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Introduction

The evolution of hominin behavior during the Oldowan–Acheulean transition: Recent evidence from Olduvai Gorge and Peninj (Tanzania)

1. Introduction

The emergence of human behavior, understood as a distinct adaptive pattern among primates, which created a material record in the form of archaeological sites, has been widely studied during the Oldowan phase of human evolution. Behavior, as a crucial part of adaptation, is tightly linked to ecology. The Olduvai Paleoecology and Paleoanthropology Project (TOPPP) stressed the importance of studying archaeological sites and the behavior represented therein within their broader paleoecological settings. A multidisciplinary effort integrating the geology, paleobotany, paleochemistry and archaeology of Olduvai Bed I was published as a monographic issue of *Quaternary Research* in 2010. In this collective work, compelling evidence was provided of the heuristic value of conceiving archaeology within the broader framework of paleoecology.

In the past five years, TOPPP has collected a wealth of information from a diversity of sites both at Olduvai Bed I and Bed II, including most of the few anthropogenic sites that are categorized as Developed Oldowan and Acheulean. This information is archaeological (technological, behavioral, taphonomic) as well as geomorphological, geological, geochemical, paleobotanical and paleontological. Using this information jointly, we can address the evolution of human behavior from the Oldowan through Developed Oldowan and Acheulean in conjunction with the evolution of landscapes in two of the most important localities for this type of study in Africa: Olduvai Gorge and Peninj (Lake Natron) (Tanzania). The relevance of this information for Quaternary and human evolutionary studies is evident. There is a vacuum of behavioral information for Developed Oldowan and Acheulean hominins in comparison with older Oldowan hominins. Site functionality is basically unknown in these more recent sites. The comparison of the three types of archaeological record and their landscapes will contribute to understand this crucial part of human evolution. Understanding to what extent *Homo erectus* hominins were behaviorally similar or different from early *Homo* will contribute to more accurate reconstructions of the evolution of subsequent *Homo* taxa. The present volume introduces important advances made on the reconstruction of Bed I hominin paleoecology during the Oldowan and its transition into the Acheulean during the formation of Bed II.

Bunge (1998) argued that to scientifically address any topic, it was necessary to properly define the object of study prior to the formulation of hypotheses (Domínguez-Rodrigo, 2012). Unfortunately, this has not been frequently done in archaeological research dealing with the Acheulean. The definition of Acheulean is still a vague concept, which includes definitions spanning the presence/absence of the "*fossil directeur*" (i.e., handaxes) (Leakey, 1936, 1951; de la Torre and Mora, 2013), its representation in specified frequencies (Kleindienst, 1962; Leakey, 1971), or its definition in technological terms (e.g., Boëda, 1991; see review in; Diez-Martín and Eren, 2012).

The evolutionary interpretation of the "*fossil directeur*" has a biological component understood in traditional Darwinian terms: each stone tool industry was made by a specific hominin taxon. The earliest Acheulean slightly postdates the earliest set of clearly-defined *H. erectus* (Beyene et al., 2013), by a substantial amount of time if including earlier Homo remains not fitting the *Homo habilis* hypodigm (Wolpoff, 1999). In addition, the binomial *H. erectus*-Acheulean fails to explain why *H. erectus georgicus* did not have an Acheulean technology or why the presence of *H. erectus* outside Africa precedes by several hundreds of thousands of years the earliest occurrence of non-African Acheulean. It also does not explain why if *H. erectus* emerged at least by 1.7 Ma, the overwhelming majority of the archaeological record until 1.5 Ma is Oldowan. Only two sites (Kokiselei 4 and Konso Gardula) have been documented as Acheulean prior to 1.5 Ma (Beyene et al., 2013). de la Torre and Mora (2013) argue that Oldowan sites could be attributed to *H. habilis* and Acheulean sites could be attributed to *H. erectus*. Their argument is that sites under tuff IIB are Oldowan and those above this marker are all Acheulean. However, no *in situ* fossil of *H. erectus* is known under Bed III. Only a surface find is reported for Bed II: OH 9. This fossil was discovered in a gully in which only Beds III and IV and a small portion of upper Bed II are exposed (Leakey, 1971). The portion of Bed II exposed corresponds to the section of this bed overlying tuff IID; so, if OH9 belongs in these strata, it certainly overlies several Bed II Acheulean and most Developed Oldowan sites. Therefore, the bulk of Developed Oldowan/Acheulean sites comprised between tuff IIB and tuff IIC (six out of the eleven sites documented by Leakey for all Bed II) are either devoid of hominin fossils or only physically associated to remains of *H. habilis* and *Paranthropus*. Linking stone tool assemblages to hominin types based on the presence or absence of hominin fossils is an epistemically futile exercise. For example, *Paranthropus* is still a widely represented hominin in Bed I and II sites: FLK Zinj, FLK NN (probably OH8) (Gebo and Schwartz, 2006), HWK, BK, SC. If using the same chrono-stratigraphic associative arguments, it could equally be supported that Oldowan or Acheulean tools were made by this taxon.

Although the Developed Oldowan–Acheulean debate has prompted varied interpretations, such as the impact of raw material

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(Stiles, 1977, 1979, 1980, 1991), representation of different reduction sequences (Jones, 1994) or functional differences (Gowlett, 1986; Domínguez-Rodrigo et al., 2009a), most of these approaches emphasize the overall similarity of Developed Oldowan and Acheulean sites in Olduvai Bed II. Variability is most generally conceived as triggered by functional and ecological factors (Leakey, 1975; Hay, 1976; Domínguez-Rodrigo et al., 2009a). The only seeming consensus of all these diverse interpretations is that "the Acheulean is recognized by the presence of bifaces rather than by any other criterion" (Lycett and Gowlett, 2008:22–23) and, to a lesser extent, the ability to produce large flakes (Isaac, 1969). If we take this definition as a starting criterion to identify Acheulean sites, then we must admit that it is an utterly useless one when we attempt to understand the large array of assemblages that have traditionally been classified as either Developed Oldowan or traditional Acheulean within an ecological framework. Alternatively, archaeologists should ponder whether they want a technological definition of these sites (i.e., some of the technical steps undertaken to craft some tools in Acheulean and Developed Oldowan sites were similar) or a functional/adaptive definition, which has the potential for scientifically-based behavioral reconstructions. A technical approach to this question will not by itself provide an explanation for site functionality, especially because this is contingent on what criteria are determined to be illustrative of technological importance when comparing Acheulean to Developed Oldowan sites and also on methodological shortcomings stemming from inferences derived from small and statistically unreliable small sample sizes. This latter approach could be potentially interpreted according to the tool set that is represented in each site. Site functionality is determined by the activities carried out at each site (which required specific tool sets). These activities are in turn conditioned by the interplay of hominin adaptation to certain environments, following specific ecological criteria. All this is overlooked when cataloging sites as Acheulean only because handaxes are present or because the technology is similar. Leakey's (1971) typological approach was more useful in this regard because it separated sites according to the representation of sets of tools (potentially indicative of diverse activities), regardless of how they were knapped.

If acknowledging that simple small flakes and large handaxes are two functionally different stone tool types, and that they can be represented at any given assemblage in drastically different frequencies, the logical conclusion of this syllogism is that different assemblages (e.g., Developed Oldowan [usually with <10% handaxes] vs. traditional Acheulean [>40% handaxes]) represent two functionally different types of sites.

Although some authors overrule any ecological/functional interpretation of these sites in favor of a biological one, this is done by misreading Hay's (1976) original interpretation of site distribution at Olduvai. Hay (1976: 113) provided a paleogeographic interpretation of Developed Oldowan and Acheulean sites as follows: "Sites situated a kilometer or less from the lake are classed as lake-margin, and those more distant are termed inland. The minimum shoreline is taken as a reference point for classifying those sites where the shoreline is not accurately located for the time represented by the site… the result of this analysis is that thirty-eight sites are lake-margin, eighteen are inland and seven are indeterminate. The indeterminate sites are above tuff IID, where a perennial lake, if present, was greatly reduced in size. Despite possible errors in paleogeographic assignment, it seems highly significant that nine of the ten Acheulean sites are inland and the other is indeterminate, whereas seven of the Oldowan B sites are lake-margin, and the others are indeterminate. " This interpretation was reproduced at Peninj where the Acheulean sites occurred more distally to the lake than the Oldowan ones (Domínguez-Rodrigo et al., 2009a). This prompted the conversion of Hay's paleogeographic interpretation into the "Ecological hypothesis of early African Acheulean", in which it was claimed that the bipolar distribution of Oldowan sites (near the lake) and Acheulean sites (distant from the lake, commonly in alluvial settings with fluvial input) had a functional-behavioral cause determined by ecology (Domínguez-Rodrigo et al., 2005). Neither Hay (1976) nor Domínguez-Rodrigo et al. (2005) framed the duality according to sedimentary facies (lacustrine versus fluvial). Fluvial facies are an integral part of the lacustrine systems (even in their proximal sections). Hay (1976) discussed extensively lacustrine sands and sandstones. Therefore, one could find a site in a fluvial context just a few meters away from the lake shoreline. Both Oldowan and Acheulean sites are found associated with fluvial facies in Bed II. However, both types of sites are ecologically and paleogeographically located in different settings. Oldowan sites, as Hay (1976) remarked, occur in higher frequencies near the lake and Acheulean sites distally to it.

In order to see this dual distribution properly, one has to select sites within defined chronological markers, which allow comparisons of location according to specific geomorphological reconstructions. For Olduvai, the best stratigraphic interval for this purpose is the one comprised between tuff IIB and tuff IIC, where most of the Developed Oldowan and the Acheulean sites co-exist (Fig. 1A). The Olduvai Acheulean sites show a high proportion of handaxes (HX) when compared to complete small flakes (SF). Using Leakey's (1971) data, the HX:SF ratio for EF-HR is 0.33. MNK Main site (ratio = 0.03), FC West occupation floor (ratio = 0.05) and SHK (ratio = 0.1) have substantially lower ratios, despite the fact that in assemblages like SHK, most of the flakes and debitage were not collected. Provisionally, if we use an artificial threshold of 10% of the large cutting tools being handaxes to divide "Developed Oldowan" and "Acheulean" assemblages, it can be clearly seen that those assemblages where the ratio is >10% are situated more distant from the lake shoreline than those where the ratio is <10%. This must certainly have a functional/adaptive connotation.

Arguments against this paleogeographic differential distribution disregard the contextual information provided by time-constricted paleogeographic reconstructions, such as those provided by Hay (1976), and some are confused by bringing in examples that belong to different paleogeographic settings. For example, de la Torre and Mora (2013) argue that "assuming that the lakeshore was more or less in the same location during the two occupations (and therefore TK was positioned within the lake floodplain), then we would have an Acheulean occupation (TK LF) <1 km from the lake. Likewise, the SHK Main Site contains so-called Developed Oldowan B materials in channel environments (e.g., SHK-Channel)…". It should be stressed that the fluvial facies does not indicate anything about the paleogeographic position of SHK, which as Fig. 1A shows is inserted within the lacustrine floodplain, despite belonging in a fluvial sedimentary sequence. Secondly, TK is stratigraphically situated above tuff IID, substantially higher in the Bed II sequence than the previous sites, and the position of the lake in that moment was very different from the underlying strata. Hay (1976) doubts that there was a lake above tuff IID times and shows the former lacustrine locus covered with shallow ponds instead (Fig. 1B). The probable disappearance or drastic reduction of the lake during the formation of TK invalidates any statement that the site was closer to a purported lake than other developed Oldowan sites. As a matter of fact, even considering the locus of the pond/shallow lake area, TK is situated at >1 km from the shoreline, in contrast with the other non-Acheulean sites existing in a similar stratigraphic position (BK, SC), which are much closer. This reinforces Hay's original paleogeographic interpretation and the "Ecological hypothesis of the early Acheulean". Current evidence from Olduvai Bed II shows, therefore, that those sites where

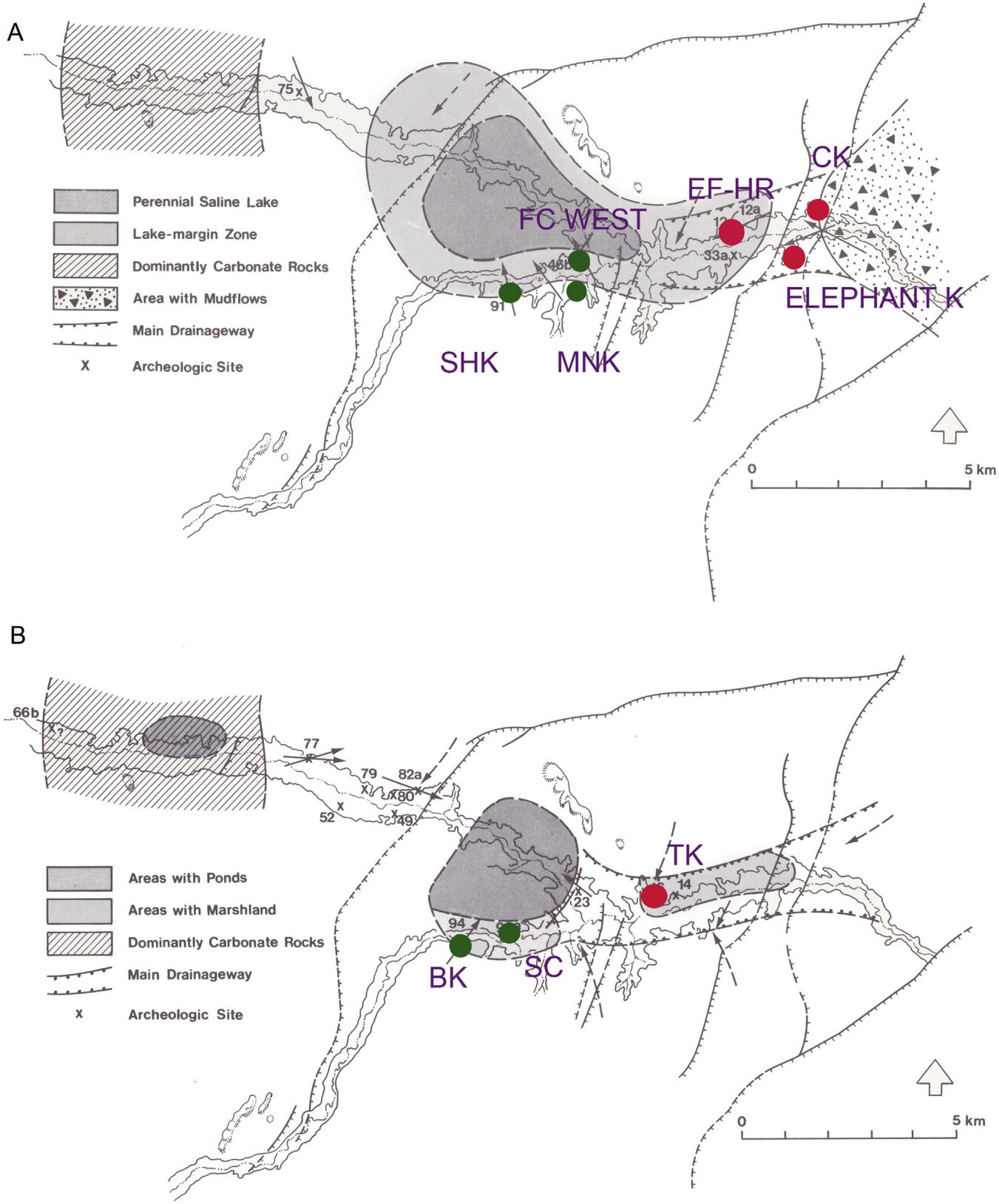

Fig. 1. Paleogeography of the Olduvai lake basin and location of sites during the middle to upper Bed II (under Tuff IID) (A) and above Tuff IID (B) (Hay, 1976). Pene-contemporary Developed Oldowan (green dots) and Acheulean (red dots) sites are shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

handaxes are marginally represented occur more frequently near the lake and sites formed by handaxe-discarding and accumulating activities seem to occur preferentially away from the lake. This is also documented in the pene-contemporary Oldowan–Acheulean sites in Gona (Semaw, pers. comm.).

It is within this ecological-adaptive framework that TOPPP's work was carried out, as will be presented in this special volume of *Quaternary International*. Sites are functional expressions of hominin behavior and adaptation to different environments. Neglecting this contextual information would deprive us of the selective criteria that are crucial to understand how the Bed II hominins behaved and survived in an environment that witnessed the decrease of felids and their activities compared to Bed I (Domínguez-Rodrigo et al., 2007) and simultaneously, an increase in the activities of hyenas in the Bed II paleo-lake basin (Egeland and Domínguez-Rodrigo, 2008).

In this functional-adaptationist-ecological approach, a constant link is made between behavior and environment. This is reflected in the technological study of lithics and in the subsistence behavior reconstructed from the taphonomic analyses of anthropogenic sites. Little was known earlier about hominin subsistence during Bed II times. Monahan's (1996) preliminary work stressed the palimpsestic nature of some of the archaeological record. This was emphasized by Egeland (2007) and Egeland and Domínguez-Rodrigo (2008) for Bed II, resulting in the conclusion that in this geological interval, only BK could be defended as an anthropogenic faunal assemblage (Domínguez-Rodrigo et al., 2009b). However, such conclusions were derived from the analysis of the collections excavated by M. Leakey. TOPPP's renewed work in BK, SHK and TK has resulted in the discovery of a larger anthropogenic component in some of this assemblages, enabling the obtainment of a wealth of data to reconstruct hominin adaptive behavior during this period. The work presented by Domínguez-Rodrigo et al. (2014a,b) on BK and SHK shows that hominins continued exploiting small and medium-sized animals in a similar fashion to that uncovered previously at FLK Zinj. A remarkable innovation in this time period is that the scanty evidence of exploitation of megafaunal remains prior to 1.5 Ma seems to become more abundant during Bed II. Exploitation of several individuals of *Pelorovis*, *Sivatherium*, and *Hippopotamus* is taphonomically demonstrated at BK and SHK. A lack of analogical frameworks for megafaunal exploitation has prevented an adequate interpretation of this archaeological evidence. For this reason, Gidna et al. (2013) contribute with a longitudinal study of carcass exploitation by felids and humans in Tarangire National Park, showing the taphonomic signatures of this behavior in a large array of carcasses. Although the reconstruction of hominin behavior at FLK Zinj (e.g., Domínguez-Rodrigo et al., 2007; Bunn and Pickering, 2010) was recently questioned (Pante et al., 2012), a reassessment of the behavioral reconstruction is presented here by analyzing jointly all bone surface modification types for the first time (Domínguez-Rodrigo et al., 2014c). Bunn and Gurtov (2014) provide further compelling evidence that hunting and not scavenging was the main strategy used to obtain animal carcasses. In addition, Cobo et al. (2014) show compelling evidence that anisotropy alone is insufficient to support allochthony in the formation of the Olduvai Bed I assemblages.

All this is done accompanied by a detailed paleogeomorphological reconstruction of the landscape surrounding FLK Zinj, which uncovers erosive processes typical of lacustrine environments. It also adds more weight to the exceptional evidence that the FLK Zinj locus was a dense concentration of faunal and lithic remains, which remain in stark contrast with the surrounding landscape (Uribelarrea et al., 2014). This complements a broader work on paleosol formation at Olduvai, where it is shown that the shallow saline-alkaline lake in the basin center and groundwater levels in the surrounding uplands fluctuated with Milankovitch-driven climatic (precession) cycles of ~20,000 years (Ashley et al., 2014a). This has a repercussion for landscape use by hominins. Closer to the lake, paleosols are thinner, vertically stacked, and separated by thin tuffs or tufa. Further from the lake margin, there is additional volcaniclastic input, and paleosols are thicker and cumulative. Paleoclimatic indicators of these paleosols show a drying trend in uppermost Bed I, which gave rise to the more arid conditions observed during Bed II when compared to Bed I (Beverly et al., 2014). These processes, linked to tectonic changes in the basin, created special loci on the landscape where freshwater acted as the drawing factor for hominins and other animals (Ashley et al., 2014b). Vegetation around these humid spots and the landscape surrounding them must have been an important element in mammal presence (Barboni, 2014). Competition at these loci must have been intense at times. Egeland (2014) shows how despite the competition generated by hominin-carnivore interaction at the Olduvai sites, factors other than competition alone account for the selection of specific spots where hominins carried out their activities. Otherwise put, hominins were not constrained by carnivore competition in their adaptation to the Olduvai paleobasin.

Although the information provided about the taphonomy and subsistence reconstruction of Acheulean sites is a novelty, it is not complete without a proper technical study of the character of the Acheulean industry. Regarding technological analyses, the results presented here add new data to the intense discussion on the Developed Oldowan/Acheulean interface and the emergence of the Acheulean techno-complex. As mentioned above, the lithic record of Bed II in Olduvai has been the referential framework for an intense debate among a number of technologists in the last decades regarding the meaning of the Developed Oldowan archaeological entity. Nowadays, most lithic analysts agree that that the Developed Oldowan as named by Mary Leakey must be technologically regarded as a specific segment, particularly representative of the hominins that inhabited in the Olduvai basin after the onset of the Acheulean innovations in East Africa. Despite understanding Developed Oldowan as part of the multifaceted Early Acheulean continuum, important differences exist in typology between both types of assemblages, which should not be diluted by classifying both types of sites under the same label.

Beyond the mere interest of grouping archaeological assemblages within classical historicist labels, this position is unraveling once again the complexity of providing meaningful interpretation for different technological behaviors in the process of human evolution. Some contributors to this issue support the current tendency to subsume Bed II sites within the Acheulean techno-complex due to the concurrence of certain technological traits converging in the Acheulean universe (Diez-Martín et al., 2014a,b). However, beyond the formal uniformity within the Acheulean umbrella, an extremely interesting site-level variability arises. Understanding technological synchronic inter-site variability is one of the most compelling issues in lithic studies and shows the direction for further technological analyses if we want to move towards a more comprehensive interpretation of Olduvai Bed II technological behaviors. The Bed II record is a particularly significant example suggesting that if we want to build robust and meaningful inferences of past hominin life strategies, we cannot separate technology from other economical, ecological, functional and regional aspects. From this perspective, Santonja et al. (2014) demonstrate the extent to which the excavated lithic samples available for study and interpretation are intimately interdependent with their ecological setting and/or the economic tasks undertaken in a specific locale. The work of Santonja et al. at TK exemplifies the degree to which final technical solutions in LCT (Large Cutting Tool) shaping are constrained by local raw material characteristics and

how hominins adapted their technical goals to this specific constraint. At SHK main site, where a well-preserved fraction of a fluvial channel and its overbank has been unearthed (Diez-Martín et al., 2014c), there is potential to interpret the typological and technological quality of assemblages derived from different loci of the same site. Gurtov and Eren (2014) undertake an experimental study that goes into detail about one of the most interesting issues currently opened in the lithic studies in the Olduvai sequence, the meaning of bipolar reduction within the array of technological solutions implemented by hominins in the basin. Their experimental analysis provides valuable information regarding the close link between the implementation of bipolar knapping and raw material selection. While in-depth, site-focused studies are showing glimpses of the synchronic variability within the Early Acheulean at Olduvai, contributions devoted to the Early Acheulean in the nearby Lake Natron region put forward other valuable aspects of the new technological innovations. Following the seminal work undertaken by Isaac (1965, 1967) and the subsequent landscape archaeology research project (Domínguez-Rodrigo et al., 2009a), renewed fieldwork in Peninj, ongoing since 2007, has focused on the study of the two classical and representative Early Acheulean sites in this region: ES2-Lepolosi (former MHS-Bayasi) and EN1-Noolchalai (former RHS-Mugulud) Diez-Martín et al. (2014a). This includes an in-depth technological and contextual analysis of ES2-Lepolosi, known for the preservation of phytoliths on a number of LCTs (Domínguez-Rodrigo et al., 2001), while Diez-Martín et al. (2014b) provide a reassessment of EN1-Noolchalai in light of new geoarchaeological and technological studies. Despite contextual disparities, both sites show again, in agreement with the broadly penecontemporaneus sites of Bed II at Olduvai, how local technological solutions cannot be separated from a broader contextual and regional framework and to what extent technology at a site level is an expression of a regional system that requires contextual information to be explained. These contributions pinpoint the direction of further technological analyses if we are to untangle the Developed Oldowan/Acheulean gradient.

The Acheulean eventually evolves into the MSA, the other end of the technological evolution documented at Olduvai Gorge, whose earliest presence is documented at the Ndutu Beds. Eren et al. (2014) show the immense potential of this stratigraphic unit for understanding the technological and behavioral evolution of hominins during a time frame that coincides with the evolution of Middle Pleistocene hominins into the earliest forms of *Homo sapiens*.

One of the methodological novelties introduced in these papers is that some of the excavations and living floors have been reproduced in 3D via photogrammetry, and these dynamic reconstructions are attached to the publications. This is the first time this has done for any lower Pleistocene site. These 3D reconstructions allow the reader to rotate it from any angle and zoom in and out as much as desired. Given that such reconstructions can be displayed in a PDF format, they are attached as supplementary materials to the papers. This will allow the reader a more complete and objective view of the sites when compared with drawings, without having to compare drawings and original photographic documentation of these assemblages.

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M. Domínguez-Rodrigo*, F. Diez-Martín, A. Mabulla, E. Baquedano, H.T. Bunn, C. Musiba
Complutense University, Prehistory, c/ Prof. Aranguren s/n, Fac. Geography and History, 28040 Madrid, Spain

* Corresponding author.
E-mail address: m.dominguez.rodrigo@gmail.com (M. Domínguez-Rodrigo).

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