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An earlier origin for stone tool making: implications for cognitive evolution and the transition to *Homo*

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The discovery of the earliest known stone tools at Lomekwi 3 (LOM3) from West Turkana, Kenya, dated to 3.3 Ma, raises new questions about the mode and tempo of key adaptations in the hominin lineage. The LOM3 tools date to before the earliest known fossils attributed to *Homo* at 2.8 Ma. They were made and deposited in a more C_3 environment than were the earliest Oldowan tools at 2.6 Ma. Their discovery leads to renewed investigation on the timing of the emergence of human-like manipulative capabilities in early hominins and implications for reconstructing cognition. The LOM3 artefacts form part of an emerging paradigm shift in palaeoanthropology, in which: tool-use and tool-making behaviours are not limited to the genus *Homo*; cranial, post-cranial and behavioural diversity in early *Homo* is much wider than previously thought; and these evolutionary changes may not have been direct adaptations to living in savannah grassland environments.

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

1. Introduction

The manufacture and use of knapped stone tools by hominins have been researched extensively by archaeologists and also more recently by primatologists, all of whom appreciate the relevance of tool making and tool use in understanding the evolution of human cognition and subsistence behaviour. The origins of lithic technology has long been viewed as one of the paramount and foundational transitions in hominin evolution, yet little is still actually known about when, where, why and how stone knapping first occurred in our early ancestors. The recent discovery of the earliest yet-known knapped stone artefacts from Lomekwi 3 (LOM3) [1] in West Turkana, Kenya, shows a significant change in hominin technological behaviour more than 3 Ma.

Conventional wisdom in human evolutionary studies had long assumed that the origins of hominin sharp-edged stone tool production were linked to the emergence of the genus *Homo* [2,3] in response to climate change and the spread of savannah grasslands [4–10]. In 1964, when Louis Leakey and colleagues described fossils looking more like later *Homo* than australopithecines at Olduvai Gorge in Tanzania [2], found in association with the then-earliest known stone tool culture, the Oldowan, being excavated there and described by Mary Leakey [11], they were assigned to a new species: *Homo habilis* or 'handy man'. The premise was that our lineage alone took the evolutionary step of hitting stones together to strike off sharp flakes and that this was the foundation of our evolutionary success. Subsequent discoveries pushed back the date for the first Oldowan stone tools to 2.6 Ma [12,13], and the earliest fossils attributable to early *Homo* to only 2.4–2.3 Ma [14,15], opening up the possibility of tool manufacture by hominins other than *Homo* [16], possibly before 2.6 Ma [17–19]. Australopithecines generally, and *Australopithecus africanus*, *A. garhi*, *A. sediba*, *A.* (*Paranthropus*) *aethiopicus* and *A.* (*Paranthropus*) *robustus* more specifically, have all been proposed as non-*Homo* stone tool knappers, or at least having manual manipulative capabilities that allowed human-like knapping ability [13,19–23]. The publication of cut-marked bones from Dikika at 3.4 Ma suggested the possibility of hominin *use* of stone tools for cutting by *Australopithecus afarensis* before 2.6 Ma, although there is no evidence for stone tool *making* [24].

Early Oldowan artefacts have long been the only evidence available of the fundamental shift in hominin technical behaviour: between processing soft material and using natural stones, to knapping hard rocks to intentionally detach flakes [18]. The development of any technical system involves an increasing number of steps. Each step consists of a chain of actions, underpinned by decision-making; the second step is a consequence of the first and allows the third and so on, until the anticipated goal is achieved [18]. The success of hominin stone knapping specifically requires:

(1) an understanding of the fracture mechanics of the available stone raw materials, and most preferable sizes and shapes of the initial blocks for knapping;
(2) sensorimotor control over the force and accuracy involved in the percussive gestures required to strike off flakes from the stone block, and;
(3) a visuo-spatial understanding of the locations and angles at which to strike the core and detach flakes such that each removal doesn't alter the core's morphology in such a way that further detachments are not possible (core maintenance) [25].

Analyses on the Oldowan artefacts from the sites of Gona (2.6–2.5 Ma [13,19]), Hadar (2.36 ± 0.07 Ma [26]) and Omo (2.34 ± 0.04 Ma [27]) in Ethiopia, and especially Lokalalei 2C (2.34 ± 0.05 Ma [28]) from West Turkana, Kenya, demonstrate that Pliocene hominin knappers already had reasonable abilities in terms of raw-material selectivity, planning depth and manual dexterity [27–32]. The seemingly punctuated appearance of rather well-controlled stone knapping capabilities in the early Oldowan leads to it being characterized as a 'cognitive leap' [33] or 'something from nothing' [34]. It was often assumed that stone knapping developed directly and specifically to get sharp flakes for cutting, probably meat [35], though other analyses also have emphasized evidence of pounding activities during this period [36–38]. Palaeoanthropologists' ability to search for and discover the earliest traces of hominin stone tool manufacture has therefore been hampered by: the rarity of the behaviour, causing its signal in the archaeological record to be slight; the rarity of sedimentary exposures from the relevant time periods, causing any existing signal to be attenuated; lack of archaeological survey in these exposures, leaving any signal present to be missed; and a lack of consideration about what the earliest knapped stone artefacts might look like and how to identify them during field survey.

2. The Lomekwi 3 technology

The discovery of knapped stone artefacts dating to 3.3 Ma at the site of LOM3 on the western side of Lake Turkana in northern Kenya has fundamentally changed our understanding of early hominin evolution and the development of technological behaviour in our lineage. In addition to pushing back the beginning of the known archaeological record by 700 000 years, it places the origins of stone knapping half a million years before the earliest known fossil evidence of the genus *Homo* [39], and marks the first time a new industry of the Earlier Stone Age has been proposed in over 80 years [40].

The LOM3 site is a low hill eroded into by a small ravine that exposes a series of interdigitated lenses of sands, granules and silts corresponding to different facies of the same sedimentary environment related to the distal fan deposit in which the artefacts are preserved. The surface and excavated artefacts from the deposits exposed at LOM3 above the Toroto Tuff are firmly dated to 3.3 Ma by a combination of $^{40}Ar/^{39}Ar$ dating and magnetostratigraphy [1]. The lithic material recovered in 2011 and 2012 comprised 149 surface and *in situ* artefacts: 83 cores, 35 flakes (whole and broken), 7 passive elements or potential anvils, 7 percussors (whole, broken or potential), 3 worked cobbles, 2 split cobbles and 12 indeterminate pieces [1]. Technological analysis of these artefacts provide evidence of sensorimotor performance and an effective control of elementary percussive gestures [30,41,42] even though the flake scars and their organization do not indicate a mastery of stone knapping like that shown by later Oldowan knappers [29].

In addition to the results from the 2011 and 2012 field seasons at LOM3 already published [1], continuing excavation in 2014 and 2015 has uncovered 16 additional well-preserved artefacts and several fossil remains from the *in situ* level (figures 1 and 2). These materials are being recovered from under 3 m of sterile Pliocene overburden in a layer containing granule to small-pebble sand lenses (figure 3). There are no other such granule/small-pebble lenses in the stratigraphy above this one, and no other cobbles the size of the artefacts in the section above the site. As the artefact-bearing level still continues under the hill, excavation will continue for the foreseeable future. During excavation, a rigorous trace and use wear analysis protocol is being employed in which excavators wear sterile gloves while artefacts and fossils are carefully extricated to ensure their surfaces and any adhering sediment is preserved, and in which samples from the surrounding soil matrix are collected for comparative analysis. The artefacts are not handled or examined until cleaned under laboratory conditions and trace materials collected for analysis. The majority of these recently recovered artefacts and fossils have therefore not yet been studied in detail technologically; further results will be forthcoming.

As part of our ongoing research, an experimental programme was undertaken to replicate the lithics found at the site from the same raw materials locally available at LOM3, and the knapper subjected to various manual constraints in order to reconstruct more accurately the techniques and reduction strategies used to produce the LOM3 artefacts. Together with the technological analysis of the archaeological material, these replication experiments suggest that the LOM3 knappers were predominantly using both the passive hammer technique, in which the core is held in both hands and struck downwards onto an anvil; and the bipolar technique, in which one hand stabilizes the core on the anvil and the other strikes the hammer down vertically onto the core [1]. These techniques have rarely been identified in the

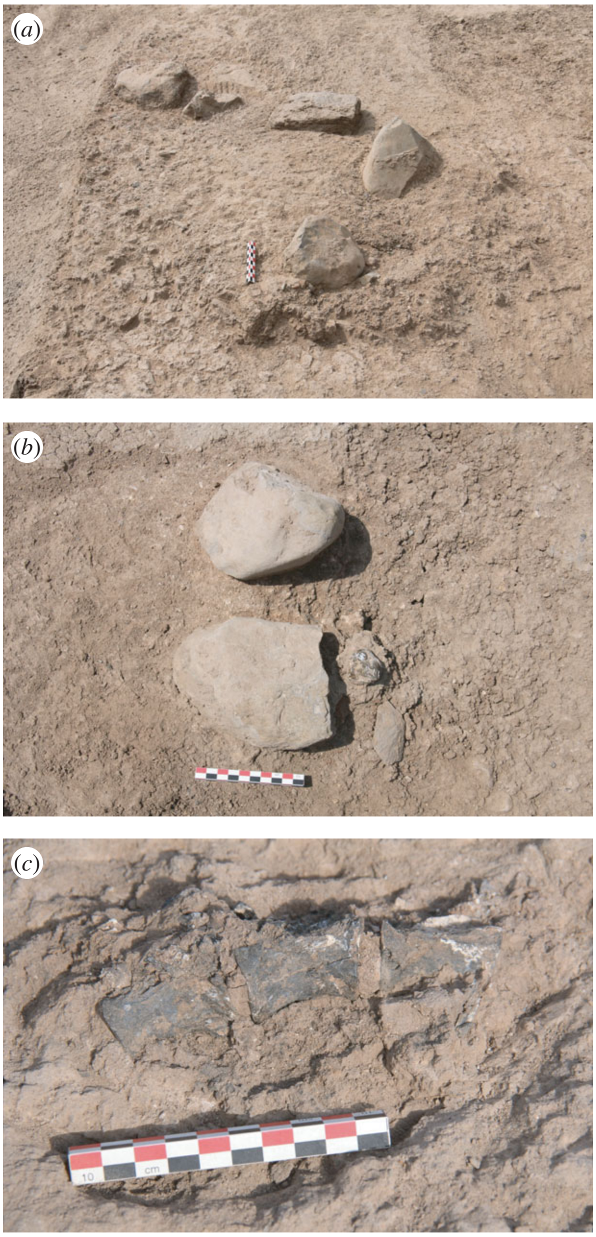

Figure 1. Photos from the LOM3 excavation in July 2014. (*a*) Overview showing several artefacts being uncovered *in situ*. (*b*) Two large cores and a flake *in situ* in association with a fossil hippo tooth. (*c*) Mid-sized mammal vertebrae *in situ* in anatomical connection. (Online version in colour.)

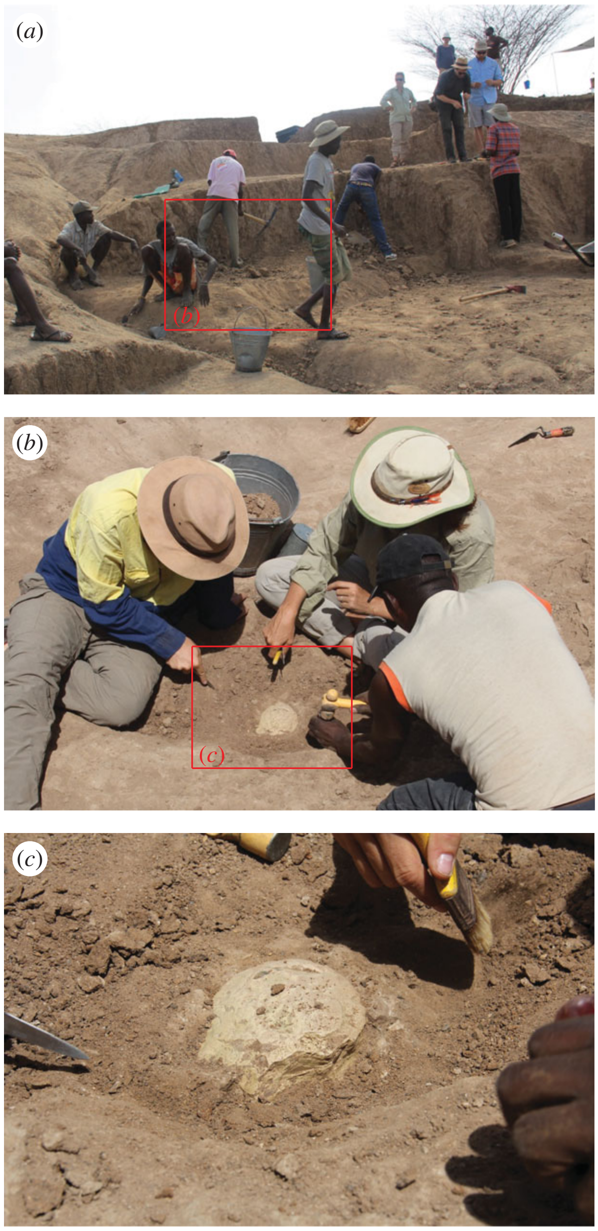

Figure 2. Photos from the LOM3 excavation in July 2015. (*a*) Overview showing opening of squares beneath 3 m of sterile Pliocene overburden. (*b*) Discovery of large core *in situ*. (*c*) Close-up of core from *b* showing knapping scars and fresh condition. (Online version in colour.)

Oldowan [36,37,43,44]. These replication experiments have shown that Lomekwian tool manufacture using these two techniques does not require human-like manipulative capabilities [1,45] (see the electronic supplementary material for more information).

3. Implications of other recent palaeoanthropological discoveries

Just as new archaeological discoveries have been changing our view of the evolution of technological behaviour, several Plio-Pleistocene hominin fossil discoveries and new analyses over the past year have fundamentally altered long-standing views on the origins of our genus. A synthesis of new discoveries and results, given below, points towards a common conclusion: cranial, post-cranial and behavioural diversity in early *Homo* was much wider than previously thought, emerging from similarly high diversity in Pliocene genera and earlier than previously thought. These varying suites of derived characters appear to have been emerging in dispersed hominin groups and probably in response to different selective pressures than those evoked by the conventional narrative described in the introduction.

Computed tomography (CT)-based virtual reconstruction of the 1.8 Ma OH7 *H. habilis* holotype and three-dimensional geometric morphometric comparison with many hominin fossils and living hominoid and human samples concluded that the mandible was rather primitive, with a long and narrow dental arcade and prognathic lower face, yet coupled with a larger endocranial volume estimate than previously proposed based on the preserved morphology of the parietal bones [46]. A new fossil mandible attributed to early *Homo* was discovered from Ledi-Geraru, Afar, Ethiopia, dated to 2.80–2.75 Ma and showing a mix of primitive traits seen in *Australopithecus* and derived morphology associated with later *Homo* [39]. Other maxillary and mandibular fossils from the Woranso–Mille

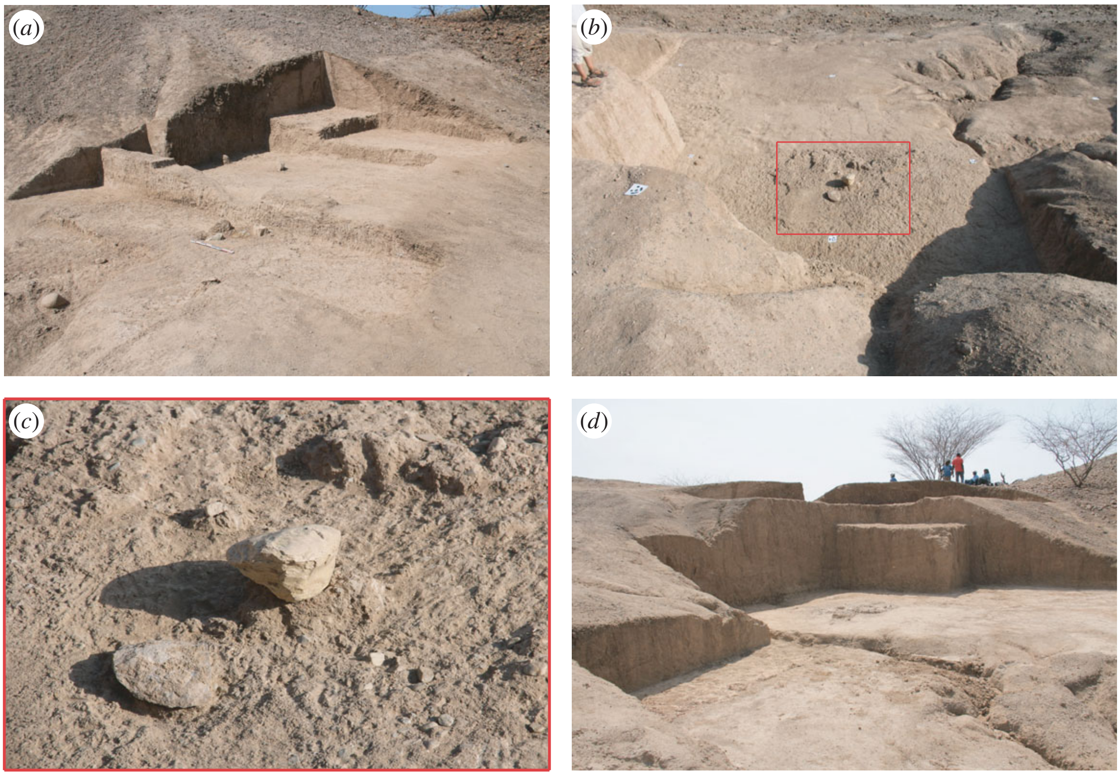

Figure 3. Progression of the LOM3 excavation since 2012. (*a*) Overview showing site towards the end of the 2012 season. (*b*) View of the excavation from above in July 2015 showing *in situ* level with new artefacts uncovered. (*c*) Close-up of artefacts uncovered from *b*. (*d*) Overview showing site at the end of the 2015 season. (Online version in colour.)

study area, central Afar, Ethiopia, dating to 3.3–3.5 Ma, also display a suite of primitive and derived traits that distinguish them from *A. afarensis*, *Kenyanthropus platyops* and early *Homo*, leading the authors to attribute them to a new species: *Australopithecus deyiremeda* [47].

New associated partial ilium and femur specimens from Koobi Fora, Kenya, dating to 1.9 Ma, have been attributed to the genus *Homo*, but display a unique combination of traits suggesting the presence of at least two post-cranial morphotypes within early *Homo*, reflecting underlying body form and/or adaptive differences [48]. Most recently, an assemblage of over 1500 fossil elements representing at least 15 hominin individuals recently described in detail from the Rising Star cave system near Swartkrans, South Africa, again combines primitive characteristics, such as small brain size, curved fingers and australopith-like shoulder, trunk and hip morphology, with derived features in the wrists, hands, legs and feet. This unique combination leads the authors to attribute them to a new species: *Homo naledi* [49]. Unfortunately, these fossils are not yet dated nor are they associated with any archaeological remains [50], so the possible consequences of their morphology for technological behaviour is unknown. CT-based analyses of the trabecular architecture of the metacarpals of living humans, apes and fossil hominins demonstrate that *A. africanus* and *Australopithecus robustus*, traditionally considered not to have engaged in habitual tool manufacture, have a human-like trabecular bone pattern in the metacarpals consistent with forceful opposition of the thumb and fingers typically adopted during tool use [23]. Whether this is indicative of habitual tool use in these individuals, or rather that having a broad range of manipulative capabilities is a primitive condition among hominoids and especially hominins, remains to be determined [51].

4. Discussion

Many inferences from analysis of the LOM3 artefacts can be used to try to reconstruct aspects of the cognitive abilities of their makers. For example, were the LOM3 knappers carefully choosing which stone raw materials to work, or randomly picking up rocks and hitting them together? Initial survey of the conglomerate source located 100 m from the site shows that cobbles and blocks of all sizes were available locally, from which the largest were consistently selected for knapping, though it has not yet been determined if there was a selection for morphology [1]. The presence of numerous percussion marks on the cortical surfaces of many artefacts, and the use of several different knapping techniques (at least bipolar and passive hammer, if not also direct freehand), suggests a flexibility in the LOM3 hominins' technological behaviour that was both much older than previously acknowledged and different from the generally uni-purpose stone tools used by primates [52,53].

Significant knapping accidents occurred during flaking at LOM3, with numerous hinge and step flake terminations visible on cores (figures 4 and 5) [1]. These could be due to large size of the initial blocks, the quality of the raw materials used (basalts and phonolites), or the ability of the LOM3 knappers who could have been less capable of foreseeing where or how to remove a flake in order to maintain the platform angle and keep knapping, and/or had less-developed sensorimotor performance to execute the strikes accurately.

The available fossil evidence for both brain and body size of hominins living in East Africa at 3.3 Ma suggests that the degree of encephalization had only modestly surpassed what is observed in the extant great apes [54,55]. Recent analyses have demonstrated different scaling coefficients in the

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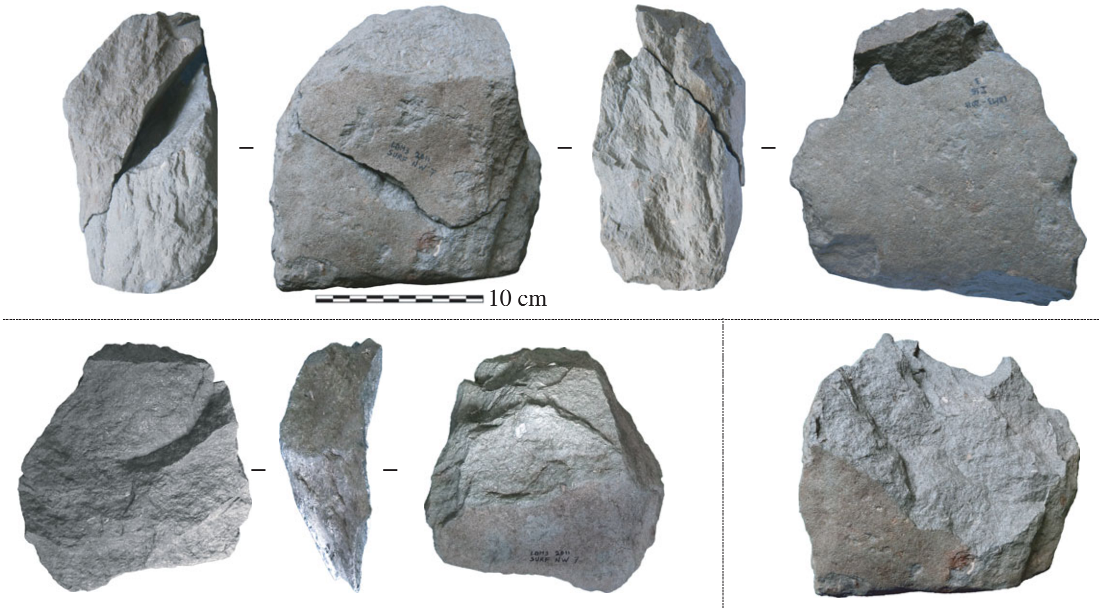

Figure 4. *In situ* core (LOM3-2011-I16-3, 1.85 kg) and refitting surface flake (LOM3-2011 surf NW7, 650 g). Unifacial core, passive hammer and bipolar technique. Both the core and flake display a series of dispersed percussion marks on cortex showing that percussive activities occurred before the removal of the flake, potentially indicating the block was used for different purposes. (Online version in colour.)

left versus right prefrontal hemisphere of the brain of monkeys, apes and living humans. Those results suggest that the primary factor underlying the evolution of primate brain architecture is left hemispheric prefrontal hyperscaling, and humans are the extreme of a left prefrontal ape specialization in relative white to grey matter volume [56]. Language, handedness, tool use, planning and coordinating actions towards higher-level goals and social information processing have all been associated with prefrontal, motor and parietal cortex asymmetries [42,57–63]. The passive hammer knapping technique, in which both arms are performing the same motion, arguably requires less lateralization in upper-limb motor control than does direct freehand knapping. The bipolar knapping technique is arguably more similar to those involved in the hammer-on-anvil technique chimpanzees and other primates use when engaged in nut cracking [40,43] than to the direct freehand percussion evident in Oldowan assemblages. The use of these two techniques may imply less prefrontal and motor cortex asymmetry in the brain of the LOM3 knappers compared with modern humans, but more than that of living great apes [64]. Taken together, the above suggest that the origins of stone knapping may have been associated with increased development of prefrontal, motor and parietal cortex asymmetries, and their consequent cognitive and physical capabilities, but not with the drastic increases in absolute and relative brain size seen after 2 Ma with the genus *Homo*.

The LOM3 artefact discovery also challenges the conventional wisdom on who the first toolmakers were, and why they began knapping. Pending new discoveries, the only hominin species known to have been living in the region at 3.3 Ma are *A. afarensis* [65] and/or *K. platyops* [55]. *Australopithecus deyiremeda* is evinced at that same date in the Ethiopian Afar 1000 km to the northeast [47]. The LOM3 artefacts were made and deposited in a setting surrounded by a high percentage of C_3 vegetation, and if isotopic values from modern African landscapes are used as a proxy, the site can be reconstructed as having a woodland/bushland/thicket/shrubland palaeoenvironment [1]. The site's palaeosol $d^{13}C_{VPDB}$ values are comparable with those from other East African hominin environments between 3.2 and 3.4 Ma, but significantly more C_3 than the 2.6 Ma artefact site at Gona, Ethiopia [1]. While LOM3 is only one site, this data point raises the possibility that early knappers may not have been living in open savannah grassland environments. What might the LOM3 hominins have been doing with the artefacts if living in a more closed environment? The classic hypothesis that early knapping was aimed at producing flakes for cutting meat can't be ruled out, and as has been shown, even a woodland-bound hominin still would have had access to carcasses such as tree-stored leopard kills [66–68]. Given the large size of the cores and anvils and percussion marks on the cortical surfaces of the tools [1], along with what is known of primate percussion behaviours seen among chimpanzees and capuchins [52,53,69–71], it may also be likely that the LOM3 artefacts were used to process plant food. These converging lines of evidence could suggest the earliest stone knapping developed within Pliocene hominins naturally from pre-existing pounding behaviours, rather than more punctually and directly to flaking for cutting edges.

5. Conclusion

Three possible evolutionary scenarios can be proposed to explain the existence of knapped stones at such an early date:

(1) stone tool making might still be a defining characteristic of the genus *Homo*, but the lineage would extend much further back in time and fossils dating to before 2.8 Ma have not yet been found;
(2) stone tool making might no longer be considered characteristic only of *Homo*. It could now also be attributed to earlier hominins like *Australopithecus* or *Kenyanthropus*, having developed from pre-existing stone manipulation and tool-use behaviours of our primate ancestors; or

Figure 5. *In situ* unifacial core (LOM3-2012-H18-1, 3.45 kg), bipolar technique. (Online version in colour.)

(3) stone tool making might not be unique to the hominin lineage; all great apes and their ancestors might have developed this ability. The LOM3 tools could have been made by any hominoid at the time, and the ability has been lost in the lineages leading to the living great apes.

We consider the second scenario the most plausible, and that the LOM3 discovery forms part of an emerging paradigm shift in palaeoanthropology. Instead of the conventional narrative described above, evidence is quickly amassing that stone tool-making behaviours are not necessarily limited to *Homo*; cranial, post-cranial and behavioural diversity in early *Homo* is much wider than previously thought, emerging from similarly high diversity in Pliocene genera and *earlier* than previously thought; and these evolutionary changes may not have been directly related to living in savannah grassland environments. To search for the roots of our genus and for the behaviours characteristic of what it means to be human, palaeoanthropologists must now focus on the time period between 4 and 3 Ma.

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