HAYNES, G. 1983. A guide for differentiating mammalian carnivore taxa responsible for gnaw damage to herbivore limb bones. *Paleobiology* **9**, 164–172.

HAYNES, G. 1988. Longitudinal studies of African elephant death and bone deposits. *Journal of Archaeological Science* **15**, 131–157.

HAYNES, G. 1991. *Mammoths, Mastodonts, and Elephants: Biology, Behaviour and the Fossil Record.* Cambridge, Cambridge University Press.

HENSHILWOOD, C. & SEALEY, J. 1997. Bone artefacts from the Middle Stone Age at Blombos Cave, southern Cape, South Africa. *Current Anthropology* **38**, 890–95.

HENSHILWOOD, C., D'ERRICO, F., MAREAN, C., MILO, R. & YATES, R. 2002. An early bone tool industry from the Middle Stone Age at Blombos Cave, South Africa: implications for the origins of modern human behaviour, symbolism and language. *Journal of Human Evolution* **41**, 631–678

HOVERS, E. 2001. Treading carefully: site formation processes and Pliocene lithic technology. **In**: Moreno, J.M., Torcal, R.M. & de la Torre Sainz, I. (eds), *Oldowan: Rather More Than Smashing Stones,* 145–164. First Hominid Technology Workshop, Bellaterra.

HOWELL, F.C. & FREEMAN, L.G. 1983. Ivory points from the earlier Acheulean of the Spanish Meseta. **In**: *Homenaje al Prof. Martin Almagro Basch,* 41–61. Madrid, Ministerio de Cultura.

HOWELL, F.C., BUTZER, K.W., FREEMAN, L.G. & KLEIN, R.G. 1995. Observations on the Acheulean occupation site of Ambrona (Soria Province, Spain) with particular reference to recent investigations (1980–1983) and the lower occupation. *Jahrbuch. Römisch-Germanischen Zentralmuseum Mainz* **38**, 33–82.

ISAAC, G. Ll. 1971. The diet of early man: aspects of archaeological evidence from Lower and Middle Pleistocene sites in East Africa. *World Archaeology* **2**, 278–299.

ISAAC, G. Ll. 1978. The food-sharing behaviour of protohuman hominids. *Scientific American* **238**, 90–108.

ISAAC, G. Ll. 1983. Bones in contention: competing explanations for the juxtaposition of early Pleistocene artefacts and faunal remains. **In**: Clutton-Brock, C. & Grigson, C. (eds), *Animals and Archaeology. Vol. 1. Hunters and Their Prey,* 3–19. Oxford, British Archaeological Reports International Series 163.

KAPPELMAN, J. 1984. Plio-Pleistocene environments of Bed I and lower Bed II, Olduvai Gorge, Tanzania. *Palaeogeography, Palaeoclimate, Palaeoecology* **48**, 171–196.

KEELEY, L.H. & TOTH, N. 1981. Microwear polishes on early stone tools from Koobi Fora, Kenya. *Nature* **293,** 464–465.

KEYSER, A. 2000. New finds in South Africa. *National Geographic* **May**, 77–83.

KIBUNJIA, M. 1994. Pliocene archaeological occurrences in the Lake Turkana Basin. *Journal of Human Evolution* **27**, 159–171.

KITCHING, J.W. 1963. Bone, tooth and horn tools of Palaeolithic man: an account of the osteodontokeratic discoveries in Pinhole Cave, Derbyshire. Manchester, Manchester University Press.

KLEIN, R.G. 1975. Palaeoanthropological implications of the non-archaeological bone assemblage from Swartklip I, south-western Cape Province, South Africa. *Quaternary Research* **5**, 275–288.

KOBY, F.E. 1943. Les soi-disant instruments osseux du Paléolithiques alpin et le charriage à sec des os d'ours des cavernes. *Verhandlungen der Naturforschenden Gesellschaft Basel* **54**, 59–95.

KUMAN, K. 1994. The archaeology of Sterkfontein – past and present. *Journal of Human Evolution* **27**, 471–495.

KUMAN, K. 2003. Site formation in the early South African Stone Age sites and its influence on the archaeological record. *South African Journal of Science* **99**(5/6), 251–254.

KUMAN, K. & CLARKE, R.J. 2000. Stratigraphy, artifact industries and hominid associations for Sterkfontein, Member 5. *Journal of Human Evolution* **38**, 827–847.

LEAKEY, M.D. 1971. *Olduvai Gorge. Vol. 3. Excavations in Beds I and II.* Cambridge, Cambridge University Press.

LEAKEY, L.S.B., TOBIAS, P.V. & NAPIER, J.R. 1964. A new species of the genus *Homo* from Olduvai Gorge. *Nature* **202**, 5–7.

LEMOINE, G.M. 1997. Use wear analysis on bone and antler tools of the Mackenzie Inuit. *BAR International Series 679.*

LYMAN, R.L. 1984. Broken bones, bone expediency tools, and bone pseudotools: lessons from the blast zone around Mount St. Helens, Washington. *American Antiquity* **49**(2), 15–333.

LYMAN, R.L. 1994. *Vertebrate Taphonomy.* Cambridge, Cambridge University Press.

MACGREGOR, A. 1975. Problems in the interpretation of microscopic wear patterns: the evidence from bone skates. *Journal of ArchaeologicalScience* **2**, 385–390.

MAGUIRE, J.M., PEMBERTON, D. & COLLETT, M.H. 1980. The Makapansgat Limeworks Grey Breccia: hominids, hyaenas, hystricids or hillwash? *Palaeontologia Africana* **23**, 75–98.

MANIA, D. 1990. *Auf den Spurendes Urmenschen: Die Funde von Bilzingsleben.* Berlin, Deutscher Verlag der Wissenschaften.

MANIA, D. 1995. The utilization of large mammal bones in Bilzingsleben: a special variant of Middle Pleistocene man's relationship to his environment. **In**: Ullrich, H. (ed.), *Man and Environment in the Paleolithic,* 239–246. Liege, E.R.A.U.L.

MANIA, D. & WEBER, T. 1986. *Bilzingsleben III.* Berlin, Deutscher Verlag der Wissenschaften.

MARSHALL, L.G. 1989. Bone modification and the 'laws of burial'. **In**: Bonnichsen, R. & Sorg, M.H. (eds), *Bone Modification,* 7–24. Orono, University of Maine Centre for the Study of the First Americans. Thompson-Shore Inc, U.S.A.

MARZKE, M.W. 1997. Precision grips, hand morphology and tools. *American Journal of Physical Anthropology* **102**, 91–110.

MERCADER, J., PANGER, M. & BOESCH, C. 2002. Excavation of a chimpanzee stone tool site in the African rainforest. *Science* **296**, 1452–1455.

OLIVER, J.S. 1994. Estimates of hominid and carnivore involvement in the FLK *Zinjanthropus* fossil assemblage: some socioecological implications. *Journal of Human Evolution* **27**, 267–294.

OLSEN, S.L. 1989. On distinguishing natural from cultural damage on archaeological antler. *Journal of Archaeological Science* **16**, 125–135.

OLSEN, S.L. & SHIPMAN, P. 1988. Surface modification on bone: trampling versus butchery. *Journal of Archaeological Science* **15**, 535–553.

PEI, W.C. 1938. Le rôle des animaux et des causes naturelles dans la cassure des os. *Palaeontologia Sinica* **7**, 1–16.

PELTIER, A. 1986. Étude experimental des surfaces osseuses faconnées et utilisées. *Bulletin de la Societé Préhistorique Française* **83**(1), 5–7.

PERETTO, C., ANCONETANI, P., CROVETTO, C., EVANGELISTA, L., FERRARI, M., GIUSBERTI, G., THUN HOHESTEN, U. & VIANELLO, F. 1996. Approccio sperimentale all comprensione delle attività di sussistenza condotte nel sito di Isernia La Pineta (Molise-Italia). La Frattura intenzionale. **In**: Peretto, C. (ed.), *I reperti paleontologici del giacimento do Isernia La Pineta,* 187–451. Isernia, Cosmo Iannone Editore.

PETRAGLIA, M.D. & KORISETTAR, R.I. 1998. *Early Human Behavior in Global Context: The Rise and Diversity of the Lower Palaeolithic Record.* One World Archaeology, No. 28. New York, Routledge.

POTTS, R. 1988. *Early Hominid Activities at Olduvai.* New York, Aldine de Gruyter.

RADMILLI, A.M. 1985. Scavi nel giacimento del Paleolitico inferiore di Castel di Guido presso Roma. **In**: Bietti Sestieri, A.M. (ed.), *Preistoria e Protostoria nel territorio di Roma,* 75–85. Rome, De Luca.

RADMILLI, A.M. & BOSCHIAN, G. 1996. *Gli scavi a Castel di Guido.* Firenze, Instituto Italiano di Preistoria e Protostoria, ETS.

ROBINSON, J.T. 1959. A bone implement from Sterkfontein. *Nature* **184,** 583–585.

ROCHE, H. 2000. Variability of Pliocene lithic production in East Africa. *Acta Anthropologica Sinica* **19**, 98–103.

ROCHE, H., DELAGNES, A., BRUGAL, J-P., FEIBEL, C., KIBUNJIA, M., MOURRE, V. & TEXIER, P-J. 1999. Early hominid stone tool production and technical skill 2.34 Myr ago in West Turkana, Kenya. *Nature* **399**, 57–60.

SCHMIDTGEN, O. 1929. Knochenartefakte aus den Mosbacher Sanden. *Jahrbücher des Nassauischen Vereins für Naturkunde, Wiesbaden* **80**, 1–6.

SELVAGGIO, M.M. 1998. Evidence for a three-stage sequence of hominid and carnivore involvement with long bones at FLK *Zinjanthropus,* Olduvai Gorge, Tanzania. *Journal of Archaeological Science* **25**, 191–202.

SEMAW, S., RENNE, P., HARRIS, J.W.K., FEIBEL, C.S., BERNOR, R.L., FESSEHA, N. & MOWBRAY, K. 1997. 2.5-million-year-old stone tools from Gona, Ethiopia. *Nature* **385**, 333–336.

SEMAW, S., ROGERS, M.J., QUADE, J., RENNE, P., BUTLER, R.F., DOMINGUEZ-RODRIGO, M., STOUT, D., HART, W.S., PICKERING, T.R. & SIMPSON, S. 2003. 2.6-million-year-old stone tools and associated bones from OGS-6 and OGS-7, Gona, Afar, Ethiopia. *Journal of Human Evolution* **45**, 169–177.

SHIPMAN, P. 1984. The earliest tools: re-assessing the evidence from Olduvai Gorge. *Anthroquest* **29**, 9–10.

SHIPMAN, P. 1986a. Studies of hominid–faunal interactions at Olduvai Gorge. *Journal of Human Evolution* **15**, 691–706.

SHIPMAN, P. 1986b. Scavenging or hunting in early hominids: theoretical framework and tests. *American Anthropologist* **88**, 27–43.

SHIPMAN, P. 1988. Actualistic studies of animal resources and hominid activities. **In**: Olsen, S.L. (ed.), *Scanning Electron Microscopy in Archaeology,* 261–285. Oxford, BAR International Series 452.

SHIPMAN, P. 1989. Altered bones from Olduvai Gorge, Tanzania: techniques, problems, and implications of their recognition. **In**: Bonnichsen, R. & Sorg, M.H. (eds), *Bone Modification,* 317–334. Orono, University of Maine Centre for the Study of the First Americans. U.S.A., Thompson-Shore Inc.

SHIPMAN, P. & PHILLIPS, J. 1976. On scavenging by hominids and other carnivores. *Current Anthropology* **17**(1), 170–172.

SHIPMAN, P. & PHILLIPS-CONROY, J. 1977. Hominid tool-making versus carnivore scavenging. *American Journal of Physical Anthropology* **46**, 77–86.

SHIPMAN, P. & ROSE, J.J. 1984. Cutmark mimics on modern and fossil bovid bones. *Current Anthropology* **25**(1), 116–117.

SHIPMAN, P. & ROSE, J.J. 1988. Bone tools: an experimental approach. **In**: Olsen, S.L. (ed.), *Scanning Electron Microscopy in Archaeology,* 303–335. British Archaeological Reports, International Series 452.

SHIPMAN, P., FISHER, D.C. & ROSE, J.J. 1984. Mastodon butchery: microscopic evidence of carcass processing and bone tool use. *Paleobiology* **10**(3), 358–365.

STANFORD, D., BONNICHSEN, R. & MORLAN, R.E. 1981. The Ginsberg experiment: modern prehistoric evidence of a bone-flaking technology. *Science* **212**, 438–440.

STRINGER, C.B. 1977. Evidence of climatic change and human occupation during the Last Interglacial at Bacon Hole, Gower. *Gower* **28**, 36–44.

SUSMAN, R.L. 1991. Who made the Oldowan tools? Fossil evidence for tool behavior in Plio-Pleistocene hominids. *Journal of Anthropological Research* **47**,129–151.

SUSMAN, R.L. 1994. Fossil evidence for early hominid tool use. *Science* **265**, 1570–1573.

SUSMAN, R.L. 1998. Hand function and tool behavior in early hominids. *Journal of Human Evolution* **35**, 23–46.

SUTCLIFFE, A.J. 1970. Spotted hyaena: crusher, gnawer, digester and collector of bones. *Nature* **227**, 1110–1113.

SUTCLIFFE, A.J. 1973. Similarity of bones and antlers gnawed by deer to human artefacts. *Nature* **246**, 428–430.

SUTCLIFFE, A.J. 1977. Further notes on bones and antler chewed by deer and other ungulates. *Deer* **4**(2), 73–82.

SUWA, G., WHITE, T. & HOWELL, F.C. 1996. Mandibular post-canine dentition from the Shungura Formation, Ethiopia: crown morphology, taxonomic allocation, and Plio-Pleistocene hominid evolution. *American Journal of Physical Anthropology* **101**, 247–282.

TOBIAS, P.V. 1965. *Australopithecus, Homo habilis*, tool-using and tool-making. *South African Archaeological Bulletin* **20**, 167–192.

TOTH, N., SCHICK, K., SAVAGE-RUMBAUGH, S., SEVCIK, R. & SAVAGE-RUMBAUGH, D. 1993. Pan the tool-maker: investigations into the stone tool-making and tool-using capabilities of a bonobo (*Pan paniscus*). *Journal of Archaeological Science* **20**, 81–91.

TROMNAU, G. 1983. Ein Mammutknochen-Faustkeil aus Rhede, Kreis Borken (Westfalen). *Archäologisches Korrespondenzblatt* **13**, 287–289.

VILLA, P. & BARTRAM, L. 1996. Flaked bone from a hyena den. *Paléo* **8**, 143–159.

VILLA, P. & D'ERRICO, F. 1998. Bone and ivory points in the Lower and Middle Paleolithic: a review of the evidence from Western Europe. Abstract for the Paleoanthropology Society Meeting. *Journal of Human Evolution* **36**(4), 25–26.

VILLA, P. & D'ERRICO, F. 2001. Bone and ivory points in the Lower and Middle Paleolithic of Europe. *Journal of Human Evolution* **41**, 69–112.

VILLA, P; ANZIDEI, A.P. & CERILLI, E. 1999. Bones and bone modifications at La Polledrara, a Middle Pleistocene site in Italy. **In**: Gaudzinski S. & Turner E. (eds), *The Role of Early Humans in the Accumulation of European Lower and Middle Palaeolithic Bone Assemblages,* Vol. 42, 197–206. Mainz, Römisch-Germanisches Zentralmuseum.

VINCENT, A. 1993. L'outillage osseux au Paléolithique moyen: une nouvelle approche. Thèse de Doctorat, Université Paris X.

WALKER, S.J. 1999. *Paleolithic bone handaxes.* Unpublished M.A. dissertation, University of Reading.

WHITE, T.D. 1992. *Prehistoric Cannibalism at Mancos 5MTUMR-2346.* Princeton NJ, Princeton University Press.