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New Oldowan localities at high level within Kilombe Caldera, Kenya

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Abstract

New occurrences of early artefacts ascribed to the Oldowan tradition come from localities at high level within the caldera of the extinct Kilombe volcano, located in the central rift valley of Kenya. The trachyte cone and caldera of Kilombe volcano formed at ca. 2.5 Ma, and the record of >100m of sediment-fill indicates that the caldera subsequently held a lake for long periods during the Early Pleistocene. The Oldowan artefact localities, dated by $^{40}Ar/^{39}Ar$ and palaeomagnetism to ~1.78 Ma, lie east of the centre of the caldera, on the west side of an ancient small lake, which later drained away as a gorge formed on the east side of the mountain. The artefacts are dominantly made of Kilombe trachyte, and are associated with a fauna of large animals including *Hippopotamus gorgops*. These are the first Oldowan localities to be discovered in a new area of the Kenyan rift valley in the last thirty years, and their presence at high level in rugged landscape indicates that the associated hominins were exploiting a full range of environments.

Keywords

Oldowan Caldera Rift Valley high-altitude Argon-Argon ($^{40}Ar/^{39}Ar$)

Résumé

De nouvelles occurrences d'artefacts anciens attribués à la tradition Oldowayen proviennent de localités situées à un niveau élevé de la caldeira du volcan éteint de Kilombe, situé dans la vallée centrale du Rift au Kenya. Le cône de trachyte et la caldeira du volcan Kilombe se sont formés à ca. 2,5 Ma, et la séquence de plus de 100 m de remplissage de sédiments indique qu'un lac occupait ensuite la caldeira pendant de longues périodes au cours du Pléistocène inférieur. Les sites d'artefacts d'Oldowayen, datés de $^{40}Ar/^{39}Ar$ et du paléomagnétisme à ~1,78 Ma, se trouvent à l'est du centre de la caldeira, sur le côté ouest d'un ancien petit lac, qui s'est ensuite drainé grâce a la formation d'une gorge sur le côté est de la montagne. Les artefacts sont principalement constitués de trachyte de Kilombe et sont associés à une faune de grands animaux, dont *Hippopotamus gorgops*. Ce sont les premières localités Oldowayens à être découvertes dans une nouvelle zone de la vallée du Rift kenyan au cours des trente dernières années, et leur présence à un niveau élevé dans un paysage accidenté indique que les hominidés associés exploitaient une gamme complète d'environnements.

Mots clés

Oldowayen; Caldeira; La vallée du Rift; haute altitude; Argon-Argon ($^{40}Ar/^{39}Ar$)

Introduction

The Oldowan tool-making tradition was first recognised in East Africa, and is known from numbers of sites, including Olduvai, Kanjera, East and West Turkana (Leakey 1971; Barsky 2009; Blumenschine et al. 2003, 2009, 2012a,b, 2020; de la Torre et al. 2018, 2021; Plummer et al. 1999, 2009a,b; Roche et al. 1999; Braun and Plummer 2013; Braun et al. 2008, 2009a,b), as well as various localities in Ethiopia (Braun et al. 2019; Goldman-Neuman and Hovers 2009; Morgan et al. 2012; de Lumley et al. 2018; Gallotti 2018; Gallotti and Mussi 2015), occupying an overall time range of ca. 2.6 Ma– 1.6 Ma. We report here on new high-level Oldowan occurrences from the caldera of Kilombe volcano, which represent the first discovery of entirely new Oldowan locales in Kenya for some 30 years (Figs. 1, 2). Their extra significance is that they have been found at an altitude some 500 metres higher than any others within East Africa, apart from those in the rift on the Ethiopian dome, and are the first to lie in rugged landscape away from the rift valley floor. They thus provide direct evidence that hominins were exploiting high, as well as low, areas of the landscape early in the Pleistocene, and give potential to examine hypotheses about such occupations (Peters and Blumenschine 1995; Blumenschine and Peters 1998; Blumenschine et al. 2009, 2012a,b).

The extinct Kilombe volcano lies 10 km south of the Equator on the west side of the Kenyan portion of the East Branch of the African Rift Valley, and at the south end of the Baringo Basin. It sits approximately midway between the Oldowan localities of Olduvai to the south and Lake Turkana to the north (Figs. 1, 2). Following mapping by Jennings (1971), the area was extensively studied by the East African Geological Research Unit (EAGRU) in the 1970s (Bishop 1978; King 1978). In the course of that work W.B. Jones found the major Acheulean site of Kilombe (GqJh1) which has since been intensively studied (Jones 1975, 1985; Bishop 1978; Gowlett 1978, 1993, 2021; Gowlett et al. 2015, 2017).

This site, and others previously known, all lie on the southern flanks of Kilombe mountain. In contrast the new occurrences reported here all come from higher levels (~2000 m asl) within the volcano's caldera, which formed early in the Pleistocene (McCall 1964, 1967; Jennings 1971; Jones and Lippard 1979; Hoare et al. 2021). Kilombe mountain is formed of trachyte, with its base about 20 km across, surmounted by a cone estimated to comprise 15 km^3 of lava (Ridolfi et al. 2006). The caldera is approximately circular, and has a diameter of around 3km (Fig. 3); in recent times it was largely forested, but it is now mainly occupied by small farms.

In recent research we have established that extrusion of the trachytes of the volcano began from at least 2.5 million years ago (Hoare et al. 2021). After the caldera formed sedimentation began within it, leaving a sequence at present around 150 m(EARLIER WE SAY 100m) thick. For a period in the early Pleistocene there was a caldera lake: laminated lacustrine sediments are visible in the very lowest exposures of the caldera fill, at the base of a waterfall in the modern gorge, some 60 m below the levels discussed here, where they are underlain by mudflow diamictites. $^{40}Ar/^{39}Ar$ dates show that the lake was extant ca. 1.8 Ma–1.7 Ma (Hoare et al. 2021), and probably for considerable periods both before and after this. The lake environs appear to have attracted animals and drawn hominin occupation, at least at times, and we report here in outline on the evidence of that attributed to the Oldowan.

Stratigraphic record of the staircase exposures

The sedimentary infilling of Kilombe caldera is best exposed in two series of exposures now named the *Upper Staircase* and the *Lower Staircase* (Hoare et al. 2021) (Figs. 3, 4, 5). The Lower Staircase is the older, and is exposed within the gorge that drains the caldera in a stream exiting eastwards and falling towards the rift valley floor through a gorge. The Lower Staircase exposures extend around 200m horizontally and ~60 m vertically, starting from a small side valley at the edge of the caldera and running down to the stream at the base of the gorge. Thinly laminated lacustrine sediments are visible 300m to the west, exposed in the cliff of the waterfall at the head of the gorge. No archaeological traces or fauna have yet been found in the levels of the lower staircase, but it provides important evidence of the final activity of Kilombe volcano (see below).

The Upper Staircase is exposed within the caldera, and is most clearly seen where it extends 400m along a trackway, rising 40 m along its length. The Oldowan levels occur near its base, and can be traced laterally, especially to the north. Above them, a series of tuffs and interbedded claystones crops out up to the top of the slope, where the sequence is capped with mudflows containing Acheulean artefacts. Their age remains uncertain, but from their stratigraphic position they can be inferred to be older than the million-year-old Acheulean main site outside the caldera (Gowlett et al. 2015). There is then a major time gap in the caldera record until deposition at about 0.48 Ma of an ashflow tuff, emplaced into a pronounced proto-gully. This AFT (Ash Flow Tuff of Jones 1975) is widespread in the area both within and without Kilombe volcano (Bishop 1978; Jones 1985; Gowlett et al. 2015; Hoare et al. 2021).

Palaeogeographic setting of Kilombe Caldera

An important feature in the general setting is the presence of an Early Pleistocene caldera lake. From exposures it is confirmed to have occupied the eastern and northern areas within the caldera, but its extent to the west is obscured by later sediments cloaked with modern vegetation. The preserved archaeological and palaeontological sites are on the western side of the exposed sediments. Within the 3 km x 3 km dimensions of the caldera, the maximum dimensions of the lake are likely to have been about 2 x 1 km, but this is a provisional estimate.

The largest archaeological assemblage described below (GqJh13A) was contained in an outcrop on the Upper Staircase. It and the other occurrences accumulated on a centripetally inclined fan-delta apron that was sourced off the caldera rim of Kilombe volcano. By this time effusive Kilombe volcanic activity had ceased (Hoare et al. 2021), the last obvious effect of that activity a thin trachyte lava flow (Jones 1975), interleave within the Lower Staircase succession (Figs 4, 5) (Hoare et al. 2021). At this stage the caldera floor was still subsiding, gradually providing accommodation space for additional caldera-fill. The fill comprised material derived by erosion from the caldera rim, interspersed with externally derived volcanic products derived from sources other than the by then extinct Kilombe volcano.

Figure 6 shows that a variety of fan-delta apron lithofacies was deposited on and interleaved with the caldera lake lithofacies. Of the latter, clays were deposited at the GqJh13A site when the central palaeolake body expanded and onlapped the fan, to produce claystone and sandy claystone lithofacies during lake highstands, sedimented respectively off- and nearshore (cf. in the case of Olduvai, Stanistreet et al. 2018a, 2020a). The succession also records subaerial facies, indicating that lake-levels alternately rose and fell pronouncedly. Primary volcanic facies include fine to coarse airfall ash tuffs, pyroclastic flow lapilli tuffs and pumiceous lapilli ash tuffs, recording variably sized explosive eruptions of one or several nearby volcanoes, whose products were repeatedly trapped by the caldera. Thicker units of diamictite, resulting from reworking of primary volcanic products are also interleaved, typically containing abundant Kilombe Trachyte clasts. They represent volcanic mudflows (lahars: for other examples in East Africa see Stanistreet et al. 2018b; de la Torre et al. 2018) incident off the steep intra-caldera rim within the volcanic cone. Additionally, volcaniclastic sandstones represent the deposits of short-headed (maximum length of 1.0-1.5 km) streams, also sourcing from the caldera rim. A high proportion of the subaerially deposited lithofacies sit on erosional incision surfaces, generated by the rim-sourced streams, particularly at times when lake-levels were low. Some of these erosional land surfaces show evidence of rooting beneath.

Context and chronology of the artefact and faunal localities

Finds of artefacts and fauna have been made at several localities near the foot of the Upper Staircase, starting with fossil bones found by Mr Philip Kogai during the digging of a latrine pit. Artefacts were first noted in our investigations in 2016. The known Oldowan localities known extend along a front of outcrops of a diamictite and tuffs for about 200 metres, and are designated from south to north: GqJh13A, GqJh12B, GqJh12C and GqJh12A.

The artefact localities are associated with the interface between a diamictite ca 50 cm thick, sitting on an erosion surface into underlying clayey surfaces developed over a tuff. It is significant that the faunal remains and tools have been found immediately below one of the diamictite units. The evidence discussed below indicates that the assemblages were rapidly covered, preserved and only slightly modified by a mudflow, in a manner similar to that described by Stanistreet et al. (2018a, b); de la Torre et al. (2018; 2021) for assemblages at Olduvai Gorge, Tanzania. Details of the interface are most clear within the GqJh13A excavation, discussed below.

In terms of vegetation and palaeoenvironment, the preliminary results of the combined study of phytoliths and diatoms indicate for GqJh13A locality, immediately below the diamictite level, a littoral environment with neutral to slightly alkaline and low water speed (a channel or a wetland). This environment would be dominated by sedges and few C4 grasses. In addition, the elevated number of bulliform silicified cells suggests, for this time-period, that plants suffered water stress due to increasing drought stress (decreasing precipitation or decreasing air relative humidity, or increasing transpiration rates (Bremond et al. 2005, Issaharou-Matchi et al. 2016).

Average values for the Chemical Index of Alteration (CIA), Weathering Index of Parker (WIP), and Vogt's residual index calculated from multiple samples (n=6) representing the main artefact horizon are 74, 29 and 4 respectively, which together indicate reduced chemical weathering in the GqJh13A sediments for the Oldowan locality. The magnetic properties of these sediments are coarse grained (χ_{FD}%= 2.4 and χ_{ARM}/SIRM 0.4) and the magnetic mineralogy is dominated by magnetite with significant contribution from hematite and/or goethite (S-ratio values av. 90%). Total organic carbon percentages are also relatively low in these samples with average values of 0.13%. Combined these data are also suggestive of relatively dry conditions and decreasing precipitation, and/or increased rates of sedimentation (Nesbitt and Young, 1982; Evans and Heller, 2003).

In the area of the Oldowan occurrences in the caldera, the surface of the underlying clays is near-horizontal at present. The distribution of artefact localities suggests a shallowly sloping lake margin. It is possible that quite large areas were regularly exposed to animal and human activity, but perhaps inundated seasonally or from time to time, given the evidence mentioned above of rises and falls in water levels. Evidence of fluctuations is seen clearly in clay compositions of sediment cores drilled from these levels (Cores 18 and 3). Used with caution, clay minerals can contribute to palaeoclimatic interpretation: Singer (1984) notes that abundant smectite, as in this sequence, can form under relatively dry, semi-arid, conditions, but also humid subtropical. Next most abundant is kaolinite which can indicate intensive weathering and humid periods; a raised proportion of illite may indicate periods when it was relatively dry (Galán 2006; cf Deocampo 2015; Deocampo et al. 2010). The top of the archaeological layer in GqJh13A is composed of 80% silt and 20% clay fractions. The clay minerals are 64.8% smectite, 26.5 % kaolinite and 8.7 % illite. These levels of smectite and illite are compatible with relatively dry conditions as noted above, although there are variations through the clays perhaps indicating changes in the lakeside environment. Levels above the diamictite have markedly different clay composition (Fig. 6).

The levels including the archaeological and fossil material can be traced northwards from GqJh13A (on the Upper Staircase) for some two hundred metres, into land currently used for growing maize. As of 2019 four localities are associated with artefacts and or faunal remains. These several localities with artefacts attributed to the Oldowan are all at approximately the same stratigraphic levels. The tuff immediately underlying the finds has been dated by $^{40}Ar/^{39}Ar$ to 1.814 ± 0.004 Ma (Kil-3-2) in the northern locality (GqJh12A) and there is a date of 1.762 ± 0.020 Ma (Kil-2-8) for a level immediately overlying the finds in the southernmost locality at the base of the Upper Staircase (GqJh13A). A minimum age is further set by a date of 1.761 ± 0.022 Ma (Kil-2-4) on a tuff 11 m higher in the sequence.

Palaeomagnetism

Palaeomagnetic block samples were taken from 14 layers within 10 block samples running from the base of the Upper Staircase sequence through the GqJh13A Oldowan locality and up to the level of the ~1.761 ± 0.20 Ma $^{40}Ar/^{39}Ar$ sample, as well as from a single deposit close to the GqJh12A Oldowan locality (Figures 5, 6). Samples were oriented using a Suunto magnetic compass in the field. After transport to the laboratory in Australia each block was cut into ~2.5 cm deep layers with 3 subsamples taken from each layer and mounted in standard palaeomagnetic cubes for analysis. Samples were subjected to an alternating field demagnetisation (AFD) cleaning strategy to isolate the primary remanence of each sample using an AGICO LDA5 Alternating Field Demagnetiser and JR-6A magnetometer. Samples were also measured for their room magnetic susceptibility (K_{LF}) to help understand the magnetic mineralogy of the samples.

The samples all had an extremely low K_{LF} (8-12 SI) when compared to sediments from Kilombe Main site outside of the Caldera (600-1800 SI), indicating that the Upper Staircase sequence has a relatively consistent mineralogy in terms of it having a much smaller ferrimagnetic content than in sequences outside the caldera. After the removal of a low field overprint the underlying Characteristic Remanence is carried in the majority of the samples by a stable ferrimagnetic mineralogy that is stable up to around 40 mT.

Layers close to Oldowan locality GqJh12A that have been $^{40}Ar/^{39}Ar$ dated to 1.814 ± 0.04 Ma record a normal magnetic polarity and suggest that this unit formed within the very later part of the Olduvai subchron between 1.818 and 1.810 Ma. Around 200 m further south, deposits at the base of the Upper Staircase sequence (KCUS03L, 04 and 05) record a southerly oriented declination (196.5 to 210.6°), with shallow negative inclinations (-12.6 to -19.4°). These samples have palaeolatitudes (Plat) of between -54.3° and -69.7° indicative of a reversed magnetic polarity (Plat>45°). This is then followed by samples (KCUS03U, 06, 02, 13) that record a change from intermediate (Plat -8°), to normal (Plat 57.1 and 56°) and back to intermediate polarity (Plat 18.7 to 12.3°) with steep inclinations (-65.9° to 70.6°). The lowest layers of the GqJh13A Oldowan locality lie below the KCUS13 intermediate polarity layer while the upper layers lie between this sample and reversed sample KCUS01 (Plat -88.6 and -89.5°). Samples above this (KCUS07 and 08) also record reversed magnetic polarity (Plat -60.6 to -77.8°) (Fig. 6). These reversed polarity layers are consistent with the $^{40}Ar/^{39}Ar$ date of 1.762 ± 0.022 from a layer within these levels, suggesting deposition soon after the reversal at the end of the Olduvai subchron at 1.78 Ma. A date of 1.761 ± 0.020 Ma for a layer approximately 11m higher (Hoare et al. 2021) suggests that the Upper Staircase sediments immediately overlying GqJh13A did not accumulate very rapidly.

The magnetic field behaviour of this lower part of the Upper Staircase section indicates a predominantly reversed polarity with a short normal polarity magnetic period, although the Plat of many of the samples is quite low, and just above the threshold used to define a reversed or normal polarity (±45°). The GqJh12A Oldowan locality occurs within an intermediate polarity period at the end of this normal polarity period. No such normal polarity events have been identified within the reversed polarity period occurring after the Olduvai subchron (Singer, 2014). However, a number of studies have suggested the occurrence of a reversed, or mixed polarity period occurring within the very end of the Olduvai subchron, before a final short period of normal polarity (Yang et al. 2008), with two such sequences occurring at site 102 at Koobi Fora (Lepre and Kent, 2010) and in the Nachukui Formation, West Turkana (Lepre et al. 2011). The sequence at Koobi Fora is in too low resolution to define field change during this period, whereas the Nachukui Formation (Kaitio Member) sequence suggests rapidly alternating field directions followed by a single layer suggesting a short normal polarity period before consistent reversed polarity directions occurring post the Olduvai subchron (Lepre et al. 2011). However, this part of the sequence is in low resolution and the nature of the record maybe influenced by both the low intensity of the magnetic field during a phase of magnetic field change as well as lock in depths within the sediment layers. Based on the location of the KBS Tuff (~1.87 Ma) in this section along with the base and top of the Olduvai subchron the alternating polarity would occur from around about 1.81 Ma and take approximately 27 ka based on a suggested depositional rate of 22cm per 1000 years (Lepre et al. 2011). This is consistent with estimates of 24 to 31 ka for sequences in the Chinese Loess (L25; Yang et al. 2008).

An alternative view of these records is that this alternating behaviour is linked to lock-in issues related to the deposits in question and that this variability represents behaviour during the magnetic reversal at the end of the Olduvai subchron itself. Kusu et al. (2016) identify such a reversal sequence in sediment cores from Japan and suggest that this variability occurred over a much shorter period of time between ~1.796 and 1.780 Ma, during the transition from Marine Isotope Stage 64 to 63 and with a polarity transition length of about 16 ka. A similar polarity transition has been suggested between 1.781 and 1.776 Ma at ODP Site 983, suggesting a shorter duration of ~5 ka. Further palaeomagnetic analysis of the Kilombe Caldera sequence may hopefully resolve a high resolution sequence for this period but this preliminary data suggests that the GqJh13A Oldowan layers are dated to the very end of the magnetic reversal at the end of the Olduvai subchron at ~1.78 Ma (Ogg, 2020), but certainly younger than the normal polarity deposits close to Oldowan site GqJh12A dated to 1.818 - 1.810 Ma.

Detail of the Oldowan Localities

The Oldowan localities known so far extend along a front of outcrops of the diamictite for about 200 metres, and as noted are designated from south to north: GqJh13A, GqJh12B, GqJh12C and GqJh12A.

GqJh 13A : this locality is near the base of the Upper Staircase; initially a bone was found on the south side of the road, in the road section (coordinates: 04.526 S 50.750 E). Further bones were subsequently found embedded in diamictite in the roadway. A small cut was made to follow the first bone, and further bone was found, together with a large artefact of trachyte. Following negotiation with the landowners, we were allowed in March 2018 to lay out a trench 5 m x 3m for excavation which was carried out in July/August, revealing artefacts and faunal remains across the whole area.

Around 100 artefacts and 12 bone finds were found within the area of 5 x 3 metres, giving an average of 6-10 finds per square metre. The finds are dispersed but with some small clusters. The abrasion state of artefacts is varied, with some examples being entirely sharp, and a few considerably abraded. This suggests that the surface stayed open for a considerable period. The preservation of fossil bone also varies, but this is partly owing to size and thickness variation. Cancellous bone within specimens has sometimes decayed so that they are preserved as hollow shells.

Within the excavation of GqJh13A the surface is slightly undulating. In some areas there appear to be two thin layers of clay, with distinct surfaces that are dark on top, but it is not clear whether this appearance is original or owed to recent infiltration and staining by organics. Artefacts are associated with both levels; the separation is most obvious along the road section, and around two small depressions (Fig. 7). It is conceivable that these were originally large animal footprints, but if so they are too blurred for definite recognition: they were probably no more than shallow puddles. In places a thin bluey-grey laminated clay/tuff about 7 cm thick runs between the two horizons, partly filling the two small depressions just mentioned.

No finds were made below the lower clayey surface on which the artefacts and fauna lie. Many specimens are on that surface (and locally some centimetres higher); others appear to have risen somewhat into the diamictite as it was deposited: it appears that the lahar flowed over the surface lifting a few of the artefacts, but not by more than 10 cm (77.7 % of plotted finds were concentrated vertically within a zone of 12 cm).

GqJh 12A : known informally as the maize field site, this locality is about 200 m north of the Upper Staircase (coordinates: 04.418 S 50.725 E). Here there is a small outcrop of hard tuffs in the field. Mr P. Kogai had recognised bone in disturbed blocks of the tuff. A trial sounding made in 2016 was later extended in a 2m broad step trench, taken down to a depth of about 1.5 metres. Fossil bone occurs in the upper 50 cm only, and is directly incorporated in the tuff. Artefacts were sparsely represented, with one in situ in a large piece of diamictite, and two or three others found on the surface nearby.

GqJh 12B : this locality is about 100 m south of GqJh12A, and just inside the northern boundary of Mr Philip Kogai's farm (coordinates: 04.475 S 50.723 E). A step trench was made following the discovery of one bone, and 3 or 4 stone artefacts were found in the soil in the area. Expanded excavation of the tuff at the base of the section yielded at least two further bones, but no artefacts in situ. This base layer correlates with the diamictite at GqJh13A.

GqJh12C: preliminary investigation at this locality was carried out in 2019. A shoulder of hard diamictite outcrops into the edge of a field. An area of the Pleistocene sediments was cleared for investigation, following discovery by P. Kogai of a well-preserved bovid bone. Around [10] artefacts were then found in superficial sediments, with evidence of in situ material.

The lithic industry and fauna

The artefacts from GqJh13A are approximately 100 in total, and best allow for preliminary classification of the industry, with the caveat that its nature may vary between localities.

The raw material is almost exclusively trachyte lava, suggesting local sources, probably within the caldera. Much of the material is not ideal for flaking, but a few well-struck flakes indicate that the tool makers were able to exert a full mastery of conchoidal fracture. Among the tools, the heavy duty component is prominent (following the criterion of Leakey (1971), pieces with diameter >50 mm). Two examples of choppers are described, but more pieces are typologically heavy duty scrapers, or lack a recognisable morphology.

Gq Jh13A Tools		Debitage	
Flaked cobble – Chopper	3	Flakes	20
Heavy duty scraper	3		
Other	2		
Heavy duty scraper on flake	2		
Core	4	Angular debitage	14
Flaked cobble piece	7	Angular fragments	15
Polyhedron	2	Flakes, broken	5
		Flake, split	1
		Cobble piece	4
Total	23	Total debitage	59

Several cores or core pieces are present. These have a simple form, but show that the hominins had the ability to strike flakes up to 10 cm long. In comparison with other Oldowan industries, one feature may have influenced the makers: this is the easy availability of raw material in a range of sizes in the form of block-like clasts of hard, almost unweathered, fine grained and compact microphyric trachyte lava. In places there was flow-lamination in the lava, producing tabular pieces which were then used as cores. In contrast with Olduvai or Kanjera South (Leakey 1971; Lemorini et al. 2014), there was no use of quartz and quartzite, although specimens made on a hard tuff may be present; nor were there ready supplies of rounded cobbles.

In addition to this large component, there were numbers of smaller whole flakes and angular debitage. The industry is discussed more generally below, following a description of representative pieces.

Selected artefact descriptions

GqJh13A/01 Large chopper.

This is the largest shaped tool from the series (123 x 98 x 67 mm), a chopper of trachyte in fresh condition (Fig. 8A), though covered with a thin layer of calcareous concretion characteristic of this site. In plan view the specimen appears bilaterally symmetric, but the thickness section shows that the tip is not pointed (i.e. the lateral sharp edges do not connect as in the pointed end choppers of Leakey (1971)). A quite close match to the piece is given by a two-edged chopper from Olduvai FLK illustrated by Leakey (1971: Fig 11.1); the largest specimen in that category had measurements of 115 x 79 x 62 mm. One face is more heavily worked than the other. The face that was uppermost in the ground appears to retain cobble cortex over an area approximately 4 x 5cm. The trachyte is somewhat coarse grained, and the working of the edges has resulted in a degree of step flaking. Nevertheless, both edges were flaked bifacially with flake scars extending around 3 cm from the margins.

Weight: 830 grams.

GqJh13A-41 Core

This piece is technically a core (124 x 104 x 80 mm), although there is only one major detachment (Fig. 8B). This would have released a flake ca 90 x 50 mm in size. A possible interpretation is that a large core piece was selected opportunistically to produce a single flake for a particular task.

An artefact found on the surface around 100 m east of GqJh13A, and physically at similar level, has a similar main detachment, but rather smaller. Its find-spot is on a slope facing the Upper Staircase, to the east of a modern pond.

GqJh13A-23 Heavy-duty scraper

112 x 79 x 58 mm. This specimen retains cortex on one face (reminiscent of the large chopper above) over an area of ca 30 x 60 mm (Fig. 8C). In plan view it somewhat resembles a heavy-duty scraper illustrated by Leakey 1971 (Fig. 29/1) from Olduvai Bed I. No 91 is of similar size and weight (370 g).

GqJh13A-91 Heavy-duty scraper

This piece is made on a thick flake or cobble piece, with a scraper edge on one side; the opposite side is thicker and blunt (96 x 57 x 52 mm) (Fig. 8D).

GqJh13A-40 Flake

Flake (66 x 30 x 22 mm) (Fig. 9B). Broad short flake terminating in a hinged truncation. Dorsal face preserves one sizeable and two small scars. This flake may have been formed during the shaping of a larger artefact.

GqJh13A-43 Utilised flake

Large triangular flake (69 x 44 x 23 mm), preserving platform, with apparent utilisation along right dorsal margin (Fig. 9A).

GqJh13A-60 flake

Flake of trachyte with narrow platform and broadening towards distal end (46 x 40 x19 mm; platform width 14 mm) (Fig. 9C).

GqJh13A-100 flake

Small trachyte flake, truncated distally (26 x 32 x 10 mm). Preserves curved platform indicating series in flaking (Fig. 9D).

GqJh12A-e Discoid

Small discoid of trachyte found in diamictite, from backfill of the original trench. The piece is considerably abraded/weathered, but its form and flaking area clear. With a size of 62 x 55 x 31 mm, it resembles specimens illustrated by Leakey (1971) from Olduvai DK, FLK and MNK (Figs 12, 14, 59) (Fig. 10A). At East Turkana there is only one discoid in the Oldowan levels, but several in the upper industries aged ca 1.6-1.5 Ma (Isaac et al. 1997).

GqJh12-d Cortical flake

Flake made by heavy impact from side of a smooth cobble (105 x 54 x 31 mm) (Fig. 10B). It is not certain whether the flake was made intentionally, or whether it indicates breakage in use of a hammerstone similar to that from GqJh12B, but the piece shows micro detachments around its thinner end which suggest that it was used as a flake tool.

GqJh12B Hammerstone

This find was made in the field ca 15 m to the W of site GqJh 12B. As it was a surface find, its context in the sediments cannot be absolutely guaranteed, but there is no reason to think that it is intrusive. It is a smooth cobble showing evidence of use as hammerstone (78 x 70 x 44 mm) (Fig. 10C). The cobble or pebble is flattened and slightly ovoid). It bears evident traces of use on its perimeter. Some of the marks suggest heavy striking. Two similar examples have been found outside the caldera, on the main site (c.f. Acheulean GqJh1 example, EH2033, 81 x 69 x 28 mm), and the other to the south of the main site.

Nature of the stone industry: debitage, cores and core tools

The number of finds, and their presence from several localities, are sufficient for a provisional description and characterisation to be given, although larger samples will allow better definition in the future.

The artefacts include the range of technology and forms found on most early (Oldowan) sites. Debitage forms around 70% of the assemblage. This is a substantial but fairly low percentage: several factors may reduce it relative to the proportions in an industry as knapped. Firstly, there may have been limited knapping in the areas investigated; then the mudflows may have differentially entrained smaller pieces; then in the context of the hard matrix of diamictite it is hard to separate small clasts and artefacts. The debitage does however include sharp flakes and complete flakes. These are mainly end-struck, and can be as much as 9-10 cm long. The bulbs and other flaking characters testify to competent working of a difficult raw material, although most flakes are relatively thick.

The larger artefacts can be fitted without difficulty into categories used and discussed by other authors (e.g. Leakey1971; Toth 1985; Isaac et al. 1997; de la Torre and Mora 2014, 2018; Stout et al. 2010) but there are some features which – provisionally - appear to be distinctive to the industry. Both cores and core tools are represented. Broken cobbles also occur.

Patterns of core-working can be compared to those of a number of sites including Olduvai, Peninj, Kanjera South, Melka Konturé and Hadar (Leakey 1971; de la Torre and Mora 2014, Domínguez-Rodrigo et al. 2014; Braun et al. 2008, 2009a; Goldman-Neuman and Hovers 2009, 2012; Hovers 2012). The more complex procedures of core-working, such as those at Lokalalei (Delagnes and Roche 2005; Roche et al. 1999) are not evident, perhaps because trachyte was readily available in blocks that allowed simple knapping solutions. Several cores suggest that pieces were sometimes selected for the production of a single flake, and then discarded. The flake would run the complete depth of the core, somewhat like a bread slice, except that it would be on the side or corner of the piece (Fig. 8B, Fig. 13). A similar practice of using tabular pieces to yield one or two flakes is recorded for Nyanzian andesite/dacites at Kanjera, where all the other raw materials occur in rounded cobble form (Braun et al. 2008, 2009a).

The well-worked discoid (Fig. 10A) can be matched by similar examples from East Turkana and Olduvai (Isaac et al. 1997; Leakey 1971: Fig 12 (DK)). At E Turkana they are much more common in the Karari industry, which includes a few early Acheulean bifaces, than in the earlier Oldowan material (Isaac et al. 1997; Isaac and Isaac 1997, Appendix 6). This specimen has every appearance of being a shaped tool, rather than a worked-down core, since numbers of very short but wide flakes have been detached in the final stages of working and there would be no advantage in choosing this form of blank for their production.

Metrical comparisons

Although numbers of Oldowan assemblages are made from lavas, relatively few of these are trachytes (although trachyte was used at Olduvai Bed I more than formerly thought: McHenry and de la Torre 2018). Accordingly, an especially interesting comparison is with Hadar A.L. 894 (Goldman-Neuman and Hovers 2009; Semaw 2006; Stout et al. 2005), as three lavas are found side by side – trachyte, basalt and rhyolite. Despite the 700,000 year difference in age, the trachyte length distributions from Hadar and Kilombe share three notable features: paucity of small flakes and debitage, a component of larger pieces 60-90 mm, and presence of larger pieces >100 mm (Fig. 11). This pattern contrasts strongly with the profiles for basalt and rhyolite at Hadar, which have sharp peaks at 20-30mm (as in many Lower Palaeolithic assemblages), and very few pieces >70 mm. There appears to be a weak selection in favour of trachyte, compared to its occurrence in gravels. At site EG10 Semaw (2006) found that rounded trachyte cobbles from a nearby gravel were chosen preferentially. Although the loss of small pieces may well be owed to taphonomic factors, the similarity between the two trachyte series, and the contrast with the other lavas, suggests that selection by the hominin tool users may also have been operative: possibly trachyte was favoured for heavier tasks. Weight distribution strengthens this suggestion: at Kilombe there is a peak of moderately heavy pieces at around 300 g-400 g, but with a representation of four pieces > 1 kg.

Faunal associations

All the artefact localities have a representation of bone. At GqJh12A the late James Brink identified *Hippopotamus gorgops,* and determined that some bones had been fractured in butchery. His conclusions are supported at least indirectly by the close physical association of artefacts and large bones on the GqJh13A site. Butchery is well attested to on broadly contemporary sites around East Africa (Bunn 2007; Blumenschine et al. 2012a; Bunn and Gurtov 2014; Bunn and Kroll 1986; Domínguez-Rodrigo 2009; Domínguez-Rodrigo and Pickering 2017) and therefore is not a contentious point, but it is useful to have the information that hominins had access to large carcases in this lakeside environment. Regardless of the evidence for butchery, the faunal remains, which include largely complete long bones, e.g., of bovids, testify to the presence of a variety of medium to large sized mammals close to the lake shores. The varied weathering stages of artefacts suggest that the land surface remained open for a considerable period, although taphonomic considerations would suggest that faunal remains probably belong to a short period before the deposition of the overlying diamictite.

Discussion

The localities described here are the first examples of an early industry in East Africa (Kenya and Tanzania) from a high-level environment outside the rift valley floor. In Ethiopia, the Melka Konture sites are at similar altitude, but topographically set within the rift (Chavaillon and Piperno 2004; Morgan et al. 2012). The closest site complexes for comparison are Lake Turkana (450 km north), Olduvai (350 km south) and Kanjera South (200 km to the west), all at altitudes at least 500m lower than Kilombe Caldera (Roche et al 1999; Delagnes and Roche 2005; Braun et al. 2008, 2009a; Isaac 1997; Bishop et al. 2006; Plummer and Bishop 2016; Plummer et al. 1999, 2009a,b; Leakey 1971, 1975). A major question would be, who are the hominins operating at this high level? But in the absence of hominin fossils, it is possible only to note that *Homo habilis*, *Homo rudolfensis* and *Homo erectus* are all possible candidates present in the region (Spoor et al. 2007, 2015; Bilsborough and Wood 2020). *Australopithecus boisei*, found 100 km to the north at Chesowanja (Carney et al. 1971; Gowlett et al. 1981) is also a conceivable candidate as tool maker, although its demise as late as 1.3 Ma (Domínguez-Rodrigo et al. 2013) appears to have no impact on artefact records elsewhere. Early *Homo* is known from a maxilla in the Chemeron Formation 70 km to the north of Kilombe, and dated to 2.3 Ma (Deino and Hill 2002; Sherwood et al. 2002); two mandibles of early Middle Pleistocene *Homo* were found in the nearby Kapthurin Formation (Deino and McBrearty 2002; Tallon 1978). The large size of some stone cores, and the ruggedness of the landscape, are possible clues that the hominins involved were substantial in body size. We discuss here first the stone industry and then the use of landscape which its presence implies.

(1) ***The stone industry***. The Kilombe Caldera industry represents the first occurrence of Oldowan in an entirely new area of the eastern Rift Valley for thirty years, and is the first in its area to be found at high altitude. The $^{40}Ar/^{39}Ar$ dating, combined with the palaeomagnetism is sufficiently precise to show that the finds described here have an age that correlates with the reversal at the end of the Olduvai subchron at ~1.78 Ma. The same transitional behaviour with a final short normal polarity zone is noted in the Kaitio Member of the Nachikui Formation at West Turkana, ~5m below the oldest known Acheulean from Kokiselei 4, estimated to date to ~1.76 Ma (Lepre et al. 2011). As such, the Kilombe Caldera Oldowan is beyond the age of the oldest known representation of the Acheulean (Lepre et al. 2011; Beyene et al. 2013; Diez-Martín et al. 2015; de la Torre and Mora 2020; de la Torre et al. 2021). It is however a very late Oldowan industry, and it contains traits which may presage the Acheulean such as well flaked discoids albeit in single example (cf Leakey 1971; Gowlett 1986; also Duke et al. 2021 in relation to the technology of Kokiselei 6, West Turkana, a site of similar age).

On present evidence, we attribute the Kilombe Caldera industry to the Oldowan on the grounds that:

(i) The core and flake technology corresponds to the Oldowan

(ii) The finds fall within the established temporal and geographic range of the Oldowan

(iii) The size range of pieces corresponds to Oldowan

(iv) The typological forms and their range correspond to Oldowan

(v) No artefact forms yet found are inconsistent with the Oldowan as previously described.

A significant feature of the assemblage is the consistent use of trachyte blocks (contrasting with the apparent use of very smoothly rounded cobbles as hammerstones). Although it is very difficult to test this point further through sourcing studies (owing to the widespread similarity of the trachytes), the appearance is that hominins used rocks from within the caldera for their toolkits.

In Kilombe caldera, however, trachyte may have been selected as raw material because it was readily available, rather than a preferred rock. At Lokalalei, West Turkana, there are indications that phonolite was more selected than trachyte (Harmand 2009); at Olduvai too, trachytes appear to be somewhat underselected compared to other lavas (McHenry and de la Torre 2018), but at Hadar as mentioned above, trachyte was sometimes selected preferentially (Semaw 2006).

The size of the heavy duty artefacts ranges larger than on some other Oldowan sites, and the hominins were able to strike flakes on occasion up to 10 cm long. This capability to use large artefacts, the signs of butchery of large animals, the high level of the finds, and the rugged environment, combine to suggest adaptable hominins who were capable of ranging through all parts of the landscape.

(2). ***Landscape***. In recent years it has become apparent that hominins were widely distributed around the Old World by two million years ago {Lordkipanidze 2019; Zhu et al. 2018; Yang et al. 2019) or even earlier (Malassé et al. 2016), but overall the record remains sparse and biased taphonomically, despite the concentrations of research in certain areas, especially in southern Africa and along the Rift Valley from Tanzania in the south to Ethiopia in the north (Leakey 1971, 1975; Blumenschine et al. 2003, 2012; de la Torre et al. 2018, 2021; Gallotti 2018; Herries et al. 2020; Potts et al. 1999; Toth and Schick, 2004, 2018; Braun et al. 2019). The hominin occupation beside the Kilombe Caldera lake therefore adds significantly to the general picture, and allows hypotheses about ranging and land usage to be addressed with the benefit of direct evidence.

Following very detailed studies of landscape around Olduvai, Blumenschine, Peters and colleagues have offered a useful hypothesis that hominins would have exploited both low level and high level environments, possibly with seasonal movements between wet and dry seasons (Peters and Blumenschine 1995; Blumenschine and Peters 1998). They presented evidence of modern resource distribution in support of this. The transport distances of artefacts in the Oldowan are frequently in the range 3 – 5 km, with examples of 10 km or even 20 km (Blumenschine et al. 2003, 2009, 2012a,b). General considerations of hominin group size and range based on this and other evidence (e.g. Marlowe 2005, 2010) make it highly unlikely that a hunting/scavenging and gathering group could have subsisted entirely within Kilombe caldera, given its limited area of ca 10 sq km. Modern African hunter gatherers provide useful if limited insights: they need far greater territorial ranges for a group, and within the range may transport food for considerable distances. In the case of the Hadza, however, carrying times for transporting meat from kill sites to camp are rarely more than one hour (90 mins max) (O'Connell et al. 1988). As return journeys in and out of the caldera would take longer than that – and the caldera rim was probably steeper before erosion (and the gorge formed later) – it seems likely that hominins would be based within the caldera at least for some days at a time. In the caldera, the rising topography would mean that hominins could make use of viewpoints and perhaps choose times of descent to the lake margin for their exploitations there, including animal butchery.

This interpretation of localised activity accords with the predominant use of Kilombe mountain trachyte as raw material, but we do not yet know what other rocks might have been available in the region (the trachyphonolites now blanketing the area south of the mountain and favoured later in the Acheulean had not then been extruded). At Kanjera, highland sites are not preserved, but raw material sourcing also suggests that hominins spent time at higher altitudes in the mountains (Braun et al. 2008, 2009a). The evidence from Kilombe is sufficient to indicate more than trips for raw materials: at least for a period around 1.8 Ma there was substantial exploitation at this high level, with the multiple occurrences of artefacts with bone and, the varied state of artefacts indicate a significant duration for these exploitative activities.

Useful insights into the ecology and environment are provided by the presence of hippopotamus within this small enclosed basin as well as by the phytoliths and the diatoms that suggest an open landscape with sedges and C4 grasses and water. Hippopotamus normally reside in water during the day and forage nocturnally on land. Harris et al. (2008) indicate that the diet of early Pleistocene hippopotamus around Lake Turkana was largely C4 plant based, implying an even greater degree of grazing than in modern hippo. A strong preference for grass is seen in present day contexts, with an estimate from the Luangwa river in Zambia of around 6 hectares of grazing area needed per animal (Chansa et al. 2011) and similar ranging figures for other rivers in the region (O'Connor and Campbell 1986; Stears et al. 2019). Although knowledge of hippo spatial ecology is limited (Stears et al. 2019), and projection to past species demands particular caution, it is clear that the caldera context would need to provide both deep water and adequate grazing. Assuming perhaps 6 sq km of land in the caldera relative to ~3 sq km lake, this could translate very roughly to a population of 50-100 animals, on the basis of 50-100% grass cover. Such figures would fit with a local community, probably coupled with migrations back and forth from the nearest river, perhaps a proto-Molo less than 5 km to the south. Bovids also appear to have been common in the caldera. A diverse hominin diet is feasible at this period (Braun et al. 2010), but we have no information on whether animals were scavenged or hunted.

The high level hominin occupation of the caldera may give some insights into the multi-species problem of the early Pleistocene. Over a long period authors have postulated the use of high level sites by hominins as long term refugia during drier phases (e.g., Foley 1989; Trauth et al. 2010; Cuthbert et al. 2017). Although such refugia may have played a part in creating geographic separations of populations thus promoting evolutionary change (Foley 1989; Lahr and Foley 2016; Louys and Turner 2012), very long separations would be needed for speciation. This is not likely on the landscape scale of Kilombe, where high and low levels are quite close together. But it may be noted that *Australopithecus boisei*, has not yet been found at high level, whereas the Kilombe setting is strong evidence that at least one hominin species (by inference *Homo*) was well adapted to montane environments.

Renewed work in the area of Kilombe mountain has greatly extended the stratigraphic record in Central Kenya, so that it now runs through almost the entire Pleistocene. The older sediments are preserved in the caldera of the extinct Kilombe volcano. Sedimentation within the caldera extends beyond two million years, but the best-dated part of the sequence is in the time range ca 1.8-1.7 Ma, and it includes the Oldowan archaeological sites described here. The sites and artefacts have value as the first discoveries for thirty years of Oldowan artefacts in an entirely new area of the Kenyan rift. More importantly, the finds are the first occurrences of Oldowan set in a rugged landscape as well as at high level. They show that early hominins were able to exploit the shorelines of the caldera lake of Kilombe volcano, seemingly frequenting these areas repeatedly and possibly intensively. We prove for the first time that hominins were occupying high level settings that have been postulated as refugia during protracted Milankovitch-driven phases of drier palaeoclimate. This supports ideas that isolated sub-populations in such refugia might have propagated hominin evolutionary change. The capability of hominins to adapt to diverse parts of the landscape is also relevant to their dispersal across much of the Old World (Agusti and Lordkipanidze 2019), seen to have occurred by the date of the early Kilombe occurrences.

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References

Agusti, J., Lordkipanidze, D. 2019. An alternative scenario for the first human dispersal out of Africa. *L'Anthropologie* 123, 682-687.

Barsky, D. 2009. An overview of some African and Eurasian Oldowan sites: evaluation of hominin cognitive levels, technological advancement and adaptive skills. In: Hovers, E., Braun, D.R. (Eds.), *Interdisciplinary Approaches to the Oldowan.* Springer, Dordrecht, pp. 39-47.

Beyene, Y. , Katoh, S., WoldeGabriel, G., Hart, W.K., Uto, K., Kondo, M., Hyodo, M., Renne, P.R., Suwa, G., Asfaw, B. 2013. The characteristics and chronology of the earliest Acheulean at Konso, Ethiopia. *Proc. Natl Acad. Sci. USA* 110, 1584–1591. https://doi.org/10.1073/pnas.1221285110)

Bilsborough, A., Wood, B. 2020 Evolutionary diversity and adaptation in early *Homo*. In: Cole, J., McNabb, J., Grove, M. Hosfield, R. (Eds.), *Landscapes of Human Evolution*. Archaeopress, Oxford, pp. 29-41.

Bishop, L.C., Plummer, T.W., Ferraro, J.V., Braun, D., Ditchfield, P.W., Hertel, F., Kingston, J.D., Hicks, J., Potts, R. 2006. Recent research into Oldowan hominin activities at Kanjera South, Western Kenya. *Afr. Archaeol. Rev.*, 23, 1572-9842.

Bishop, W.W. 1978. Geological framework of the Kilombe Acheulian Site, Kenya. In: Bishop, W.W. (Ed.), *Geological Background to Fossil* Man. Scottish Academic Press, Edinburgh, pp. 329-336.

Blumenschine, R.J., Peters, C.R. 1998. Archaeological predictions for hominid land use in the paleo-Olduvai Basin, Tanzania, during lowermost Bed II times. *J. Hum. Evol.* 34, 565-607.

Blumenschine, R.J., Peters, C.R., Masao, F.T., Clarke, R.J., Deino, A.L., Hay, R.L., Swisher, C.C., Stanistreet, I.G., Ashley, G.M., McHenry, L.J., Sikes, N.E., van der Merwe, N.J., Tactikos, J.C., Cushing, A.E., Deocampo, D.M., Njau, J.K., Ebert, J.I. 2003. Late Pliocene *Homo* and hominid land use from western Olduvai Gorge, Tanzania. *Science* 299, 1217-1221

Blumenschine, R., Masao, F.T., Stanistreet, I.G. 2009. Changes in hominin transport of stone tools across the eastern Olduvai Basin during lowermost Bed II times. In: Schick, K., Toth, N. (Eds.), *The Cutting Edge: New Approaches to the Archaeology of Human Origins*. Stone Age Institute Press, Gosport, pp. 1-15.

Blumenschine, R.J., Stanistreet, I.G., Njau, J.K., Bamford, M.K., Masao, F.T., Albert, R.M., Stollhofen, H., Andrews, P., Prassack, K.A., McHenry, L.J., Fernandez-Jalvo, Y., Camilli, E.L., Ebert, J.I. 2012a. Environments and activity traces of hominins across the FLK Peninsula during Zinjanthropus times (1.84 Ma), Olduvai Gorge, Tanzania. In: Blumenschine, R.J., Masao, F.T., Stanistreet, I.G., Swisher, C.C. (Eds.), Five Decades after Zinjanthropus and Homo habilis: Landscape Paleoanthropology of Plio-Pleistocene Olduvai Gorge, Tanzania. *J. Hum. Evol.* 63(2), 364-383.

Blumenschine, R.J., Masao, F.T., Stollhofen, H., Stanistreet, I.G., Bamford, M.K., Albert, R.M., Njau, J.K., Prassack, K.A., 2012b. Landscape distribution of Oldowan stone artifact assemblages across the fault compartments of the eastern Olduvai Lake Basin during early lowermost Bed II times. In: Blumenschine, R.J., Masao, F.T., Stanistreet, I.G., Swisher, C.C. (Eds.), Five Decades after Zinjanthropus and Homo habilis: Landscape Paleoanthropology of Plio-Pleistocene Olduvai Gorge, Tanzania. *J. Hum. Evol.*, 63(2), 384-394.

Braun, D.R., Harris, J.W.K. 2003. Technological developments in the Oldowan of Koobi Fora: innovative techniques of artifact analysis. In: Martinez, J., Mora, R., de la Torre, I. (Eds.) Oldowan: rather more than smashing stones. *Treballs d'Arqueologia* 9, 117-144.

Braun, D.R., Plummer, T.W. 2013. Oldowan technology at Kanjera South: technological diversity on the Homa Peninsula. In: M. Sahnouni (Ed.), *Africa: Cradle of Humanity: Recent Discoveries*. CNRPAH, Algeria, pp. 131-145.

Braun, D.R., Harris, J.W.K., Levin, N. E., McCoy, J.T., Herries, A.I.R., Bamford, M.K., Bishop, L.C., Richmond, B.G., Kibunjia, M. 2010. Early hominin diet included diverse terrestrial and aquatic animals 1.95Ma in East Turkana, Kenya. *Proc. Natl. Acad. Sci. USA* 107: 10002-10007.

Braun, D.R., Plummer, T.W., Ditchfield, P., Ferraro, J.V., Maina, D., Bishop, L.C., Potts, R. 2008. Oldowan behavior and raw material transport: perspectives from the Kanjera Formation. *J. Archaeol. Sci.* 35: 2329-2345.

Braun, D.R., Plummer, T.W., Ditchfield, P.W., Bishop, L.C., Ferraro, J.V. 2009a. Oldowan technology and raw material variability at Kanjera South. In: Hovers, E., Braun, D.R. (Eds.), *Interdisciplinary Approaches to the Oldowan.* Springer, Dordrecht, pp. 99-110.

Braun, D., Plummer, T. W., Ferraro, J., Ditchfield, P., Bishop, L. 2009b. Raw material quality and Oldowan hominin toolstone preferences: Evidence from Kanjera South. *J. Archaeol. Sci.* 36: 1605–1614.

Braun, D.R., Aldeias, V., Archer, W., Arrowsmith, J.R., Barakif, N., Campisanog, C.J., Deino, A.L., DiMaggio, E.N., Dupont-Nivet, G., Engda, B., Feary, D.A., Garello, D.I., Kerfelew, Z., McPherron, S.P., Patterson, D.B., Reeves, J.S., Thompson, J.C., Reed, K.E. 2019. Earliest known Oldowan artifacts at >2.58 Ma from Ledi-Geraru, Ethiopia, highlight early technological diversity. *Proc. Natl. Acad. Sci. USA* 116, 11712-11717.

Bremond, L., Alexandre, A., Peyron, O., Guiot, J. 2005. Grass water stress estimated from phytoliths in West Africa. *J. Biogeogr.* 32, 311–327.

Bunn, H.T. 2007. Meat made us human. In: Ungar, P.S. (Ed.) *Evolution of the human diet: the known, the unknown, and the unknowable*. Oxford University Press, New York, pp. 191-211.

Bunn, H.T., Gurtov, A.N. 2014. Prey mortality profiles indicate that Early Pleistocene *Homo* at Olduvai was an ambush predator. *Quat. Int.* 322, 44-53.

Bunn, H.T., Kroll, E.M. 1986. Systematic butchery by Plio/Pleistocene hominids at Olduvai Gorge, Tanzania. *Curr. Anthropol.* 27, 431-452.

Carney, J., Hill, A., Miller, J.A., Walker, A. 1971. A late Australopithecine from Baringo District, Kenya. *Nature* 230, 509-514.

Chansa, W., Nyirenda, V.R., Chabwela, H. 2011. The influence of grass biomass production on hippopotamus population density distribution along the Luangwa River in Zambia. *J. Ecol. Nat. Environ.* 5, 186-194.

Chavaillon, J., Piperno, M. (Eds.) 2004. *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia*. Istituto Italiano di Preistoria e Protostoria, Florence.

Cuthbert, M.O., Gleeson, T., Reynolds, S.C., Bennett, M.R., Newton, A.C., McCormack, C.J., Ashley, G.M. 2017. Modelling the role of groundwater hydro-refugia in East African hominin evolution and dispersal. *Nat. Commun.* 8, 15696. https://doi.org/10.1038/ncomms15696

Deino, A.L., Hill, A. 2002. $^{40}Ar/^{39}Ar$ dating of the Chemeron Formation strata encompassing the site of hominid KNM-BC 1, Tugen Hills, Kenya. *J. Hum. Evol.* 42, 141-151.

Deino, A.L., McBrearty, S. 2002. $^{40}Ar/^{39}Ar$ dating of the Kapthurin Formation, Baringo, Kenya, *J. Hum. Evol.* 42, 185-210.

Delagnes, A., Roche, H. 2005. Late Pliocene hominid knapping skills: the case of Lokalalei 2C, West Turkana, Kenya. *J. Hum. Evol.* 48, 435-472.

de la Torre, I., Mora, R. 2014. The Transition to the Acheulean in East Africa: an Assessment of Paradigms and Evidence from Olduvai Gorge (Tanzania). *J. Archaeol. Method Theory* 21 781-823. https://doi.org/10.1007/s10816-013-9176-5

de la Torre, I., Mora, R. 2018. Oldowan technological behaviour at HWK EE (Olduvai Gorge, Tanzania). *J. Hum. Evol*. 120, 236–273. https://doi.org/10.1016/j.jhevol.2018.04.001

de la Torre, I., Mora, R. 2020. How many handaxes make an Acheulean? A case study from the SHK Annexe Site, Olduvai Gorge, Tanzania. In: Cole, J., McNabb, J., Grove, M., Hosfield, R. (Eds.), *Landscapes of human evolution*. Oxford, Archaeopress, pp. 64-91.

de la Torre, I., Albert, R.M., Arroyo, A., Macphail, R., McHenry, L.J., Mora, R., Njau, J.K., Pante, M.C., Rivera-Rondón, C.A., Rodríguez-Cintás, A., Stanistreet, I.G., Stollhofen, H., Wehr, K. 2018c. New excavations at the HWK EE site: Archaeology, paleoenvironment and site formation processes during late Oldowan times at Olduvai Gorge, Tanzania. *J. Hum. Evol.* 120, 140–202

de la Torre, I., Benito-Calvo, A., Martín-Ramos, C., McHenry, L.J., Mora, R., Njau, J.K., Pante, M.C., Stanistreet, I.G., Stollhofen, H. 2021. New excavations in the MNK Skull site, and the last appearance of the Oldowan and *Homo habilis* at Olduvai Gorge, Tanzania. *J. Anthropol. Archaeol.* 61, 101255.

de Lumley, H., Barsky, D., Moncel, M.-H., Carbonell, E., Cauche, D.,Celiberti, V., Notter, O., Pleurdeau, D., Hong, M.-Y., Rogers, M.J., Semaw, S. 2018. The first technical sequences in human evolution from East Gona, Afar region, Ethiopia. *Antiquity* 92, 1151-1164.

Deocampo, D.M. 2015. Authigenic clay minerals in lacustrine mudstones. *Geological Society of America Special Papers* 515, 49–64. Geological Society of America. https://doi.org/10.1130/2015.2515(03)

Deocampo, D. M., Behrensmeyer, A. K., Potts, R. 2010. Ultrafine clay minerals of the Pleistocene Olorgesailie Formation, southern Kenya Rift: diagenesis and paleoenvironments of early hominins. *Clays Clay Miner. 58*(3), 294–310. https://doi.org/10.1346/CCMN.2010.0580301

Diez-Martín, F., Yustos, P.S., Uribelarrea, D., Baquedano, E., Mark, D.F., Mabulla, A., Fraile, C., Duque, J., Díaz, I., Pérez-González, A., Yravedra, J. 2015. The origin of the Acheulean: the 1.7 million-year-old site of FLK West, Olduvai Gorge (Tanzania). *Sci. Rep.* 5,17839. https://doi.org/10.1038/srep17839

Domínguez-Rodrigo, M. 2009. Are all Oldowan sites palimpsests? If so, what can they tell us of hominid carnivory? In: Hovers, E., Braun, D.R. (Eds.), *Interdisciplinary Approaches to the Oldowan.* Springer, Dordrecht, pp. 129-148.

Domínguez-Rodrigo, M., Pickering, T.R. 2017. The meat of the matter: an evolutionary perspective on human carnivory. *Azania* 52, 4-32.

Domínguez-Rodrigo, M., Alcalá, L., Luque, L. 2014. *Peninj: a research project on human origins*. Oxbow Books, Peabody Museum, Harvard MA.

Domínguez-Rodrigo, M., Pickering, T.R., Baquedano, E., Mabulla, A., Mark, D.F., Musiba, C., Bunn, H.T., Uribelarrea, D., Smith, V., Diez-Martin, F., Pérez-González, A., Sánchez, P., Santonjaa, M., Barboni, D., Gidna, A., Ashley, G., Yravedra, J., Heaton, J.L., Arriaza, M.C. 2013. First partial skeleton of a 1.34-million-year-old *Paranthropus boisei* from Bed II, Olduvai Gorge, Tanzania. *PLoS ONE* 8, e80347.

Duke, H., Feibel, C., Harmand, S. 2021. Before the Acheulean: the emergence of bifacial shaping at Kokiselei 6 (1.8 Ma), West Turkana, Kenya. *J. Hum. Evol.* 159, 103061. https://doi.org/10.1016/j.jhevol.2021.103061

Evans, M.E., Heller, F. 2003. *Environmental magnetism: principles and applications of Enviromagnetics*. Academic Press, London.

Foley, R.A. 1989. *Another unique species: patterns in human evolutionary ecology*. Longman, Harlow.

Galán, E. 2006. Genesis of Clay Minerals. In: Bergaya, F., Theng, B.K.G., Lagaly, G. (Eds.), *Developments in Clay Science, Vol. 1*. Amsterdam, Elsevier, pp. 1129–1162. https://doi.org/10.1016/S1572-4352(05)01042-1

Gallotti, R. 2018. Before the Acheulean in East Africa: An Overview of the Oldowan Lithic Assemblages. In: Gallotti, R., Mussi, M. (Eds.), *The Emergence of the Acheulean in East Africa and Beyond*. Springer International Publishing, Cham, pp. 13–32.

Gallotti R., Mussi M. 2015. The Unknown Oldowan: ~1.7-Million-Year-Old standardized obsidian small tools from Garba IV, Melka Kunture, Ethiopia. *PLoS One* 10: e0145101.

Goldman-Neuman, T., Hovers E. 2009. Methodological issues in the study of Oldowan raw material selectivity: insights from A.L.894 (Hadar, Ethiopia). In: Hovers, E., Braun, D.R. (Eds.), *Interdisciplinary Approaches to the Oldowan.* Springer, Dordrecht, pp. 71-84.

Goldman-Neuman, T., Hovers, E. 2012. Raw material selectivity in late Pliocene Oldowan sites in the Makaamitalu Basin, Hadar, Ethiopia. *J. Hum. Evol.* 62, 353-366.

Gowlett, J.A.J. 1978. Kilombe - an Acheulian site complex in Kenya. In: Bishop, W.W. (Ed.), *Geological Background to Fossil Man*. Scottish Academic Press, Edinburgh, pp. 337-360.

Gowlett, J.A.J. 1986. Culture and conceptualisation - the Oldowan-Acheulean gradient. In: Bailey, G.N., Callow, P. (Eds.), *Stone Age Prehistory: studies in memory of Charles McBurney*. Cambridge University Press, Cambridge, pp. 243-260.

Gowlett, J.A.J. 1991. Kilombe - Review of an Acheulean site complex. In Clark, J.D. (ed.) *Approaches to Understanding Early Hominid life-ways in the African Savanna*.Romisch - Germanisches Zentralmuseum Forschungsinstitut fur Vor- und Fruhgeschichte in Verbindung mit der UISSP, 11 Kongress, Mainz, 31 August - 5 September 1987, Monographien Band 19, Dr Rudolf Habelt GMBH, Bonn, pp. 129-136.

Gowlett, J.A.J. 1993. Le site Acheuléen de Kilombe: stratigraphie, géochronologie, habitat et industrie lithique. *L'Anthropologie* 97 (1), 69-84.

Gowlett, J.A.J. 2021. Deep structure in the Acheulean adaptation: technology, sociality and aesthetic emergence. *Adapt. Behav.* 29, 197-216. https://doi.org/10.1177/1059712320965713

Gowlett J.A.J., Harris J.K.W., Walton D., Wood B.A. 1981. Early archaeological sites, hominid remains and traces of fire from Chesowanja, Kenya. *Nature* 294, 125-129.

Gowlett, J.A.J., Brink, J.S., Herries, A.I.R., Hoare, S., Onjala, I., Rucina, S.M. 2015. At the heart of the African Acheulean: the physical, social and cognitive landscapes of Kilombe. In: Coward, F., Hosfield, R., Wenban-Smith, F. (Eds.), *Settlement, Society and Cognition in human evolution: Landscapes in Mind.* Cambridge University Press, Cambridge, pp. 75-93.

Gowlett, J.A.J., Brink, J.S., Herries, A.I.R., Hoare, S., Rucina, S.M. 2017. The small and short of it: mini-bifaces and points from Kilombe, Kenya, and their place in the Acheulean. In: Wojtczak, D., Al Najjar, M., Jagher, R., Elsuede, H., Wegmüller, F. (Eds), *Vocation Préhistoire: Homage à Jean-Marie Le Tensorer*. ERAUL 148, Liège, pp. 121-132.

Harmand, S. 2009. Variability in raw material selectivity at the Late Pliocene sites of Lokalalei, West Turkana, Kenya. In: Hovers, E., Braun, D.R. (Eds.), *Interdisciplinary Approaches to the Oldowan.* Springer, Dordrecht, pp. 85-98.

Harris, J. M., Cerling, R.E., Leakey, M.G., Passey, B.H. 2008. Stable isotope ecology of fossil hippopotamids from the Lake Turkana Basin of East Africa. *J. Zool.* 275, 323-331.

Herries, A.I.R., Martin, J.M., Leece, A.B., Adams, J.W., Boschian, G., Joannes-Boyau, R., Edwards, T.R., Mallett, T., Massey, J., Murszewski, A., Neubauer, S., Pickering, R., Strait, D.S., Armstrong, B.J., Baker, S., Caruana, M.V., Denham, T., Hellstrom, J., Moggi-Cecchi, J. Mokobane, S., Penzo-Kajewski, P., Rovinsky, D.S., Schwartz, G.T., Stammers, R.C., Wilson, C., Woodhead, J., Menter, C. 2020. Contemporaneity of *Australopithecus, Paranthropus,* and early *Homo erectus* in South Africa. *Science* 368, eaaw7293. https://doi.org/10.1126/science.aaw7293

Hoare, S., Brink, J. S., Herries, A. I. R., Mark, D. F., Morgan, L. E., Onjala, I., Rucina, S. M., Stanistreet, I. G., Stollhofen, H., Gowlett, J. A. J. 2021. Geochronology of a long Pleistocene sequence at Kilombe volcano, Kenya: From the Oldowan to Middle Stone Age. *J. Archaeol. Sci. 125*, 105273. https://doi.org/10.1016/j.jas.2020.105273

Hovers, E. 2012. Invention, reinvention and innovation: the makings of Oldowan lithic technology. In: Elias, S. (Ed.), *Origins of Human Innovation and Creativity*. In: van der Meer, J.J.M. (Ed.), *Developments in Quaternary Science* 16. Elsevier B.V., pp. 51–68.

Isaac, G.Ll., Harris, J.W.K., Kroll, E.M. 1997. The stone artefact assemblages: a comparative study. In: Isaac, G.Ll., Isaac, B. (Eds.), *Koobi Fora Research project Volume 5: Plio-Pleistocene Archaeology*. Clarendon Press, Oxford, pp. 262-362.

Isaac, G.Ll., Isaac, B. (Eds.) 1997. *Koobi Fora Research project Volume 5: Plio-Pleistocene Archaeology*. Clarendon Press, Oxford

Issaharou-Matchi, I., Barboni, D., Meunier, J.-D., Saadou, M., Dussouillez, P., Contoux, C., Zirihi-Guede, N. 2016. Intraspecific biogenic silica variations in the grass species Pennisetum pedicellatum along an evapotranspiration gradient in South Niger. *Flora* 220, 84–93.

Jennings, D.J. 1971. *Geology of the Molo area*. Ministry of Natural Resources, Geological Survey of Kenya, Report No. 86.

Jones, W.B. 1975. *The geology of the Londiani area of the Kenya Rift Valley*. Unpublished PhD thesis, Univ. London.

Jones, W.B. 1985. Discussion on the geological evolution of the trachyte caldera volcano Menengai, Kenya Rift Valley. *J. Geol. Soc. London* 142, 711-712.

Jones, W.B. 1988. Listric growth faults in the Kenya Rift Valley. *J. Struct. Geol.* 10, 661-672.

Jones, W.B., Lippard, S.J. 1979. New age determinations and geology of the Kenya Rift-Kavirondo Rift junction, W Kenya. *J. Geol. Soc. London* 136: 693-704.

King, B.C. 1978. Structural and volcanic evolution of the Gregory Rift Valley. In: Bishop, W.W. (Ed.), *Geological Background to Fossil* Man. Scottish Academic Press, Edinburgh, pp. 29-54.

Kusu, C., Okada, M., Nozaki, A., Majima, R., Wada, H. 2016. A record of the upper Olduvai geomagnetic polarity transition from a sediment core in southern Yokohama City, Pacific side of central Japan. *Prog. Earth Planet. Sci.* 3: 26. https://doi.org/10.1186/s40645-016-0104-7

Lahr, M.M., Foley, R.A. 2016. Human evolution in late Quaternary Eastern Africa. In: Jones, S.C., Stewart, B.A. (Eds.), *Africa from MIS 6-2: Population dynamics and palaeoenvironments*. Dordrecht, Springer, pp. 215-231.

Leakey, M.D. 1971. *Olduvai Gorge. Vol. 3: excavations in Beds I and II, 1960-1963*. Cambridge University Press, Cambridge.

Leakey, M.D. 1975. Cultural patterns in the Olduvai sequence. In: Butzer, K.W., Isaac, G. Ll. (Eds.), *After the Australopithecines*. Mouton, The Hague, pp. 477-494.

Lemorini, C., Plummer, T.W., Braun, D., Crittenden, A., Marlowe, F., Bishop, L.C., Ditchfield, P., Hertel, F., Oliver, J., Schoeninger M. *et al*. 2014. Old stones song: functional interpretation of the Oldowan quartz and quartzite assemblage from Kanjera South (Kenya). *J. Hum. Evol.* 72, 10-25.

Lepre, C. J., Kent, D. V. 2010. New magnetostratigraphy for the Olduvai Subchron in the Koobi Fora Formation, northwest Kenya, with implications for early *Homo*. *Earth Planet. Sci. Lett.* 290, 362–374.

Lepre C. J., Roche H., Kent D.V., Harmand S., Quinn R.L., Brugal J.-P., Texier P.-J., Feibel C.S. 2011. An earlier origin for the Acheulian. *Nature* 477, 82–85.

Louys, J., Turner, A. 2012. Environments, preferred habitats and potential refugia for Pleistocene *Homo* in Southeast Asia. *C.R. Palevol*, 11, 203-211.

McCall, G.J.H. 1964. Kilombe caldera, Kenya. *Proc. Geol. Assoc.* 75, 563-572.

McCall, G.J.H. 1967. *Geology of the Nakuru-Thomson's Falls-Lake Hannington are*a. Ministry of Natural Resources, Geological Survey of Kenya, Report No. 78.

McHenry, L.J., de la Torre, I. 2018. Hominin raw material procurement in the Oldowan-Acheulean transition at Olduvai Gorge. *J. Hum. Evol*. 120, 378-401. https://doi.org/10.1016/j.jhevol,2017.11.010

Malassé, A.D., Singh, M., Karir, B., Gaillard, C., Bhardwaj, V., Moigne, A.-M., Abdessadok, S., Chapon Sao, C., Gargani, J., Tudryn, A., Calligaro, T., Kaur, A., Pal, S., Hazarika, M. 2016. Anthropic activities in the fossiliferous Quranwala Zone, 2.6 Ma, Siwaliks of Northwest India, historical context of the discovery and scientific investigations. *C. R. Palevol* 15 (3–4), 295-316.

Marlowe, F. 2005. Hunter-gatherers and human evolution. *Evol. Anthropol.* 14, 54-67.

Marlowe, F. W. 2010. *The Hadza: hunter-gatherers of Tanzania*. University of California Press, Berkeley.

Morgan, L.E., Renne, P.R., Kieffer, G., Piperno, M., Gallotti, R., Raynal, J.-P. 2012. A chronological framework for a long and persistent archaeological record: Melka Kunture, Ethiopia. *J. Hum. Evol.* 62, 104-115. https://doi.org/ 10.1016/j.jhevol.2011.10.007

Nesbitt, H.W., Young, G.M. 1982. Early proterozoic climates and plate motions inferred from major element chemistry of lutites. *Nature* 279, 715-717.

O'Connell, J.F., Hawkes, K., Blurton-Jones, N.B. 1988. Hadza hunting, butchering and bone transport and their archaeological implications. *J. Anthropol. Res.* 44, 113-161.

O'Connor, T.G., Campbell, B.M. 1986. *Hippopotamus* habitat relationships on the Lundi River, Gonarezhou National Park, Zimbabwe. *Afr. J. Ecol.* 24,7-26 .

Ogg, J.G., 2020. Geomagnetic Polarity Time Scale. In: Gradstein, F.M., Ogg, J.G., Schmitz, M.D., Ogg, G.M. (Eds.), *Geologic Time Scale 2020, Volume 1.* Elsevier, Amsterdam, pp.159-192.

Peters, C.R., Blumenschine, R.J. 1995. Landscape perspectives on possible land use patterns for early hominids in the Olduvai Basin. *J. Hum. Evol.* 29, 321–362.

Plummer, T.W., Bishop, L.C. 2016. Oldowan hominin behaviour at Kanjera South, Kenya. *J. Anthropol. Sci*. 94, 29-40.

Plummer, T., Bishop, L.C., Ditchfield, P., Hicks, J. 1999. Research on Late Pliocene Oldowan sites at Kanjera South, Kenya. *J. Hum. Evol.* 36, 151-170.

Plummer, T.W., Bishop, L.C., Ditchfield, P.W., Ferraro, J.V., Kingston, J.D., Hertel, F., Braun, D.R. 2009a. The environmental context of Oldowan hominin activities at Kanjera South, Kenya. In: Hovers, E., Braun, D.R. (Eds.), *Interdisciplinary Approaches to the Oldowan.* Springer, Dordrecht, pp. 149-160.

Plummer, T.W., Ditchfield, P.W., Bishop, L. C., Kingston, J.D., Ferraro, J.V., Braun, D., Hertel, F., Potts, R.B. 2009b. Oldest evidence of toolmaking hominins in a grassland-dominated ecosystem. *PLoS One* 4: e7199.

Potts, R., Behrensmeyer, A.K., Ditchfield, P. 1999. Paleolandscape variation and Early Pleistocene hominid activities: Members 1 and 7, Olorgesailie Formation, Kenya. *J. Hum. Evol.* 37, 747-788.

Ridolfi, F., Renzulli, A., Macdonald, R., Upton, B.G.J. 2006. Peralkaline syenite autoliths from Kilombe volcano, Kenya Rift Valley: Evidence for subvolcanic interaction with carbonatitic fluids. *Lithos*, 91, 373-392.

Roche, H., Delagnes, A., Brugal, J.-P., Feib C., Kibunjia, M., Mourre, V., Texier, J.-P. 1999. Early hominid stone tool production and technical skill 2.34Myr ago in West Turkana, Kenya. *Nature* 399, 57-60.

Semaw, S. 2006. The oldest stone artifacts from Gona (2.6-2.5 Ma), Afar, Ethiopia: implications for understanding the earliest stages of stone knapping. In: Toth, N., Schick, K. (Eds.), *The Oldowan: case studies into the earliest Stone Age*. Stone Age Institute Press, Indiana, pp. 43-75.

Sherwood, R.J., Ward, S.C., Hill, A. 2002. The taxonomic status of the Chemeron temporal (KNM-BC 1). *J. Hum. Evol.* 42, 153-184.

Singer, A. 1984. The paleoclimatic interpretation of clay minerals in sediments -- a review. *Earth-Sci. Rev.* 21, 251-293.

Singer, B.S., 2014. A Quaternary geomagnetic instability time scale. *Quat. Geochronol*. 21, 29-52.

Spoor, F., Leakey, M.G., Gathogo, P.N., Brown, F.H., Anton, S.C., McDougall, I., Kioie, C., Manthi, F.K., Leakey, L.N. 2007. Implications of new early *Homo* fossils from Ileret, east of Lake Turkana, Kenya. *Nature* 448, 688-691.

Spoor, F., Gunz, P., Neubauer, S., Stelzer, S., Scott, N., Kwekason, A., Dean, M.C. 2015. Reconstructed *Homo habilis* type OH 7 suggests deep-rooted species diversity in early *Homo*. *Nature* 519, 83–86.

Stanistreet, I., McHenry, L.J., Stollhofen, H., de la Torre, I. 2018a. Bed II Sequence Stratigraphic context of EF-HR and HWK EE archaeological sites, and the Oldowan/Acheulean succession at Olduvai Gorge, Tanzania. *J. Hum. Evol.* 120, 19-31. https://doi.org/10.1016/j.jhevol.2018.01.005

Stanistreet, I.G., Stollhofen, H., Njau, J.K., Ferrugia, P., Pante, M.C., Masao, F.T., Albert, R.M., Bamford, M.K. 2018b. Lahar inundated, modified and preserved 1.88 Ma early hominin (OH24 and OH56) Olduvai DK site. *J. Hum. Evol*. 116, 27–42.

Stears, K., Nuñez, T.A., Muse, E.A., Mutayoba, B.M., McCauley, D.J. 2019. Spatial ecology of hippopotamus in a changing watershed. *Sci. Rep.* 9, 15392. https://doi.org/10.1038/s41598-019-51845

Stout, D., Quade, J., Semaw, S., Rogers, M.J., Levin, N.E. 2005. Raw material selectivity of the earliest stone tool makers at Gona, Afar, Ethiopia. *J. Hum. Evol.* 48, 365-380.

Stout, D., Semaw, S., Rogers, M.J., Cauche, D. 2010. Technological variation in the earliest Oldowan from Gona, Afar, Ethiopia. *J. Hum. Evol*. 58, 474-491.

Tallon, P.W.J. 1978. Geological setting of the hominid fossils and Acheulian artefacts from the Kapthurin Formation, Baringo District, Kenya. In: Bishop, W.W. (Ed.), *Geological background to fossil man*. Edinburgh, Scottish Academic Press, pp. 361-374.

Toth, N. 1985. The Oldowan reassessed: a close look at early stone artefacts. *J. Archaeol. Sci.* 12, 101-121.

Toth, N., Schick, K. (Eds.) 2004. *The Oldowan: Case Studies into the Earliest Stone Age*. Bloomington, Indiana, Stone Age Institute Press.

Toth, N., Schick, K. 2018. An overview of the cognitive implications of the Oldowan Industrial Complex, *Azania* 53 (1), 3-39. https://doi.org/10.1080/0067270X.2018.14395

Trauth,M.H., Maslin, M.A., Deino, A.L., Junginger, A., Lesoloyia, M., Odada, E.O., Olago, D.O., Olaka, L.A., Strecker, M.R., Tiedemann, R. 2010. Human evolution in a variable environment: the amplifier lakes of Eastern Africa. *Quat. Sci. Rev.* 29, 2981-2988

Yang, S.-X., Deng, C.-L., Zhu, R.-X., Petraglia, M.D. 2019. The Paleolithic in the Nihewan Basin, China: evolutionary history of an Early to Late Pleistocene record in eastern Asia. *Evol. Anthropol.* 2019, 1-18. https://doi.org/10.1002/evan.21813

Yang,T., Hyodo, M., Yang, Z., Ding, L., Li, H., Fu, J., Wang, S., Wang, H., Mishima, T. 2008. Latest Olduvai short-lived reversal episodes recorded in Chinese loess. *J. Geophys. Res.* 113, B05103. https://doi.org/10.1029/2007JB005264

Zhu, Z.Y., Dennell, R., Huang, W.W., Wu, Y., Qiu, S., Yang, S., Rao, Z., Hou, Y., Xie, J., Han, J., Ouyang, T. 2018. Hominin occupation of the Chinese Loess Plateau since about 2.1 million years ago. *Nature* 559, 608-612.

Figures

1. Position of Kilombe volcano in the Baringo Basin, central Rift Valley of Kenya. Rectangle indicates position of Figure 3.

2. Oldowan sites in East Africa.

3. Kilombe volcano: map of the caldera and southern part of the mountain showing archaeological sites.

4. Above: Oblique view of Kilombe Caldera showing Oldowan localities (courtesy Google Earth); below: outline section along the line indicated by white dashes.

5. Stratigraphic Column of Kilombe Caldera, indicating (left) the stratigraphic range of the Upper Staircase, and the position of GqJh13A.

6. Section of locality GqJh13A near the base of the Upper Staircase, showing palaeomagnetic record, stratigraphic column, and clay composition, with artefact vertical range marked as a black triangle. The magnetism graph indicates reversed, intermediate and normal (R, I, N) magnetisations based on the Palaeolatitude of the samples (in degrees) at the end of the Olduvai normal SubChron within the Matuyama reversed Chron (see text)

7. Plan of finds in GqJh13A excavation, indicating in photoview the original find of a chopper and associated bone.

8. A, Chopper, B, core and C, D, two scrapers from GqJh13A (see text for detailed description) The arrow indicates direction of striking of the main flake on the core (B).

9. Four flakes from GqJh13A (see text for detailed description). Arrows indicate direction of striking as evident on ventral faces.

10. A, Small discoid from GqJh12A; B, cortical flake from smooth cobble, and C, hammerstone on cobble, both from GqJh12B area (see text for detailed description).

11. Length distribution of artefact finds from GqJh13A compared with Hadar A.L. 894 (Hadar data after Goldman-Neuman and Hovers 2012), and debitage from the Kilombe Acheulean Main Site area EH. Finds from Hadar and the Caldera are of trachyte, those from Kilombe EH mainly of trachyphonolite.

12. Weight distribution in numbers of stone finds from GqJh13A.

13. Schematic diagram of the way that flakes were struck from tabular trachyte cores in the Kilombe Caldera Oldowan. Sometimes a single main flake was detached. Arrows indicate direction of striking.

Figures

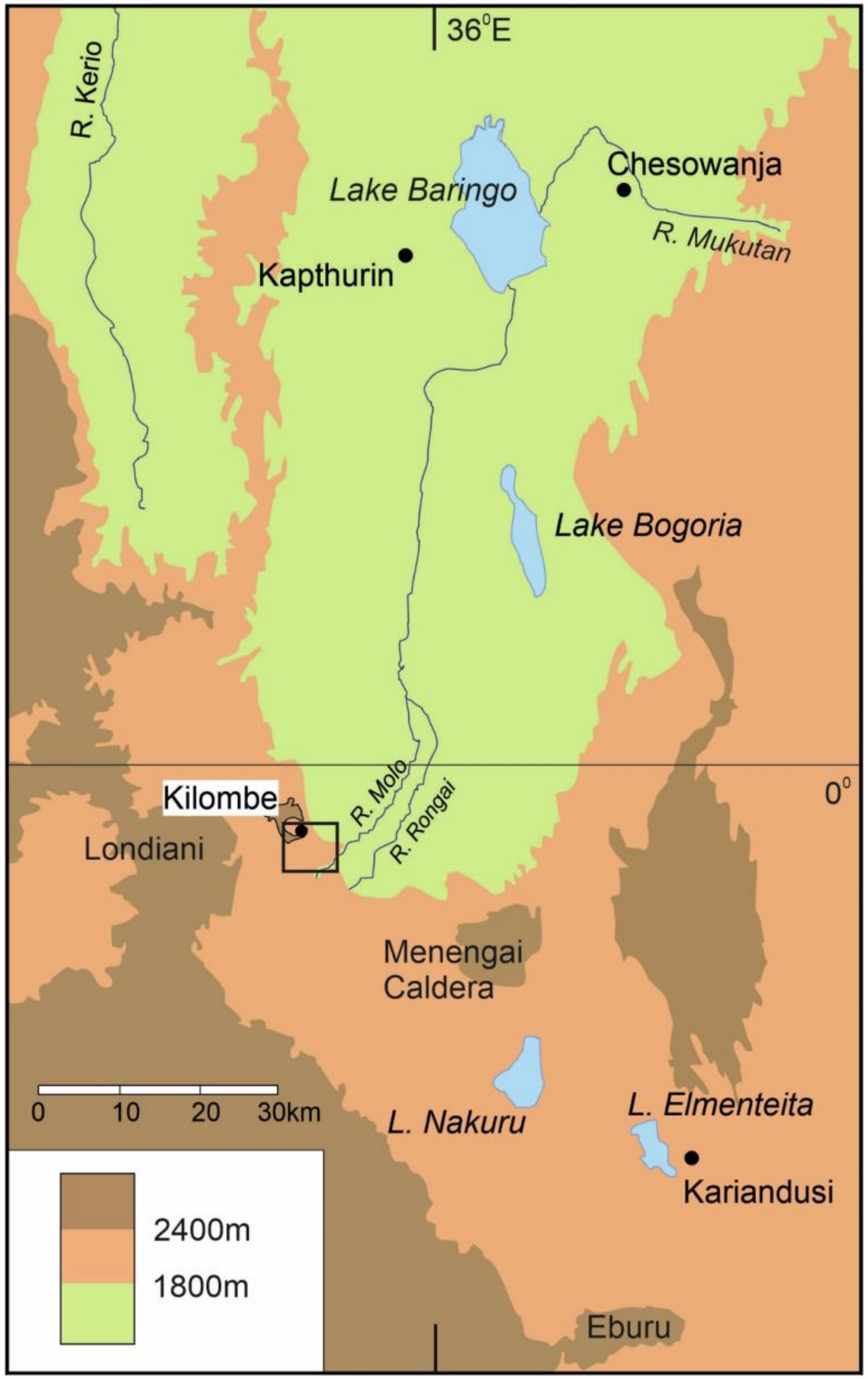

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Fig. 2: Oldowan sites in eastern Africa

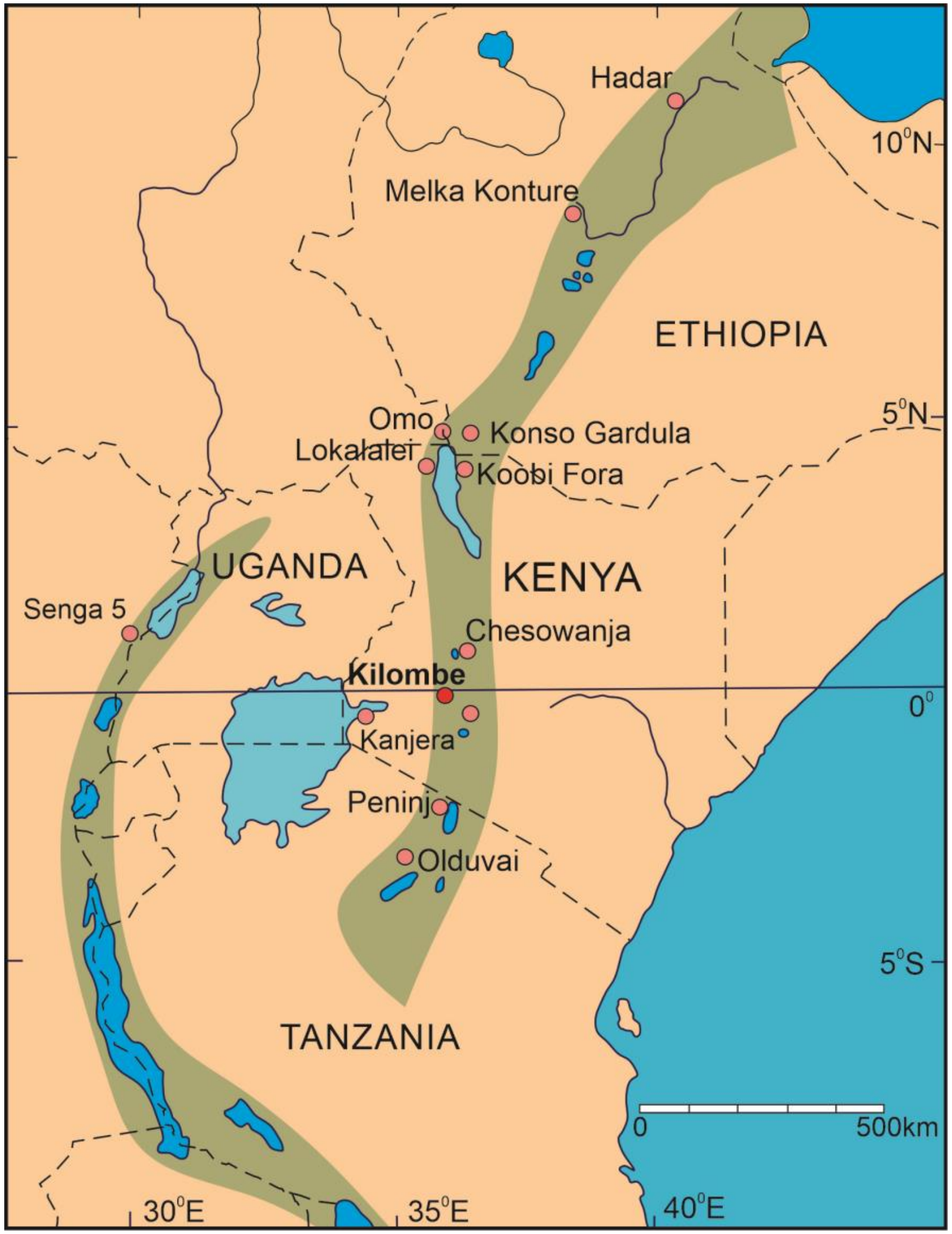

Fig 3: Kilombe volcano: map of the caldera and southern part of the mountain showing archaeological sites.

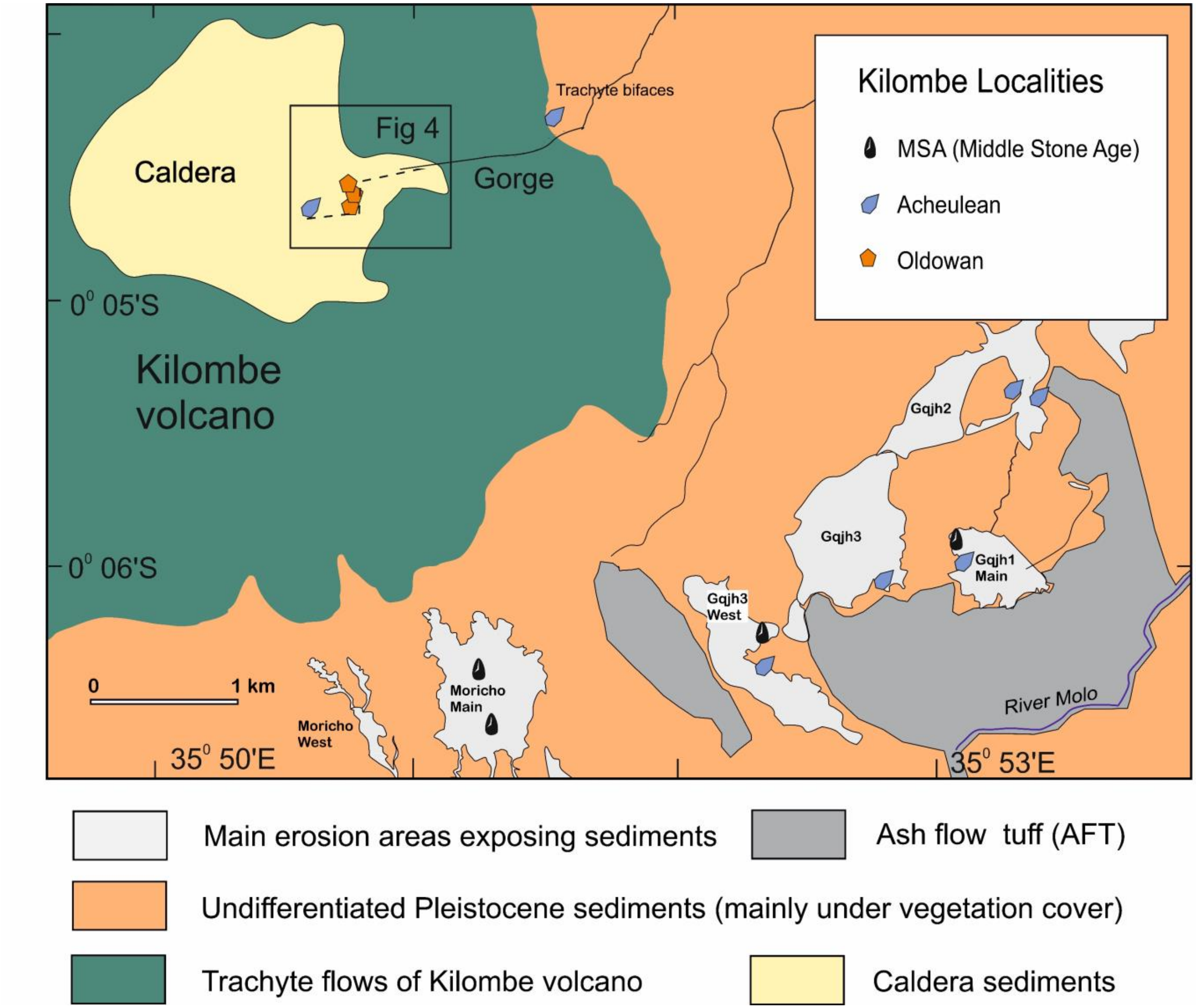

Fig 4: Above: Oblique view of Kilombe Caldera showing Oldowan localities (courtesy Google Earth); below: outline section along the line indicated by white dashes.

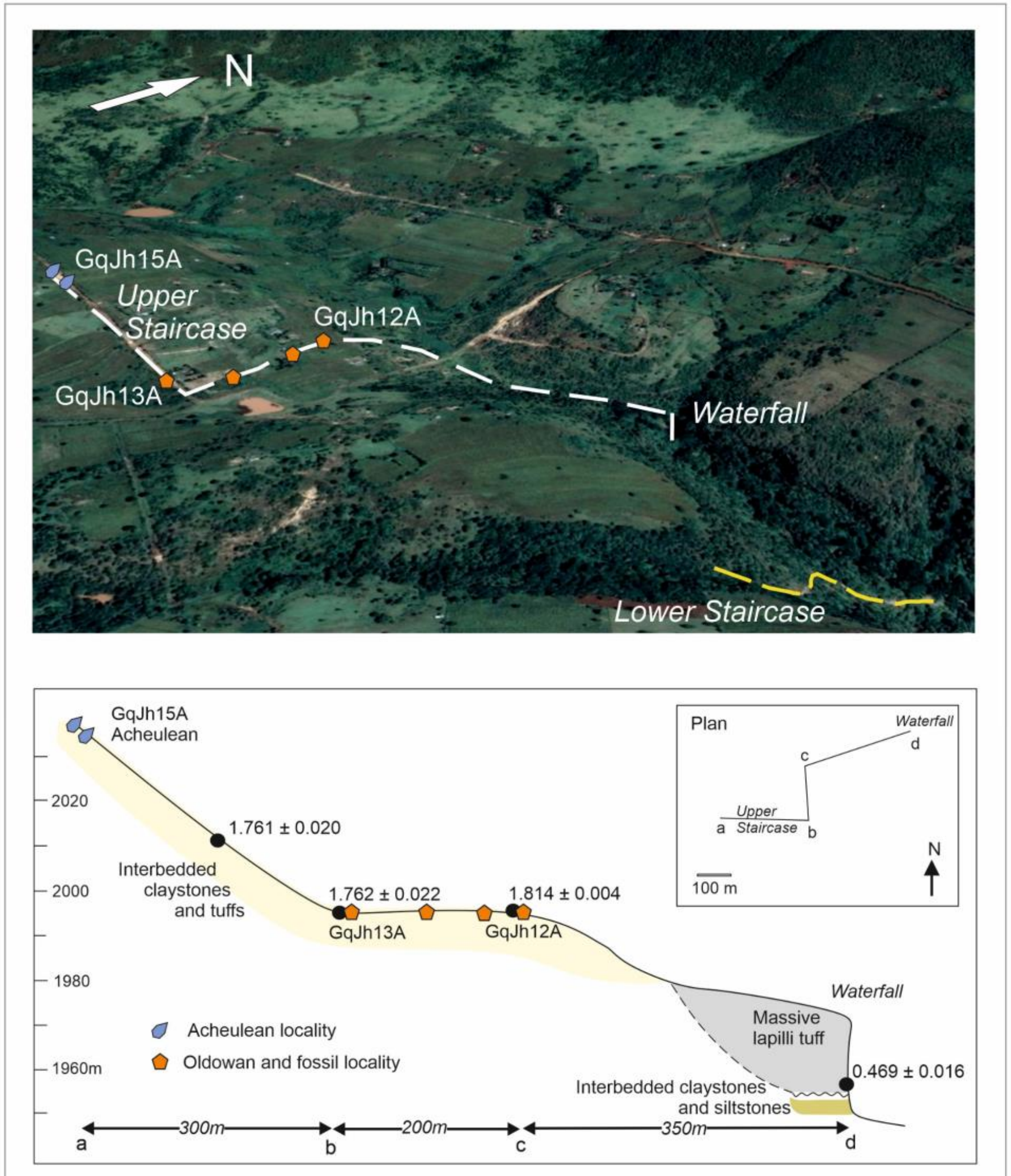

Fig. 5: Stratigraphic Column of Kilombe Caldera, indicating (left) the stratigraphic range of the Upper Staircase, and the position of GqJh13A.

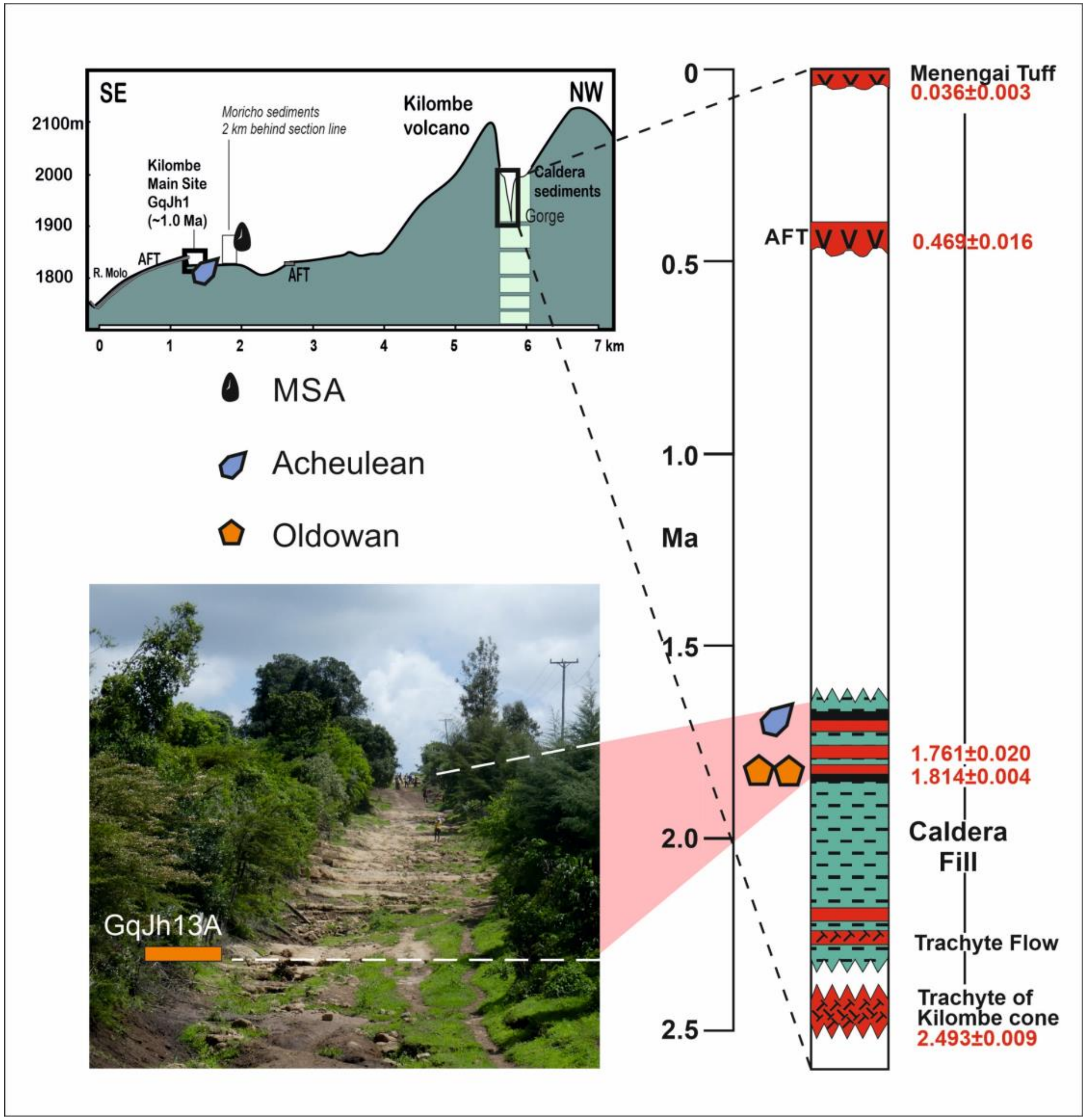

Fig. 6: Section of locality GqJh13A near the base of the Upper Staircase, showing palaeomagnetic record, stratigraphic column, and clay composition, with artefact vertical range marked as a black triangle. The magnetism graph indicates reversed, intermediate and normal (R, I, N) magnetisations at the end of the Olduvai normal SubChron within the Matuyama reversed Epoch (see text).

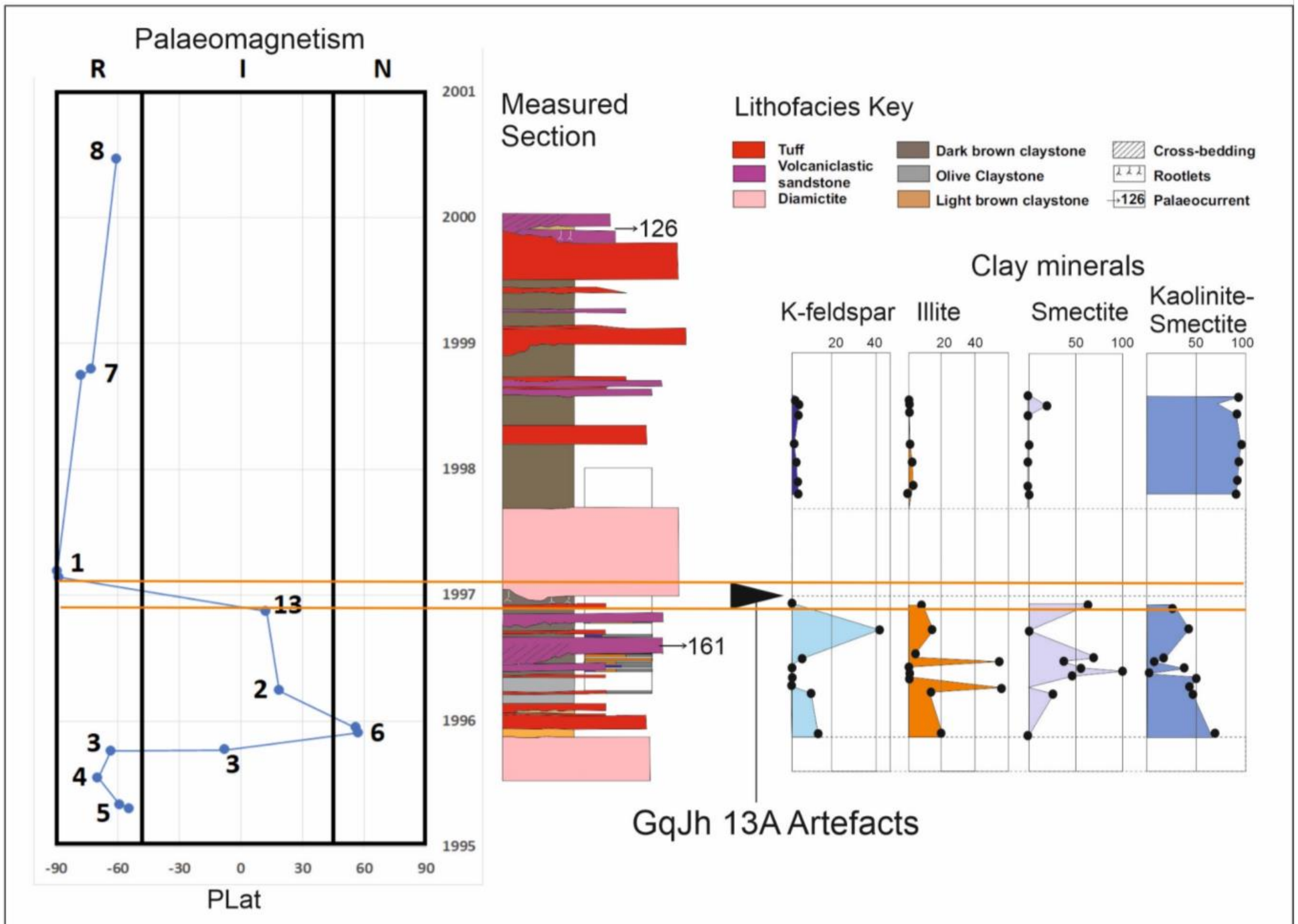

Fig 7: Plan of finds in GqJh13A excavation, indicating in photoview the original find of a chopper and associated bone.

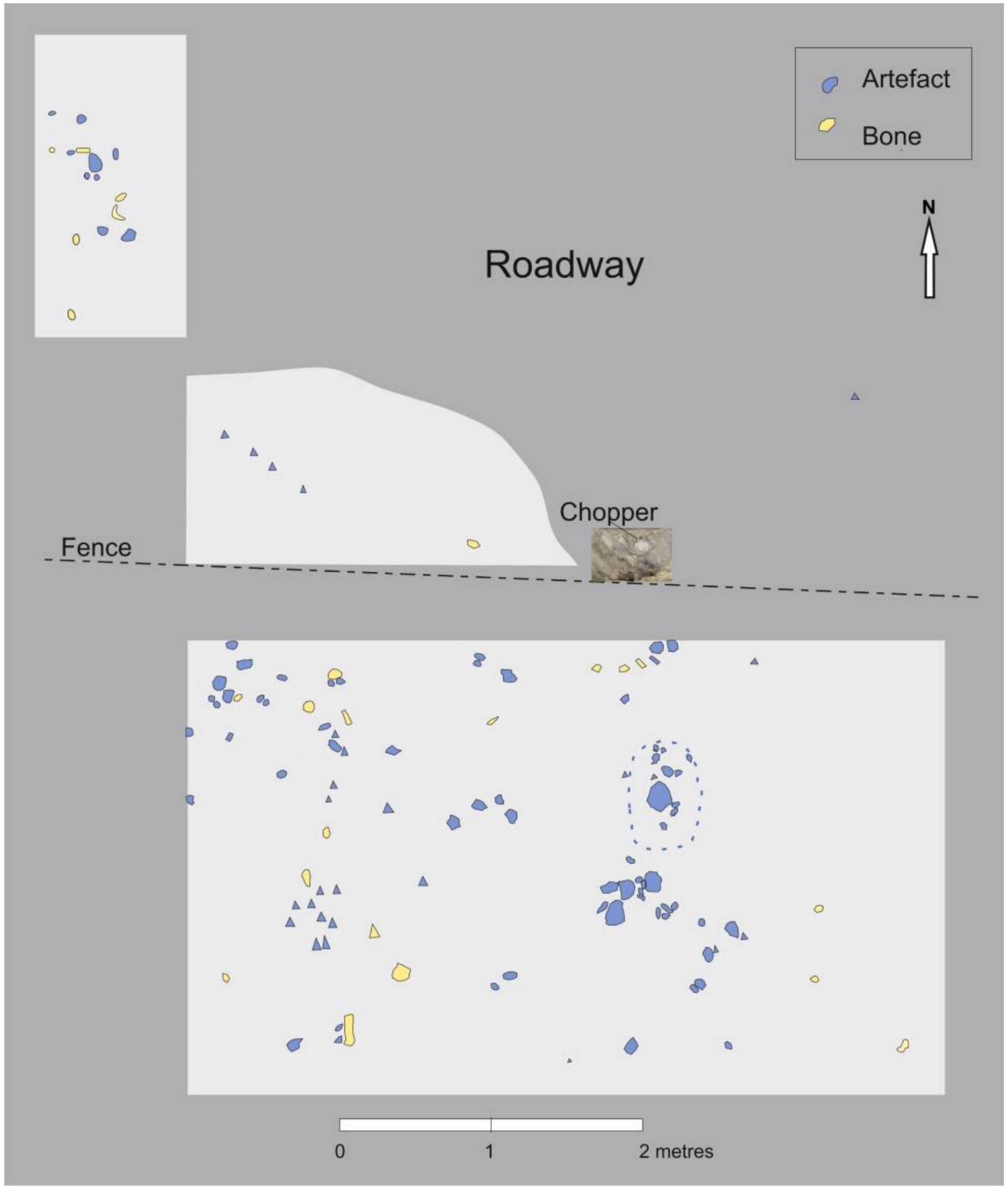

Fig 8: A, Chopper, B, core and C, D, two scrapers from GqJh13A (see text for detailed description).

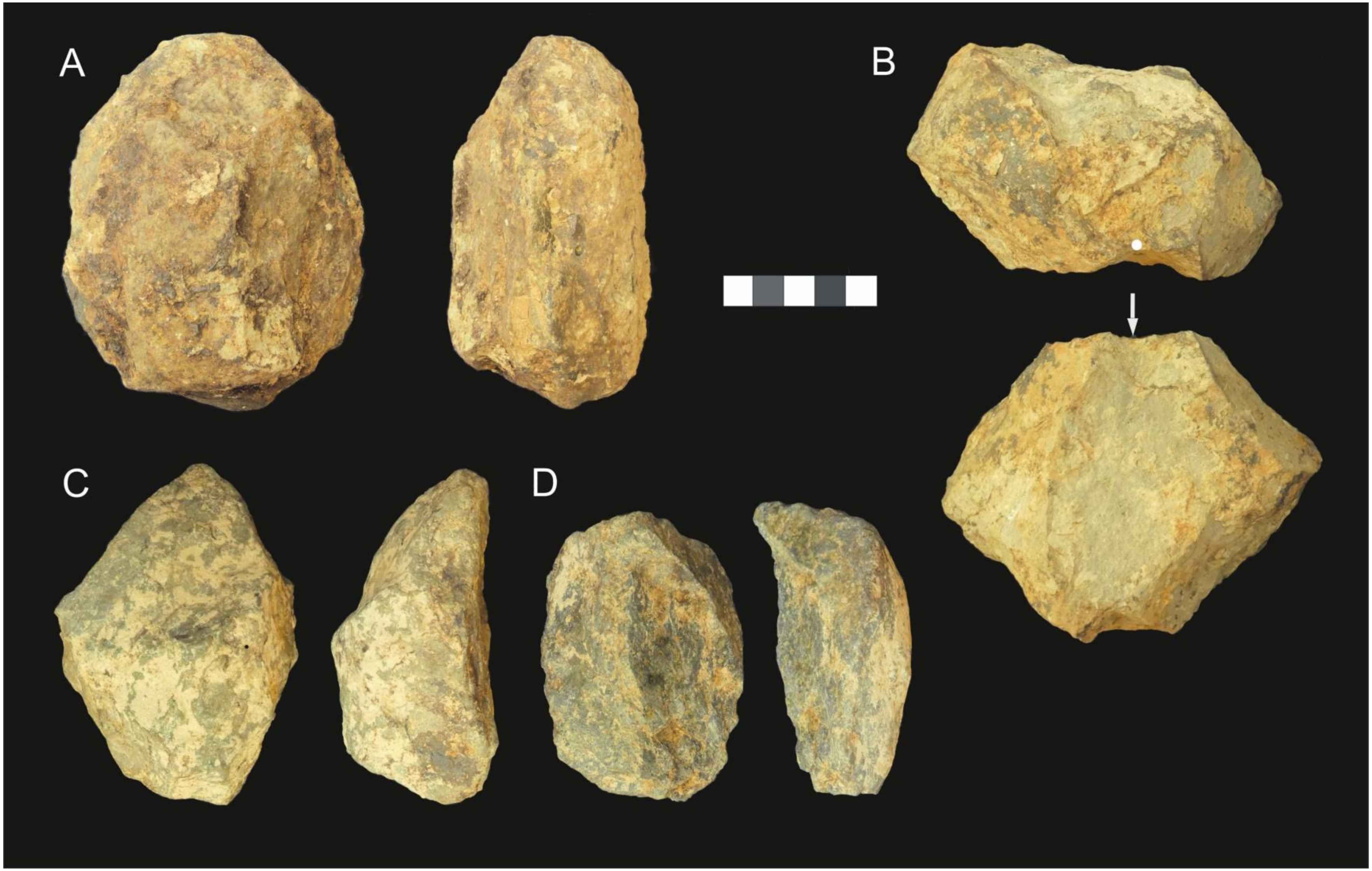

Fig. 9: Four flakes from GqJh13A (see text for detailed description).

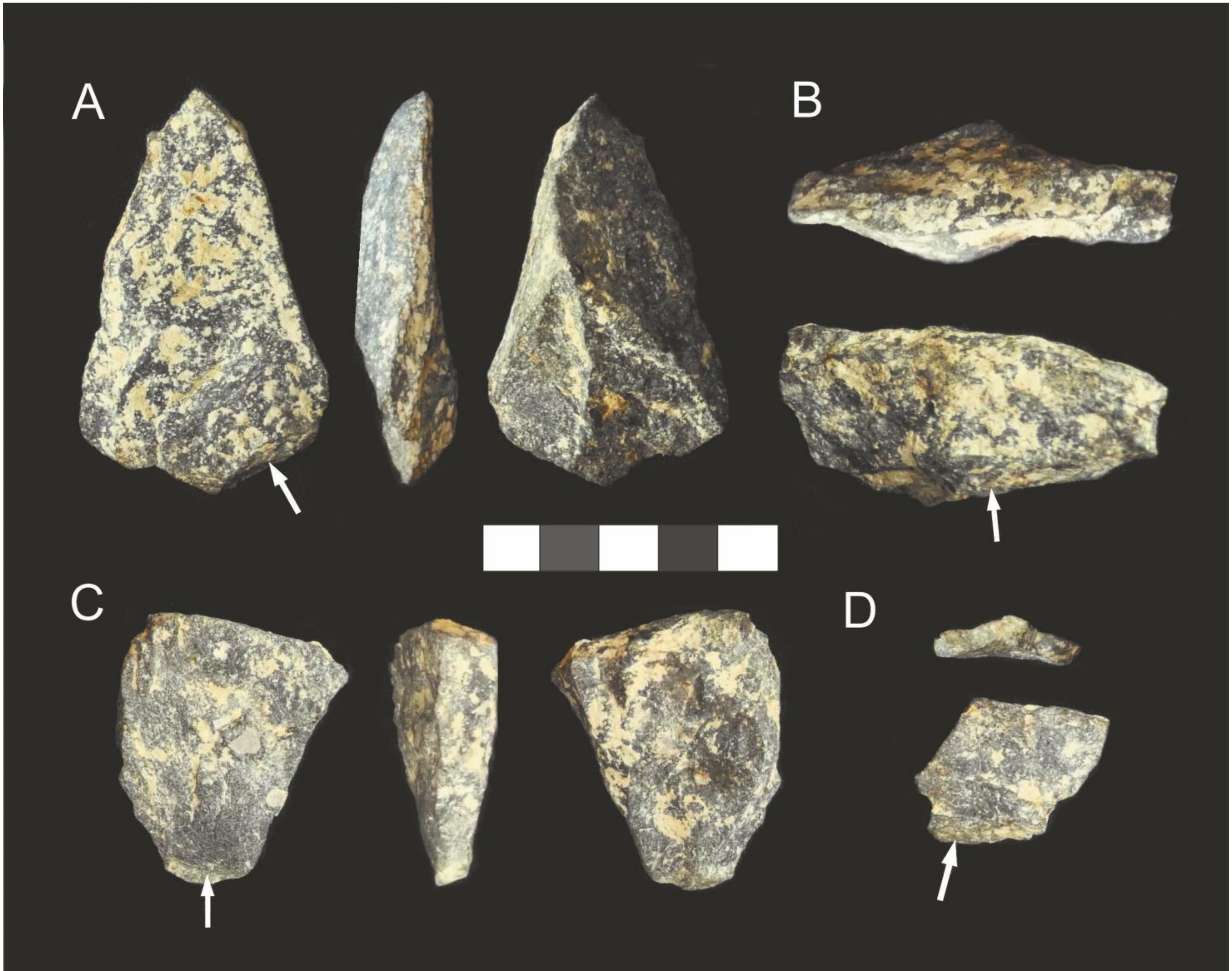

Fig. 10: A, Small discoid from GqJh12A; B, cortical flake from smooth cobble, and C, hammerstone on cobble, both from GqJh12B area (see text for detailed description).

Fig. 11: Length distribution of artefact finds from GqJh13A compared with Hadar A.L. 894 (Hadar data after Goldman-Neuman and Hovers 2012), and debitage from the Kilombe Acheulean Main Site area EH. Finds from Hadar and the Caldera are of trachyte, those from Kilombe EH mainly of trachyphonolite.

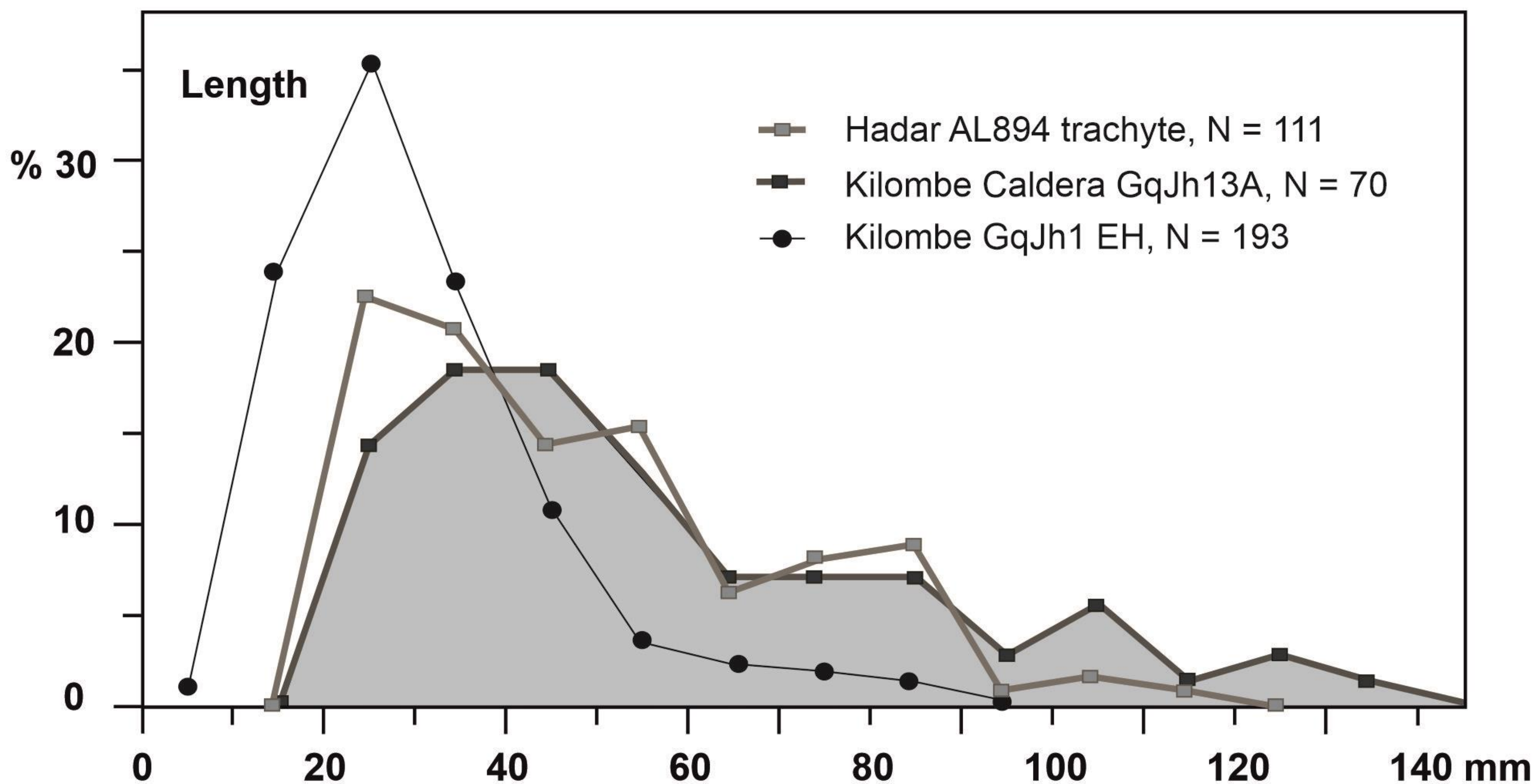

Fig. 12: Weight distribution in numbers of stone finds from GqJh13A.

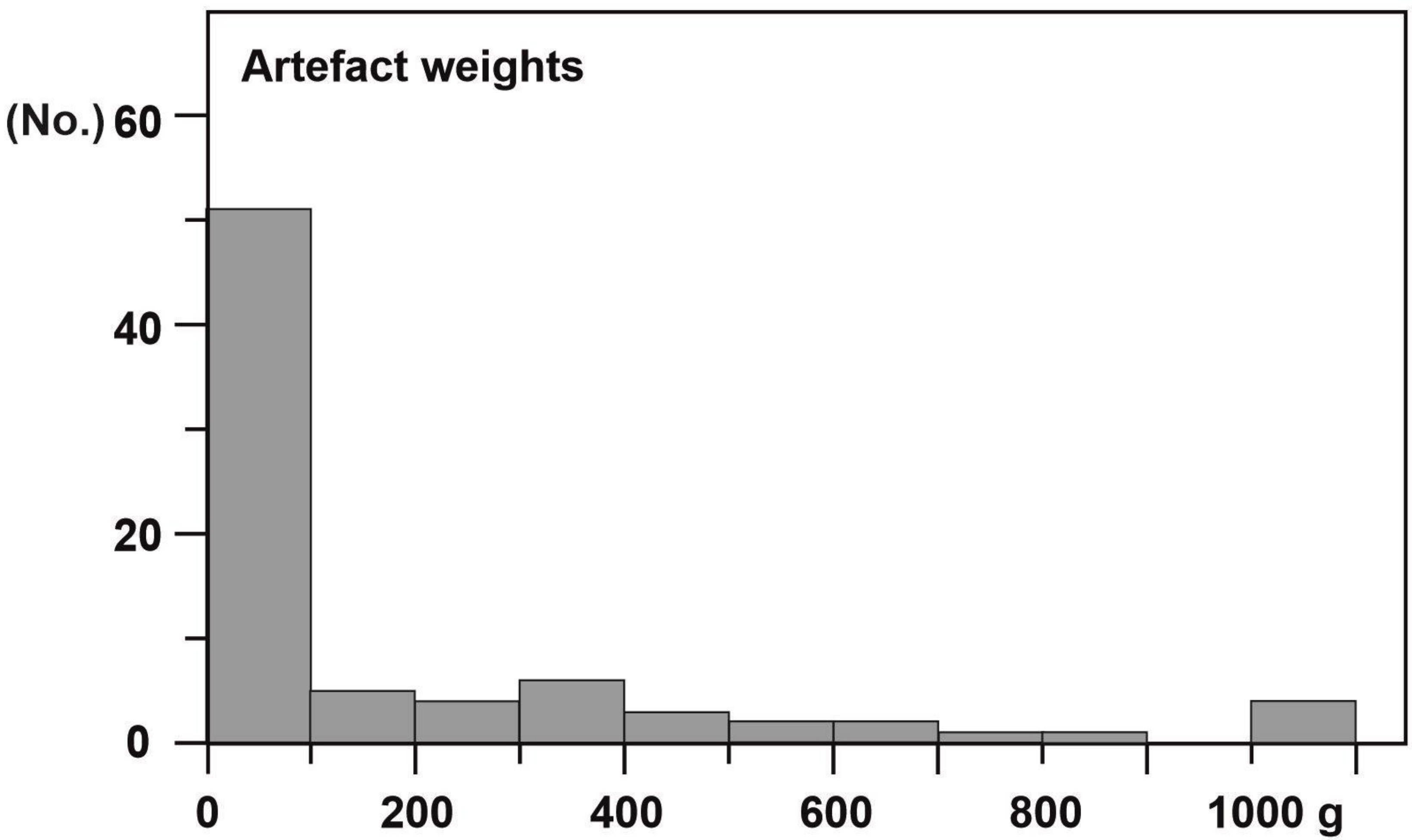

Fig 13: Schematic diagram of the way that flakes were struck from tabular cores in the Kilombe Caldera Oldowan.