Is there a Developed Oldowan A at Olduvai Gorge? A diachronic analysis of the Oldowan in Bed I and Lower-Middle Bed II at Olduvai Gorge, Tanzania

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Keywords: Olduvai, Early Pleistocene, Oldowan, Early Stone Age, Lithic technology, Lithic variability

Abstract

Debates regarding the validity of the Developed Oldowan as separate cultural facies within the Oldowan techno-complex have primarily concentrated on the Developed Oldowan B/Acheulean transition, with little attention paid to the validity of the Developed Oldowan A (DOA) as a valid technological differentiation. This study presents a diachronic technological analysis and comparison of Oldowan and DOA lithic assemblages from Olduvai Gorge, Tanzania, dated between 1.84 and 1.6 Ma, to test the validity of Leakey's original distinction between these two cultural facies. The results from this comparative analysis show very few technological differences between the lithic assemblages previously assigned to the DOA and Classic Oldowan. Significant diachronic variation in raw material availability and use is, however, identified between Bed I and Lower/Middle Bed II of Olduvai Gorge, which may go some way to explaining the originally perceived techno-cultural differences. The results suggest an increase in hominin knapping and percussive activities, as well as a clear ability to preferentially select high quality raw materials stratigraphically above Tuff IF. Technological innovation and complexity, however, does not seem to vary significantly between the Classic Oldowan and DOA assemblages. The results of this analysis along with similar studies from the wider eastern African region lead to the conclusion that the term Developed Oldowan A should no longer be used.

Introduction and background

Olduvai Gorge and the Oldowan

Olduvai Gorge is one of the most important Early Stone Age archaeological and paleoanthropological sites in the world. Since its scientific discovery in 1911(Leakey, 1978), it has been paid constant attention by researchers investigating a wide range of issues, including archaeological studies investigating the nature of early hominin technological evolution (Leakey et al., 1971; Stiles, 1979; Wynn, 1981; Potts, 1988; Kimura, 1999; Ludwig, 1999; de la Torre and Mora, 2005, 2014; Diez-Martin et al., 2010, 2014), subsistence strategies (Speth and Davis, 1976; Bunn, 1981; Blumenschine et al., 2012a, b; Bunn and Gurtov, 2014; Domínguez-Rodrigo et al., 2014; Organista et al., 2016), and palaeoanthropological work describing and increasing our current knowledge base of hominin fossils (Leakey and Leakey, 1964; Leakey, 1969, 1971; Holloway, 1980; Kidd et al., 1996; Clarke, 2012; Njau and Blumenschine, 2012; Ungar et al., 2012; Hlusko et al., 2015),as well as geological research concerned with correlating and refining the dating of archaeological and hominin remains (Hay, 1967, 1976; Walter et al., 1991, 1992; Deino, 2012; McHenry, 2012; Stanistreet, 2012).

In Mary Leakey's 1971 monograph on the archaeology of Beds I and II, she described in full the Oldowan technology identified at Olduvai and put forward a classification system, defining the Oldowan in terms of typological tool forms (Leakey, 1971). These were represented by various forms of choppers (side choppers, end choppers, pointed choppers, two-edge choppers), protobifaces, polyhedrons, discoids, heavy duty scrapers, light duty scrapers, subspheroids, burins, hammerstones, utilized cobbles, and light duty flakes (Leakey, 1971). While Leakey described the Oldowan as unchanging in form and composition throughout Bed I, she recognized two variations of this technology in Lower and Middle Bed II based on relative frequencies of typologies. The first was a slightly more advanced version of the Classic Oldowan, differing only in the increased frequency of proto-bifaces, spheroids and subspheroids, and light duty tools, coupled with a decrease in choppers (Leakey, 1971). The term Developed Oldowan A (DOA) was used to describe this technology and was identified initially at two archaeological sites: HWK E Levels 3, 4, and 5 and FLK N Sandy Conglomerate. The lithic material at HWK E Level 2 was initially considered to be an intermediate form between the Oldowan and DOA (Leakey, 1971), but it was later included within the DOA (Leakey, 1975). The number of DOA assemblages increased through the excavation of MNK Chert Factory Site (Stiles et al., 1974) after the publications of Leakey's monograph (Leakey, 1971). The lithic material from this assemblage was predominantly produced on chert and, as such, did not show the full typological core forms originally identified by Leakey; however, its stratigraphic location within the sandy conglomerate unit of Bed II made it contemporaneous with the upper level of HWK E and FLK N Sandy Conglomerate (Stiles et al., 1974).

The second variation within the Oldowan, which Leakey identified as the Developed Oldowan B (DOB), was considered as a continuation of the DOA (Leakey, 1975). It was initially differentiated in typological terms through an increased frequency of light duty tools including scrapers, burins, awls, outils écailles, and laterally trimmed flakes (Leakey, 1971), as well as the inclusion of crude, diminutive handaxes. All archaeological sites assigned to the DOB were identified above Tuff IIB and comprisedMNK Main Site, FC West, SHK, BK, and the Upper and Lower floors of TK (Leakey, 1971). Initially, Leakey (1971) identified the major distinction between the DOB and the DOA as the presence of bifaces within DOB assemblages, with no such artifacts identified in DOA assemblages (Leakey, 1971). Leakey distinguished the Acheulean from the DOB as sites that contained greater than 40% bifaces (Leakey, 1971). She later expanded on this distinction, noting that the handaxes within SHK, BK, and the Upper Floor of TK could be considered less skilfully produced than those found at MNK and the Lower Floor of TK, which were relatively comparable to those identified within Acheulean assemblages (Leakey, 1975).

Traditionally, the Oldowan and Acheulean followed a dual phyla model, the former being associated with *Homo habilis* and the latter associated with *Homo erectus* (Leakey, 1971). This led to the suggestion that that the DOA and DOB may also be distinguished from the Acheulean in terms of paleoanthropological association (Leakey, 1975). It was suggested that both the DOA and DOB were produced by *H. habilis* with the latter taken as evidence of inter-species technological mimicry or appropriation (Leakey, 1971, 1975). This was a marked departure from Louis Leakey's previous view of cultural evolution at Olduvai, which was argued to be a gradual evolution from simple Chellean material to more advanced Acheulean handaxes, produced by a single hominin species (Leakey et al., 1931; Leakey, 1951, 1954).

The Developed Oldowan

Mary Leakey's (1971, 1975) definition of the Developed Oldowan has provoked much debate on the validity of this categorization, the greater part of which has centered on the distinction between the DOB and the Acheulean, as it is this transitional period that saw the advent of a new technology and new hominin species (de la Torre and Mora, 2014). Advocates for the distinction between the DOB and Acheulean have used typological statistical analyses of Leakey's original data (Davies, 1980; Callow, 1994; Roe, 1994) and first-hand re-analyses of specific tool types (Bower, 1977) to justify the distinction. Those advocating the removal of the term DOB, and its inclusion within the

Acheulean, argued for functional differences caused by variation in local environmental contexts (Isaac, 1971, 1969; Hay, 1976; Gowlett, 1988;) or raw material variability (Stiles, 1979, 1977; Voorrips and Stiles, 1980), as opposed to technological or cultural factors. Recently a small number of first-hand re-analyses of the Olduvai assemblages (de la Torre and Mora, 2005, 2014) and comparisons of the Olduvai assemblages to a wider archaeological sample throughout East Africa (Semaw et al., 2009) have renewed calls for the removal of the DOB as a distinctive cultural entity, arguing that these assemblages should be included within the Acheulean. The primary justification for this inclusion of the DOB into the Acheulean depends upon the fact that DOB assemblages contain technological elements also commonly associated with Acheulean, including the ability to produce large flakes, the production of true bifaces, management of small core debitage, and the production of retouched material (de la Torre and Mora, 2005, 2014; Semaw et al., 2009).

The distinction between the ‘Classic Oldowan’ and DOA, however, has raised little concern over the years, with a wide acceptance of Leakey’s (1975) general view of it as a slightly advanced form of the Oldowan (Bower, 1977), with advocates relying on the continued use of Leakey’s typological perspective. These studies included statistical analysis of production technique variation of a single or restricted number of tool types at Olduvai (Bower, 1977). Wider-scale investigations into typological variation (Gowlett, 1988; Stiles, 1981) either dismissed the DOA as “simply a somewhat evolved form of Oldowan, in which bifacial working is increased, but in which there are no radical new departures” (Gowlett, 1988, p14), or grouped it together with the DOB, referring to it as the Developed Oldowan, with no apparent justification (Kurashina, 1987). Early technological approaches to the study of the Oldowan and DOA also maintained Leakey’s initial distinction between the two (Kimura, 1997, 1999, 2002; Ludwig, 1999).

In a substantial comparative analysis of Oldowan, DOA, DOB, and Early Acheulean assemblages across eastern Africa, Ludwig (1999) argued that an increase in chert cores, quartzite spheroids, and subspheroids represented a departure from the Oldowan in terms of an increased understanding of fracture mechanics. However, it was argued that, when compared to the wider Oldowan lithic assemblages, no differences in the reduction of chert cores were apparent. Furthermore, it was suggested that an increase in the utilization of quartzite during the DOA was potentially linked to increased technical understanding and ranging patterns (Ludwig, 1999). The higher frequency of quartzite spheroids and subspheroids was explained because of advances in hominin understanding of advantageous raw material properties, evidenced further by the ubiquitous use of chert during this period for the production of flakes. Having noted these variations, however, Ludwig (1999) maintained the Oldowan/DOA distinction, arguing its validity, not based on typological tool type frequencies, but on variation in hominin cognitive ability.

Kimura (1997, 1999, 2002), on the other hand, although maintaining Leakey's nomenclature throughout, identified a wide range of technological similarities between the Classic Oldowan and DOA assemblages at Olduvai Gorge. These included static trends in local raw material selection, preferential selection of raw materials for flake production, the frequency of bifacial reduction, and the length of bifacial edges of cores, reduction intensity, and continuity of percussive tool use. It was also argued that knapping skill levels remained consistent throughout the Oldowan and DOA, citing similar levels of hinge fractures during the Oldowan and DOA, and arguing that an apparent increase in knapping accidents during the DOA was largely a factor of the exploitation of irregular chert nodules, being no reflection on the degree of knapping skill employed. It was argued that the appearance of chert during Lower-Middle Bed II was the driving factor behind the identification of the DOA, with little actual technological difference present (Kimura, 2002). Having said this, however, Kimura (2002) still endorsed the DOA as a valid distinction between the Oldowan and at no point suggested its removal from the vernacular.

More recently, a full technological re-analysis of Bed I and II assemblages by de la Torre and Mora (2005) argued for the wholesale removal of the term DOA. It was argued that the primary variation from the Oldowan was the use of a novel raw material, chert, as opposed to any technical innovation; and that all Oldowan and DOA assemblages share the same range of exploitation strategies: the production of small flakes and their immediate use (de la Torre and Mora, 2005). Recently, however, these authors have nuanced this initial interpretation (de la Torre and Mora, 2014).

De la Torre and Mora's initial argument was substantiated by Semaw et al. (2009) through an assessment of the wider regional Oldowan evidence. It was noted that the DOA did not occur in other Oldowan assemblages such as Gona, Ethiopia, and that artifact types assigned to the DOA such as spheroids and subspheroids had been identified at Oldowan sites that predate Olduvai (Sahnouni and de Heinzelin, 1998, Sahnouni, 2002), and may be a consequence of raw material availability rather than technological change (Willoughby, 1985; Sahnouni et al., 1997; Sahnouni and de Heinzelin, 1998; Sahnouni, 2002). Furthermore, it was suggested that the prevalence of retouched pieces within the DOA could be explained through a combination of increased chert utilization and analyst misidentification.

Recent arguments against the use of the term DOA have been based on either second-hand data (Semaw et al., 2009) or re-analysis of only a sample of the original assemblages (de la Torre and Mora, 2005, this volume). Given the strong arguments (Stiles, 1981; de la Torre and Mora, 2005, 2014; Semaw et al., 2009) presented for the inclusion of the DOB within the Acheulean, it falls to the DOA to represent any degree of technological variation within the Oldowan during the period prior to the appearance of the Early Acheulean at Olduvai. This study, therefore, presents a detailed comparative analysis using data derived from first-hand re-analyses of Classic Oldowan and all DOA assemblages at Olduvai Gorge to addresses two questions. The first is whether, considering all relevant assemblages, there are any identifiable technological trends across handaxe-free assemblages between Bed I and Lower-Middle Bed II. The second is whether Leakey's (1971) differentiation between the Oldowan and DOA of Olduvai Gorge is warranted when considered from a technological perspective.

Materials and methods

Archaeological assemblages

To address the issue of diachronic technological change, a comprehensive sample of both Classic Oldowan and assemblages originally assigned to the DOA across Bed I and Lower-Middle Bed II have been included in this study (Table 1). Full first-hand technological analyses were conducted over a period of three years at the National Museum of Tanzania, Dar es Salaam. A total of 13 assemblages were selected for analysis, totalling 9073 artifacts. The Oldowan is represented by FLK NN Level 1 and 3, FLK Zinj (Middle Bed I), FLK N Levels 1+2 (Upper Bed I), and HWK E Level 1 (Lower Bed II). In addition, an analysis of the cores from DK (Lower Bed I) was conducted in the hope of providing useful insight into the exploitation strategies employed at the oldest Oldowan assemblage at Olduvai. The Oldowan assemblages are stratigraphically located between Tuff IA (dated to 1.88 ±0.05 Ma [Deino, 2012]) and Tuff IIA (dated to 1.756–1.677 Ma [McHenry, This Volume]; Table 1). The DOA is represented by HWK E Level 2 (located between Tuff IF, dated 1.803 ± 0.002 and Tuff IIA; Lower Bed II); HWK E Levels 3, 4, and 5; FLK N SC; and MNK CFS (Lower-Middle Bed II; Fig. 1 and Table 1). These assemblages are stratigraphically located between Tuff IIA and Tuff IIB, which sits directly below a tuff dated to 1.66 ± 0.19 Ma (Uribelarrea et al., 2017), and also below the Bird print Tuff (BPT), dated to 1.664±0.019 Ma (Diez-Martin et al, 2015; McHenry, this volume; Fig. 1 and Table 1). No DOB assemblages are identified between Tuff IIA and Tuff IIB, and are found stratigraphically above Tuff IIB.

Methods

Technological analysis

The data used in this study are derived from a first-hand re-analysis of all artifacts in each assemblage. A technological analysis of each assemblage will not be presented here (but see Proffitt, 2016). Instead, the various technological aspects of the entire dataset will be addressed to determine possible variations over time. Following the suggestions by Proffitt and de la Torre (2014) with regard to increasing the accuracy of analysis, each raw material group will be dealt with both at individual and combined levels.

The analytical system employed in this study follows a technological approach to lithic analysis of cores and flakes (Inizan et al., 1999), and retouched material (Laplace, 1972). In addition, spheroids and subspheroids were studied following de la Torre and Mora's (de la Torre et al., 2013; de la Torre and Mora, 2005) methods. The systematic technological analysis of attributes of cores, flakes, and retouched pieces allows for a detailed inter-assemblage comparison. A full description of the technological categories and attributes analyzed can be found in Supplementary Online Material (SOM) 1. These were chosen to address diachronic trends in assemblage composition, raw material composition, exploitation strategies, the production of flakes, retouched material, and spheroids and subspheroids.

Statistical analysis

As both categorical (e.g. raw material types, technological classifications, exploitation types) and numerical (e.g. dimensions, core extraction dimensions) data were used, both parametric and non-parametric tests were employed depending on the distribution of data being processed. A combination of Chi-square (for categorical data) and Kruskal-Wallis and Mann Whitney U tests (for numerical data) were used to test for overall inter-assemblage variation. In each statistical test, the significance threshold was assessed at a 0.05 significance level. Posthoc analyses were then employed to further elucidate the results and identify the individual sources of variation between assemblages. For significant Chi-square results, adjusted residuals were calculated to identify significant trends within the data. For the adjusted residuals, a value of 2.0 and -2.0 were taken to assess significance at a 0.05 confidence level. For Kruskal-Wallis and Mann-Whitney U tests, post hoc pair-wise comparisons were undertaken. Where appropriate, the statistical test used is noted in the text. All statistical tests were computed using a combination of Microsoft Excel, SPSS, and PAST (Hammer et al., 2001).

Results

Assemblage composition

Significant inter-assemblage variation (Chi-square) is identified in the total frequency of artefact categories($X^2(70) = 2675.286$, $p = 0.000$), although the significant adjusted residual values show little overall diachronic trending in the expected frequencies of each category (Table 2). There is, however, a clear diachronic increase in the number of retouched pieces, and spheroids and subspheroids, and a consistent increase in the number of cores above Tuff IIA (Table 2).

Raw material composition

Three primary raw materials are prevalent: quartzite, lava, and chert. Leakey (1971) identified small quantities of gneiss and obsidian at two sites (FLK Zinj and HWK E Level 2, respectively), although these materials have been excluded from this comparative analysis. In addition to this, both FLK NN 1 and FLK NN 3 have been excluded from the analysis of raw material composition due to the low density of artifacts and the suggestion that these assemblages likely primarily represent carnivore palimpsests (Barba and Domínguez-Rodrigo, 2007; Domínguez-Rodrigo and Barba, 2007).

There is a significant inter-assemblage (Chi-square) variation in raw material frequency composition (X^2 (40) = 6120.440, p = 0.000). Quartzite is prevalent in all assemblages; however, it is significantly over-represented in all Bed I assemblages, compared to under-representations at FLK N SC and MNK CFS (Table 3).

Lava is exploited throughout both Beds I and II, with relative frequencies of artifacts not exceeding 35% of the total anthropogenic assemblage (Table 3). No clear diachronic trending in the utilization of lava is identified, with both over- and under-representations occurring in Bed I and Lower and Lower-Middle Bed II (Table 3).

Chert is identified only in assemblages stratigraphically above Tuff IIA.As this raw material is present only in the more recent assemblages, insights into variation of raw material use may be better achieved by comparing only quartzite and lava artifacts, as these raw materials are available throughout the chronological sequence.

Following the removal of all chert artifacts and the entire assemblage from MNK CFS, a significant inter-assemblage variation (Chi-square) in the frequency of lava and quartzite artifacts is identified (X^2 (7) = 389.611, p = 0.000). Adjusted residuals indicate that only FLK Zinj possesses a significant over-representation of quartzite material.

The total exploited weight of each raw material can provide information on preferential raw material selectivity (de la Torre and Mora, 2005). A significant inter-assemblage variation in total exploited weight of utilized quartzite and lava artifacts between all assemblages (X^2(7) = 21030.851, p = 0.000) is clear. Quartzite is prevalent by weight above Tuff IIA (HWKE Level 2, HWK E Level 3, HWK E Level 4, HWK E Level 5, and FLK N SC), compared to a significant under-representation of lava in most of these assemblages (HWKE Level 3, HWK E Level 4, FLK N SC, and MNK CFS;Table 3).

A finer degree of detail is gained by assessing total exploited weight of each raw material in relation to artifact categories. Four primary technological categories are included in this comparison: cores, retouched pieces, knapping products (complete and fragmented flakes and knapping debris), and percussive material (hammerstones, spheroids and subspheroids, anvils, and hammerstones with fractured angles).

Significant inter-assemblage variation in the exploited weight of quartzite artifacts (Chi-square) ($X^2(21) = 23036.094$, $p< 0.001$) is identified. A general decrease of total weight of quartzite knapping products is observed, coupled with a changing relationship between knapping products and cores. Bed I assemblages show less total weight of quartzite cores than knapping products (FLK Zinj, FLK N 1–2, HWK E Level 1), whilst most assemblages in Lower and Lower-Middle Bed II show either a greater total weight of cores than knapping products (HWKE Level 3, HWK E Level 4, FLK N SC) or a roughly equal total weight of the two (HWKE Level 5; SOM 2). Overall, quartzite percussive elements are under-represented in Bed I compared to Lower-Middle Bed II, apart from FLK N 1–2, which shows a comparable weight of percussive material to that seen in Lower-Middle Bed II assemblages (SOM 2). Quartzite retouched material presents little diachronic trending, with an overall degree of heterogeneity between all assemblages.

Lava cores and percussive material exhibit an overall degree of heterogeneity in terms of total weight throughout Beds I and Lower-Middle Bed II. Retouched lava material is under-represented in all assemblages. Lava knapping products, on the other hand, present a slight decreasing trend in total weight from Bed I to Lower-Middle Bed II (SOM 2), with significant over-representation at FLK Zinj, FLK N 1–2, and HWK E Level 1, and under-representation at HWK E Level 2, HWK E Level 3, HWK E Level 4, and FLK N SC.

Cores

With all raw materials combined, all exploitation strategies are represented in both Beds I and II, with no appearance or disappearance of new exploitation strategies (Table 4). However, a significant inter-assemblage variation (Chi-square; $X^2(22) = 70.697$, $p< 0.001$) is present. Adjusted residuals indicate higher representations of multifacial cores from Bed I to Lower-Middle Bed II, coupled with a decrease in bifacial reduction and a degree of heterogeneity of unifacial cores. In addition, Bed II exhibits a more consistent representation of each reduction method, with each one represented at every assemblage. However, multifacial exploitation is lacking from 40% of Bed I assemblages (Table 4).

Very little diachronic change is observed for unifacial and bifacial simple and abrupt exploitation strategies (Table 5). Of the more structured exploitation strategies, bifacial alternate cores are significantly over-represented within Bed II assemblages (HWKE Level 1, HWK E Level 3, and HWK E Level 4) and under-represented in Bed I assemblages (DK and FLK N 1–2). Bifacial peripheral cores are over-represented at DK and FLK N SC, and under-represented at HWK E Level 2 only. No assemblage shows an over-representation of multifacial cores, however, FLK Zinj and FLK N 1–2 possess a significant under-representation. When considering relative frequencies, however, a clear increase in multifacial reduction is represented in Bed II assemblages (Table 5).

Significant inter-assemblage variability is identified (Chi-Square; $X^2(60) = 91.307$, $p = 0.006$) in the reduction strategies of quartzite cores. This variation is derived, however, from only a small number of assemblages and exploitation strategies (SOM 3). Little variation is identified for unifacial exploitation (unifacial simple, unifacial abrupt) and the less elaborate bifacial exploitation (bifacial simple and abrupt), with both under- and over-representations occurring in only a small number of assemblages in both Bed I (FLK Zinj, FLK N 1-2) and Bed II (HWKE Level 4, FLK N SC, MNK CFS). Significant over-representations of bifacial alternate and bifacial peripheral exploitation in quartzite are present at HWKE Level 4, HWK E Level 5, and FLK N SC. Finally, multifacial exploitation is more frequent within Bed II compared to Bed I.

A significant inter-assemblage variation (Chi-square) in exploitation strategies employed on lava cores ($X^2(90) = 186.791$, $p< 0.001$) is identified. Having said this, however, little chronological trending is observable for the less elaborate unifacial and bifacial exploitation strategies (simple and abrupt), with an overall heterogeneity observed between assemblages. Bifacial alternate exploitation occurs only in assemblages above Tuff IF (HWKE Levels 1–4 and FLK N SC). Considering multifacial cores, the relative frequencies indicate a general trend of increasing frequency over time, with FLK NN 1, FLK NN 2, and FLK Zinj possessing no examples, whilst being represented at all but one Bed II assemblage (HWKE Level 5; SOM 4).

As chert is available only during Bed II, it is impossible to identify diachronic trends compared to Bed I in its exploitation. Chert exploitation in Lower-Middle Bed II shows a significant degree of inter-assemblage variation (Chi-square; $X^2(35) = 73.597$, $p = 0.000$; SOM 5), with uni-, bi-, and multi-facial exploitation present to varying degrees in all assemblages. However, a comparison of chert core exploitation against lava and quartzite core exploitation throughout Beds I and II indicates that chert exhibited a significantly greater degree of multifacial exploitation (Chi-square; $X^2(9) = 28.511$, $p = 0.000$), coupled with an under-representation of unifacial abrupt reduction. Chert cores from Bed II, when compared to quartzite and lava cores originally assigned to the DOA, exhibit a significant under-representation of unifacial and an over-representation of multifacial exploitation. Similarly, multifacial exploitation is greater in chert when compared to quartzite and lava cores originally assigned to the Oldowan (SOM 6).

Variation in reduction intensity

Dimensions

Quartzite cores show significant inter-assemblage variation (Kruskal-Wallis test) in length ($X^2(10)$ = 22.927, *p* = 0.011), width ($X^2(10)$ = 23.935, *p* = 0.008), and weight ($X^2(10)$ = 21.305, *p* = 0.019); however, no significant variation in thickness ($X^2(10)$ = 14.524, *p* = 0.150) is observed. Pair-wise analyses show no significant difference between individual assemblages in either length, width, or weight, with the variation being derived from overall variation (Fig. 2 and SOM7).

Lava cores also show significant inter-assemblage variation (Kruskal-Wallis test) in the length ($X^2(10)$ = 48.261, *p* = 0.000), width ($X^2(10)$ = 37.844, *p* = 0.000), thickness ($X^2(10)$ = 26.969, *p* = 0.003), and weight ($X^2(10)$ = 38.412, *p* = 0.000). Pair-wise analysis indicates that the cores from DK are significantly shorter, narrower, and thinner than the majority of those from other assemblages. Once DK cores are removed from the sample, no significant inter-assemblage variation (Kruskal-Wallis test) is observed (Length:$X^2(9)$ = 15.898, *p* = 0.069; width: $X^2(9)$ = 12.479, *p* = 0.188; thickness: $X^2(9)$ = 5.616, *p* = 0.778; weight: $X^2(9)$ = 5.747, *p* = 0.765; Fig. 2 and SOM 7).

Chert cores show significant inter-assemblage variation (Kruskal-Wallis test) in length ($X^2(5)$ = 33.326, *p* = 0.000), width ($X^2(5)$ =17.131, *p* = 0.004), and weight ($X^2(5)$ = 13.408, *p* = 0.020). Pair-wise comparison indicates this variation is derived from larger cores at MNK CFS (Fig. 2 and SOM 7). Once removed from the sample, no significant variation (Kruskal-Wallis test) is observed (length:$X^2(4)$ = 6.713, *p* = 0.152; width: $X^2(4)$ = 3.797, *p* = 0.434; thickness: $X^2(4)$ = 2.708, *p* = 0.608; weight: $X^2(4)$ = 3.780, *p* = 0.437). A Mann-Whitney U test indicates that chert cores within Bed II are significantly smaller in all maximum dimensions and weight compared to lava and quartzite cores previously assigned to both the Oldowan and DOA (SOM 8).

Cortex coverage

A significant inter-assemblage variation (Chi-square; $X^2(20)$ = 38.734, *p*=0.007) is observed for quartzite core cortex coverage. This variation represents a decrease of quartzite cores with >50% cortex and an increase of <50% and 0% core cortex. The increase of <50% cortical cores occurs in assemblages above Tuff IF (SOM 9).

Lava cores show an overall significant inter-assemblage variation (Chi-square; $X^2(20)$ = 61.734, *p*< 0.001); however, adjusted residual values indicate little diachronic trending (SOM 10). Chert cores within Bed II, on the other hand, exhibit an overall degree of homogeneity of cortex coverage percentage groups (Chi-square; $X^2(10)$ = 9.101, *p*=0.523; SOM 10). When comparing chert cortex coverage with both quartzite and lava cores originally assigned to the Oldowan and DOA, chert cores possess significantly less cortex coverage (SOM 11).

Core extractions

Quartzite cores show significant inter-assemblage variation (Chi-square; $X^2(30) = 55.911$, $p=0.003$). This variation is derived from a general heterogeneity across both Bed I and II assemblages (SOM 9).

Lava cores exhibit a significant inter-assemblage variation (Chi-square; $X^2(40) = 82.824$, $p< 0.001$). The relative frequencies show the majority of Bed II assemblages possessing all extraction ranges, whereas only DK and FLK N 1–2 show similar patterning in Bed I. This is corroborated by adjusted residual values, with over-representations occurring only in Bed II assemblages (SOM 10).

Chert cores exhibit an overall degree of variation (Chi-square; $X^2(20) = 47.700$, $p< 0.001$). Adjusted residuals indicate significant over-representation of 1–3 extractions at MNK CFS, 7–9 extractions at HWK E Level 3, and 10–13 extractions at HWK E Level 5, whilst indicating significant under-representation of 1–3 extractions at HWK E Level 4 and 7–9 extractions and >14 extractions at MNK CFS (SOM 11). When comparing chert extraction frequency with both quartzite and lava cores previously assigned to the Oldowan and DOA, chert cores exhibit significantly greater frequencies of extractions compared to quartzite and lava cores assigned to the Oldowan, as well as quartzite cores assigned to the DOA, and there is an overall significant difference between chert and lava cores assigned to the DOA (SOM12).

Flakes

Quartzite flakes

Quartzite flakes exhibit a general diachronic trend towards larger and heavier removals. A Kruskal-Wallis test indicates a significant inter-assemblage variation in the length ($X^2(10) = 43.563$, $p< 0.001$), width ($X^2(10)=40.564$, $p< 0.001$), thickness ($X^2(10)=73.658$, $p< 0.001$), and weight ($X^2(10)=54.645$, $p< 0.001$). Pair-wise analysis shows that variation is derived from significantly longer and narrower flakes at FLK N SC. Flakes from Bed I assemblages (FLK Zinj and FLK N 1–2), however, are significantly thinner compared to thicker flakes in Bed II (HWKE Levels 2–5 and FLK N SC), with a trend in flake weight from Bed I to Bed II (Figs. 4 and 5; SOM 13).

A significant inter-assemblage variation in platform cortex coverage (Chi-square; $X^2(30) = 82.367$, $p< 0.001$) is also identified. Non-cortical platforms are over-represented in assemblages above Tuff IIA (HWKE Level 4, HWK E Level 5, and FLK N SC; SOM 14). Dorsal cortex coverage, however, shows less diachronic trending. Although significant inter-assemblage variability (Chi-square; $X^2(30) = 64.888$, $p = 0.000$) is identified, this is derived from under- and over-representations in both Beds I and II (SOM 14). Reduction stages represented by Toth flake categories show a degree of chronological trending. An over-representation of later stage flake categories (Stage V and VI) are found above Tuff IIA, with early stage flake categories (Stage II and III) over-represented below Tuff IIA (SOM 14). Dorsal surface extraction directionality shows an over-representation of both multi-directional and transversal flake scars in several Lower-Middle Bed II assemblages (HWKE Level 3, HWK E Level 4, and HWK E Level 5), with a significant under-representation of uni-directional flake removals (HWKE Level 3 and HWK E Level 4; SOM 15).

Lava flakes

A Kruskal-Wallis test indicates significant inter-assemblage variation in all dimensions for lava flakes (length:$X^2(10) = 21.216$, $p = 0.020$, width:$X^2(10) = 19.281$, $p = 0.037$), thickness ($X^2(10) = 28.694$, $p = 0.001$), and weight ($X^2(10) = 26.377$, $p = 0.003$). Pair-wise analysis shows this variation being derived from increased dimensions of lava flakes in Bed II. This increase in flake size and weight occurs stratigraphically above HWK E Level 1 and follows a positive trend throughout Lower-Middle Bed II (Figs. 4 and 5; SOM 13).

Cortical coverage of lava flake platforms shows a significant inter-assemblage variation; this is derived, however, from only HWK E Level 1 and Level 2. Dorsal cortex coverage shows a significant inter-assemblage variation (Chi-square; $X^2(30) = 48.331$, p=0.018), with an observable diachronic increase of less cortical flakes in assemblages stratigraphically above HWK E Level 1 and more cortical flakes below HWK E Level 2 (SOM 16).

An assessment of Toth flake categories corroborates this, as most assemblages stratigraphically above HWK E Level 1 show a preponderance of later stages of flaking (SOM 16). Most assemblages within Bed II show an increase of dorsal surface flake scars (>4) compared to Bed I assemblages (<3). Lava flake scar directionality shows little in the way of diachronic trending with only HWK E Level 3 showing a significant over-representation of bi-directional removals (SOM 17).

Chert flakes

Although chert is available only during the period of Lower-Middle Bed II, inter-assemblage variation is identifiable during this time. A Kruskal-Wallis test indicates significant inter-assemblage variation in all dimensions (length ($X^2(6) = 121.33$, $p = 0.000$), width ($X^2(6) = 80.25$, $p = 0.000$), thickness ($X^2(6) = 73.54$ $p = 0.000$), and weight ($X^2(6) = 94.17$, $p = 0.000$). In each case, posthoc analysis highlights significantly larger flakes at MNK CFS when compared to those identified at HWK E Levels 3 and 4 (Figs. 4 and 5; SOM 13). A similar pattern of heterogeneity is observed when considering the technological characteristics. In all cases, flakes from MNK CFS stand out as significantly different to those from other chert bearing assemblages. These flakes possess significant over-representations of either cortical or <50% knapping platforms, compared to over-representations of non-cortical platforms at FLK N SC and HWK E Levels 3 and 4 (Chi-square; $X^2(18) = 71.27$, p =0.000). Similarly flakes from MNK CFS possess significantly more dorsal cortex coverage than HWK E Levels 1, 3, and 4 (Chi-square; $X^2(18) = 100.99$, p =0.000). These factors result in the flake assemblage at MNK CFS being dominated by the earlier stages of Toth flake categories (Stages I, II, and IV), compared to the over-representation of later stage flakes at FLK N SC (Stage V) and HWK E Levels 1 and 4 (Stage VI; Chi-square; $X^2(30) = 121.77$, p =0.000; SOM 18). In addition, flakes at MNK CFS exhibit fewer dorsal surface extractions, with over-representations of 0–3 removals and under-representations of 4–6 and 7–9 removals, when compared to the significant preference of these groups at FLK N SC, HWK E Level3, and L4 (SOM 19). This suggests that chert exploitation at MNK CFS can be considered as anomalous within the wider chert exploitation of Bed II. Once this assemblage is removed, the degree of technological variation within chert exploitation in Bed II becomes considerably more homogenous. Significant inter-assemblage variation (Kruskal-Wallis test) is still observed, however, to a lesser extent in terms of length ($X^2(5) = 11.10$, $p = 0.049$), width ($X^2(5) = 12.22$, $p = 0.032$), and weight ($X^2(5) = 11.55$, $p = 0.041$), with flakes from FLK N SC being significantly larger than those from HWK E Level 3. Inter-assemblage variation is also identified in the dorsal surface cortex (Chi-square; $X^2(15) = 51.947$, $p = 0.000$), with a degree of variation across all assemblages, and Toth flake categories (Chi-square; $X^2(25) = 85.578$, $p = 0.000$), where FLK N SC possesses an under-representation of late stage flakes (Stage VI), compared to over-representations at HWK E Levels 1, 3, and 4. No significant difference is identified in terms of platform cortex or number of dorsal surface extractions.

When chert flakes (excluding MNK CFS) are compared to quartzite and lava flakes from assemblages originally assigned to the Oldowan, they are significantly smaller in all dimensions to each raw material. In addition, they possess a significant increase in non-cortical platforms (0%, <50%, and >50%) compared to over-representation of fully cortical platforms in Oldowan quartzite and lava flakes. A similar pattern is observed for dorsal surface cortex coverage, with chert flakes possessing significantly fewer most and full cortical coverage compared to lava Oldowan flakes, and fewer non-cortical, coupled with a higher frequency of <50% cortical, flakes compared to quartzite Oldowan flakes. Chert flakes also show a higher frequency of dorsal surface extractions when compared with both quartzite and lava Oldowan flakes. In addition, chert flakes exhibit significantly fewer early stage Toth flake Categories (Stages I, II, III) compared to both quartzite and lava Oldowan flakes (SOM 20 and 21).

Retouched pieces

When considering all raw materials, there is significant variation (Chi-square) in the range of retouched types ($X^2(24) = 38.921$, $p = 0.025$), caused by an over-representation of denticulates at FLK N 1–2, scrapers at FLK N SC, and an under-representation of scrapers at HWK E Level 4. Overall, however, there is an increase in diversity of retouch types in assemblages stratigraphically above HWK E Level 2 (Table 6).

A Kruskal-Wallis test indicates a significant inter-assemblage variation in retouched artifact dimensions (length:$X^2(8)=60.001$, $p< 0.001$; width:$X^2(8)=49.004$, $p< 0.001$; thickness: ($X^2(8)=25.670$, $p=0.001$; weight:$X^2(8)=43.963$, $p< 0.001$). Posthoc analysis shows that larger retouched flakes at MNK CFS are the cause of this variation. When this material is excluded, no significant difference is found in length, width, and weight, with only thickness ($X^2(7) =14.275$, $p< 0.001$) showing a significant degree of inter-assemblage variation. A pair-wise comparison of this measurement, however, shows no diachronic trending in dimensional properties (SOM22).

Technologically speaking, no significant difference in the retouch blanks are found between assemblages (Chi-square;$X^2(24) = 15.242$, $p = 0.913$), with complete flakes predominating. Furthermore, an overall degree of heterogeneity is evident ($X^2(40) = 107.120$, $p = 0.000$) in Toth flake categories for all retouched pieces. Following Laplace's (1972) description of retouch features, no significant inter-assemblage variation in the number of retouched edges ($X^2(24)=26.639$, $p=0.322$), the retouch mode ($X^2(24) = 34.748$, $p = 0.072$), the complementary mode ($X^2(8) = 12.900$, $p= 0.115$), nor the direction of retouch ($X^2(48) = 39.736$, $p = 0.796$) is identified. Significant inter-assemblage variation is, however, identified in retouch depth ($X^2(16) = 52.753$, $p = 0.000$). However, posthoc analysis indicates no clear diachronic trending of this attribute through time, although an increase in relative frequency of very marginal retouch is present above HWK E Level 1 (SOM22 and 23). Considering all raw materials, very little diachronic change is observed. However, when chert retouched pieces and retouched artifacts in the other two raw materials are compared, a significant difference between the frequency of different retouched types ($X^2(3) = 14.564$, $p=0.002$) is present, with an over-representation of scrapers and side scrapers in chert and of denticulates in the other raw materials. Additionally, a significant difference in retouch depth ($X^2(2) = 10.974$, $p = 0.004$) is evident. Marginal retouch is over-represented, whilst deep retouch is under-represented in chert retouched pieces from Bed II, whereas the opposite is evident for the other two raw materials.

There is no significant difference of retouched sides ($X^2(3) = 5.690$, $p = 0.128$), complementary mode of retouch ($X^2(3) =0.016$, $p=0.901$), direction of retouch ($X^2(6) = 7.039$, $p = 0.317$), and form of the retouched edges ($X^2(3) = 6.152$, $p = 0.104$). In terms of dimensions, no significant differences in length ($X^2(1) = 0.043$, $p = 0.837$), width ($X^2(3) = 0.466$, $p = 0.495$), and weight ($X^2(3) = 3.765$, $p = 0.052$) are identified; however, a significant difference in thickness ($X^2(1) = 10.662$, $p = 0.001$) is present, with chert pieces being considerably thinner.

Spheroids and subspheroids

Spheroids and subspheroids are identified only in Lower-Middle Bed IIassemblages from FLK N SC and HWK E Levels 2, 3, 4, and5, and as such represent a clear diachronic difference from the assemblage composition of Bed I. All spheroids and subspheroids were produced exclusively on quartzite. The presence of spheroids and subspheroids in Bed II clearly represents a departure from the artifact types identified in all Bed I assemblages. These artifact types represent various stages along a continuum of knapping and percussive activities, involving both multifacial reduction coupled with various degrees of percussive action. All percussive stages (de la Torre and Mora, 2005) are represented within both assemblages (HWK E Levels 2, 3, 4, and 5 and FLK N SC). However, the majority show low (*n*=21, 38.9%) to medium (*n*=29, 53.7%) intensity of percussion, with only a small percentage representing intense (*n*=2, 3.7%) or total (*n*=2, 3.7%) percussive damage.

Most of these artifacts show evidence of being exploited in a multifacial manner prior to being used in a percussive manner (Proffitt, 2016). This is corroborated by a Kruskal-Wallis test showing no significant variation in length ($X^2(1) = 0.821$, $p = 0.365$), width ($X^2(1) = 0.881$, $p = 0.348$), thickness ($X^2(1) = 0.363$, $p = 0.547$), and weight ($X^2(1) = 0.169$, $p = 0.681$) between all multifacial exploited quartzite cores and spheroids and subspheroids. When considering the assemblages, which possess spheroids and subspheroids, there is no significant inter-assemblage variation ($X^2(12) = 0.564$, $p = 0.142$). However, there is an over-representation of lightly battered subspheroids at FLK N SC, and an over-representation of moderately battered subspheroids at HWK E Level 3.

Discussion

Mary Leakey's distinction between the Classic Oldowan and Developed Oldowan A at Olduvai Gorge was based on variation in the frequencies of typological tools (Leakey, 1971, 1975). In terms of cultural variation within the Olduvai sequence, it has been somewhat uncontroversial since its initial description (Gowlett, 1988). This was primarily due to subsequent researchers' adherence to Leakey's original typological data, as well as being overshadowed by the more controversial Developed Oldowan B/Acheulean transition debate (de la Torre and Mora, 2014). As no chronological overlapping of hominin taxa was associated with the Oldowan/DOA transition, as well as a lack of more complex artifact types such as the handaxe, there has been little reason to interrogate the validity of Leakey's initial claims. Recently, however, some(de la Torre and Mora, 2005, 2014;

Semaw et al., 2009) have suggested that the DOA no longer represents a valid technological change from the Oldowan (but see de la Torre and Mora, submitted).

These studies have, however, used either published second hand data or concentrated on only a handful of archaeological assemblages. Furthermore, it has been argued that technological similarities exist between the DOB assemblages and Acheulean assemblages, including the ability to produce handaxes, large flakes, and the presence of small debitage production (de la Torre and Mora, 2014), coupled with the presence of DOB and Acheulean assemblages in the same paleo-ecological settings (de la Torre and Mora, 2014). This has led to the suggestion that the DOB should no longer be considered a separate cultural entity. For this reason, the identification of any technological change or variation during the period immediately prior to the appearance of the DOB is important as it may suggest gradual development of technological aspects commonly associated with the onset of the Acheulean.

Mary Leakey's (1971, 1975) reliance on variation in frequencies of artifact types to distinguish between Classic Oldowan and the DOA at Olduvai is an aspect that should first be addressed. Considering all raw materials, there is a clear increase in the frequency of spheroids and subspheroids and retouched pieces in Bed II assemblages.

The increase in the frequency of spheroids and subspheroids is apparent in FLK N SC and levels 2through 5 of HWKE. Furthermore, retouched pieces are also more closely associated with Bed II assemblages, being over-represented at HWK E Level 4, FLK N SC, and MNK CFS. In this sense, Leakey's typological distinction is validated. However, to what extent this represents a technological distinction must be further investigated. When taking into consideration the raw material composition of each assemblage, a clear diachronic trend is apparent, as chert artifacts are significantly over-represented in Bed II assemblages. In terms of lava and quartzite artifacts, no clear diachronic trend is observed, with a general degree of homogeneity in the use of these two raw materials. The only assemblage that stands out is FLK Zinj, where an increased frequency of quartz exploitation is seen. However, when considering total weights of artifact groups, quartzite use exhibits a clear diachronic trend, with a significantly greater total weight exploited in most Lower Bed II assemblages compared to Bed I. This is primarily in the form of an over-representation of quartzite cores in Lower-Middle Bed II compared to a greater total weight of quartzite detached products in Bed I assemblages. In general, an over-representation of quartzite percussive artifacts is also identified in Bed II assemblages. The increased utilized weight of quartzite in Bed II was noted by Leakey (1971) and has been discussed by other researchers (Schick and Toth, 1994; Kyara, 1999; Ludwig, 1999). Conversely, there is a clear reduction in the total weight of lava anthropogenically modified during Lower Bed II as compared with Bed I. When considering chert exploitation, MNK CFS clearly stands out as an anomaly, with chert knapping products and retouched pieces overwhelmingly over-represented at this site.

Although this variation in raw material use represents a form of diachronic trending in keeping with Leakey's original distinction between the Oldowan and DOA assemblages, whether it represents a technological differentiation can be called into question. It has been shown that preferential raw material selection is well within the behavioral repertoire of Oldowan hominins. Higher quality tool stones were selected at Gona, Lokalalei 2C, Kanjera, and Koobi Fora (Delagnes and Roche, 2005; Stout et al., 2005; Braun et al., 2008, 2009), and indeed there is some evidence that the Lomekwi raw material was preferentially selected based on dimensions (Harmand et al., 2015; Lewis and Harmand, 2016). With this in mind, the apparent increase in the quantity of chert artifacts during the period when chert became available (Stiles et al., 1974) at Olduvai is not in the least surprising, and may be evidence of an efficient understanding of advantageous raw material properties (Ludwig, 1999, McHenry and de la Torre, submitted).

Having established that there is a degree of inter-assemblage variation in terms of artifact frequencies and raw material use, and having noted that these do not necessarily represent a marked departure from the behavioral and technological repertoire of earlier and contemporaneous Oldowan hominins, one must turn to the technological aspects of the assemblages to determine any possible diachronic differentiation.

When all raw material groups are considered together, there is an overall degree of heterogeneity in the number of faces exploited, with both simple and more structured exploitation strategies being employed throughout Beds I and II. A possible increase in the frequency of multifacial cores is evident in the Bed II assemblages, as well as an increase in more structured reduction patterns. Addressing the exploitation strategies and technological attributes of each raw material individually provides a clearer understanding of possible trending.

All exploitation types are represented in both Beds I and II, with little diachronic trending in simple unifacial and bifacial exploitation. However, when considering the more structured exploitation strategies, including bifacial alternate and peripheral exploitation, an identifiable increase is observed. Although present in Bed I assemblages, these exploitation strategies seem to become more prevalent in Lower Bed II assemblages. Multifacial exploitation is also more consistently represented in Lower Bed II compared to Bed I. All exploitation strategies identified in Bed II, including more structured reduction (bifacial alternate and bifacial peripheral), can be identified within the Oldowan assemblages of Bed I (Figs.6–9), and as such their presence in Bed II is not surprising.

In terms of the reduction intensity of quartzite cores, there is little diachronic trending towards smaller or larger cores over time, as is also observed for the dimensions of flake extractions. There is, however, an identifiable trend towards less cortical cores within Lower Bed II and an increase in extraction frequencies within the Lower-Middle Bed II. It has previously been suggested that little variation in reduction intensity between Oldowan and DOA cores is evident (Kimura, 2002). However, the data from this study point to an increased degree of reduction exhibited on quartzite cores in assemblages from Lower Bed II and Lower-Middle Bed II.

An increase in more structured exploitation and reduction intensity is also supported by the flake assemblages. An overall increase in the frequency of non-cortical, uni-, and multifaceted platforms, coupled with an increase in dorsal surface extractions representing both transversal and multidirectional directionality, is identified in the Bed II assemblages, pointing to an increase in more complex exploitation strategies. Furthermore, the increased reduction intensity observed in the cores is corroborated by significantly thicker and heavier quartzite flakes and the over-representation of later stages of Toth's flake categories above Tuff IIA.

The increased frequency of structured exploitation strategies in Lower-Middle Bed II may help explain the dichotomy between a greater reduction intensity coupled with no significant difference in core dimensions, allowing for an increase in exploitation whilst maintaining the volume of the core. Furthermore, it can be postulated that larger original quartzite blocks were reduced in Bed II compared to Bed I, with the increasing reduction intensity resulting in reduced cores of similar dimensions compared to those less heavily reduced in Bed I. Indeed, a primary characteristic identified by Kimura (2002) for the DOB assemblages in Bed II was the ability to manipulate and reduce substantially larger cores, a characteristic that may also be present to some degree in assemblages originally assigned to the DOA. In reality, a combination of both aspects may be characteristics of the quartzite assemblages in Bed II.

Similarly to quartzite exploitation, there is a general homogeneity in lava core dimensions (although DK stands out as an anomaly [Leakey, 1971]) and the number of faces exploited on lava cores throughout Bed I and II. Further similarities with quartzite cores are apparent in the range of exploitation strategies employed. More structured reduction strategies, including bifacial alternate and multifacial exploitation, are represented to a greater degree in the Lower-Middle Bed II assemblages, being largely absent from Bed I assemblages, with simple exploitation strategies present in both Bed I and II. On the face of it, this may represent a distinct technological change over time; however, these exploitation strategies are well-documented within Bed I for quartzite cores, in this study and others (de la Torre and Mora, 2005). This diachronic variation, therefore, represents the application of a preexisting exploitation strategy to a different raw material and may suggest an increased ability in Bed II to manage the exploitation of lava cobbles.

In terms of reduction intensity, there is a general degree of heterogeneity of cortex coverage through Bed I and II.However, lava cores in Bed II do seem to possess a greater number of extractions, as well as a significant over-representation of later stage Toth flake categories. This is corroborated by a significant increase in the number of dorsal surface flake extractions and less cortical lava flakes in Bed II compared to Bed I. Furthermore, it is apparent that lava flakes became significantly larger and heavier in assemblages stratigraphically above HWK E Level 1. As there is no indication that lava core dimensions altered significantly between Bed I and II, this may indicate an increasing ability or desire to detach larger lava flakes. The fragmented nature of the lava assemblages in Bed II, represented by the over-representation of later stages of Toth flake categories, was also identified by Kimura (2002), leading to the suggestion that Bed II saw an increased degree of lava transportation.

Chert only became available as a resource, in the form of nodules, as the Olduvai Paleolake receded during the increasing aridity of Lower-Middle Bed II (Hay, 1976)It has been recently argued that it is the utilization of this raw material that is characteristic of the Lower-Middle Bed II lithic assemblages (Kimura, 2002;de la Torre and Mora, 2005), and that this alone cannot be a distinguishing factor between the Oldowan and DOA (de la Torre and Mora, 2005). At this point it is important to note the anomalous position that the assemblage from MNK CFS represents within Bed II. When compared to the cotemporaneous lithic assemblages within the Sandy Conglomerate, chert flakes produced at MNK CFS are significantly larger (in many cases exceeding 10cm in maximum length; see de la Torre and Mora[submitted] for further evidence of sporadic large flake production in the Oldowan) and derived from the earlier stages of reduction. The increased frequency of flakes from earlier stages of reduction at MNK CFS has been noted in previous studies (Kimura, 1997, 1999, 2002) and has been used to suggest an initial testing of chert nodules at the source prior to transportation and further exploitation at other locations (FLK N SC and HWKE Levels 3,4, and 5), potentially representing a preference for finer-grained raw material. However, to further elucidate this aspect of raw material use, further analyses on chert provenance is needed to determine the potential transportation of chert cores within the Olduvai basin. In addition to this, retouched pieces are significantly more prevalent within the MNK CFS assemblage; an interesting distinction given the lack of faunal remains reported for this site (Stiles et al., 1974). Having said this, however, chert exploitation in Bed II exhibits the same range of exploitation types applied to both quartzite and lava cores in Bed I. It is true, however, to note that certain exploitation strategies are more prevalent within the chert assemblages of Lower Bed II. The most notable of these is a significant increase in the frequency of multifacial exploitation, when compared to both quartzite and lava exploitation in Beds I and II. This factor, coupled with the highlyreduced state of the chert cores, including being significantly smaller and possessing significantly more flake removals, suggests a strong preferential use of this raw material when it was available.

Is there a diachronic trend in retouch technology?

The presence of retouched artifacts and light duty tools constituted one of the defining differentiating features of the DOA (Leakey, 1971). In terms of relative frequencies of retouched artifacts, this distinction is corroborated, with a clear increase in frequency coupled with a diversification of retouch types above Tuff IIA.

Considering the technological aspects of retouched artifacts on all raw materials, however, little diachronic trending is observed. Blank types, number of modified edges, primary and complementary modes of retouch, and direction of retouch all show no inter-assemblage variation, with the frequency of these attributes also remaining the same when comparing chert against quartzite and lava.

Recent technological analyses, however, have argued that the increase in retouch is largely due to the sudden appearance of chert as a novel raw material in Lower Bed II (de la Torre and Mora, 2005; Kimura, 1999). One must therefore ask how much effect this raw material has on the technological composition of retouched pieces between Bed I and II? First, patterning in retouch types is evident, with chert scrapers and side-scrapers over-represented in Bed II and lava and quartzite denticulates prevalent in Bed I. Second, marginally retouched chert artifacts are significantly over-represented compared to more heavily retouched artifacts in Bed I. Once chert is removed from the assemblages, there is no significant inter-assemblage variation in the frequency or technical execution of quartzite and lava retouched artifacts between assemblages. This corroborates the previous suggestions that the increased frequency and variety of retouched types in Bed II and associated with DOA assemblages is primarily due to the appearance of chert.

Both Leakey (1971) and Kimura (2002) suggest that the high quality of chert in Bed II drove the increased production of retouched material, presumably, due to principles of raw material curation. On the other hand, it has been suggested that chert flake edges are more susceptible to post-depositional pseudoretouch (de la Torre and Mora, 2005). More recent analyses of Bed II assemblages have, however, reasserted the intentional anthropogenic origin of chert retouched material (de la Torre and Mora, submitted). In addition, the high frequency of retouched material at MNK CFS, which has seen little post-depositional alteration (Stiles et al., 1974) and which due to its close proximity to the main chert source would not have required significant tool curation, may suggest an increased degree of retouching. The same mechanical properties that made chert a preferential raw material within Bed II, including its homogeneity, ability to develop high quality conchoidal fracture, and the production of exceptionally sharp edges, may equally have made the edges of flakes less durable. This may have necessitated more frequent retouchingto strengthen the edges of chert flakes. This hypothesis will require further investigation into the mechanical properties of Olduvai raw materials beyond the scope of this study.

On the other hand, however, the diversification of retouched tool types following Tuff IIA, although not indicative of dramatic technological change, may be associated with hominin behavioral adaptations brought about by a changing environment. Following the deposition of Tuffs IF and IIA, the environment of Olduvai changed from a humid vegetated environment (Verdcourt, 1963) dominated by swamp margin grassland and gallery forest to open savannah and tree-lined channels (Jaeger, 1976; Potts, 1988; Fernández-Jalvo et al., 1998). The environment above Tuff IIA saw an increase in overall aridity and temperatures of between 22 and 25°C (Cerling and Hay, 1986), and an increase in open environments (Hay, 1976;Gentry and Gentry, 1978; Uno et al, submitted), dry and wet grasslands, and lightly wooded areas (de la Torre et al, submitted; Prassack et al, submitted; Uno et al, submitted). This was coupled with species rich environment, dominated by large herbivores (Bibi et al, submitted). The Olduvai paleolake saw a decrease in size (Hay, 1976; Stollhofen et al., 2008; Kovarovic et al., 2013), although it continued to exhibit short and long-term water level changes (Bibi et al, submitted; de la Torre et al, submitted). This is also coupled with an increase of mosaic woodland (Bamford, 2005; Kovarovic et al., 2013), grassland (Blumenschine et al., 2012a), and marshland environments (Ashley et al., 2009). The floodplain region around the lake would have been host to a large number of herbivores, drawn to the area by the fertile grassy cover (Bibi et al, this volume). These, and the freshwater sources located on the lake margin zone (Peters and Blumenschine, 1995), would have been important resources for scavenging hominins. It has been noted that following climatic and/or ecological changes, foraging groups are expected to adapt to the subsequent resource change/depletion through a strategy of technological innovation (Fitzhugh, 2001; Clarkson, 2007). Although it is difficult to use analogies based on modern human examples for the interpretation of Early Stone Age behavior, it is worth entertaining the idea that the increased retouched toolkit, as well as the appearance of spheroids and subspheroids within the Bed II tool kits, may have been strategies to mitigate risk brought on by environmental change and the necessity to occupy a more open environment. For these hypotheses, further archaeological and experimental work is required to gain a better understanding of the factors behind the increased use of retouch, and the increased diversification of tool types in Lower-Middle Bed II. Finally, it must be noted that previous experimental work has identified significant inter-analyst variation and degree of analytical accuracy (Proffitt and de la Torre, 2014) that may also affect the rate at which intentional retouch is identified on chert artifacts compared to quartzite and lava.

Is there a diachronic trend in spheroid and subspheroid production?

The final distinguishing feature of the DOA is the presence of spheroids and subspheroids. I have shown that, in terms of artifact frequency, there is a clear distinction between the Bed I and Lower-Middle Bed II assemblages. This diachronic distinction is also highlighted in other studies of lithic material in Bed II (de la Torre and Mora, submitted). However, the extent that this represents a technological departure from both core exploitation and hammerstone percussion observed in Bed I is questionable, and may be more closely associated with diachronic behavioral changes.

The production techniques of spheroids and subspheroids have been the focus of a number of studies (Clark, 1955; Kleindienst, 1962; Hay, 1971). They have been considered as either intentionally shaped artifacts (Clark, 1955; Hay, 1971; Texier and Roche, 1995) for use as missiles or elements within a bolas, or as hammerstones to access food sources. Others have, however, argued that they represent an unintentional by-product of the interplay between intentionally knapped core and subsequent percussive activities (Willoughby, 1985; Sahnouni et al., 1997;Schick and Toth, 1994;de la Torre and Mora, 2005, 2010;de la Torre, 2010;Sánchez-Yustos et al., 2015).

It has been noted that spheroids and subspheroids are identified in Classic Oldowan assemblages further afield (Semaw et al., 2009), including Ain Hanech, in Algeria, dated to between 1.9–1.77Ma (Sahnouni and de Heinzelin, 1998; Sahnouni, 2002). Secondly, the technological prerequisites to produce spheroids are initially related to knapping activities, and more specifically the multifacial exploitation of quartzite cores (Proffitt, 2016; Arroyo and de la Torre, submitted; de la Torre and Mora, submitted). Their production, therefore, does not fall outside the normal knapping behavioral capabilities identified at other Oldowan assemblages. It can be argued that, coupled with the increased frequency of multifacial quartzite cores within the Lower Bed II assemblages, both spheroids and subspheroids represent an additional marker of increased knapping intensity within these assemblages, although they do not represent a significant departure from the technical skills of the Oldowan at Olduvai. Their secondary function appears to have been closely related to percussive activities, be it bipolar knapping (Sánchez-Yustos et al., 2015), utilized as knapping hammerstones, or for as yet unknown other percussive activities (Schick and Toth, 1994; Sahnouni et al., 1997; Sánchez-Yustos et al., 2015; de la Torre and Mora, 2005; de la Torre, 2010). This study concurs with these assessments, but acknowledges that without additional investigation of the percussive wear (see Arroyo and de la Torre, submitted), pinpointing the exact percussive activity undertaken would be difficult.

Conclusions

The validity of the original distinction between the Classic Oldowan and Developed Oldowan A at Olduvai Gorge has been largely unstudied since its initial reporting. In general, this variation within the Oldowan has been less controversial than the distinction between the Developed Oldowan B and the Acheulean and was seen merely as a slight evolution of the Oldowan. However, numerous studies still maintain the terminology, based on a typological distinction. The technological data presented in this study, which considers all DOA lithic assemblages originally published by Leakey (1971) at Olduvai Gorge, strongly suggests the removal of the term DOA as a descriptor based on new technological innovation, in line with some previous studies (but see a different view in de la Torre and Mora, submitted). The assemblages originally assigned to the DOA represent a continuation of small flake production, as is seen in all Oldowan assemblages from Bed I. Although no major technological innovation or change is identified between Bed I and Lower-Middle Bed II of Olduvai, diachronic lithic variations are prevalent within the Oldowan of this period. These include an increased density of knapping activities, an increase in core reduction, a slight trend in exploiting larger quartzite cores, the production of larger flakes, and an increase in percussive activities. While these represent a slight variation from Bed I lithic exploitation, they all were within the technological repertoire of Bed I hominins.Instead of technical innovation, these variations (which include the increased frequency of spheroids and subspheroids and retouched material) may be more closely associated with behavioral changes in response to local environmental changes from Bed I to Lower and Middle Bed II. As no distinct technological change is identifiable, I would caution against using the term Developed Oldowan A in describing the non-handaxe bearing assemblages of Lower and pre-Tuff IIB Middle Bed II of Olduvai Gorge. However, due to the slight diachronic variation in tool types and raw material utilization, these assemblages stand apart from Classic Oldowan assemblages in Bed I and could be seen as a behavioral variation within the Oldowan sensu lato.

Acknowledgments

The author would like to extend his gratitude to the National Museum of Tanzania for allowing access to material. Funding from a UCL-Impact studentship, a British Academy Postdoctoral Fellowship (Project Number:542133), the British Academy (IP090186), and the European Research Council-Starting Grants (ORACEAF project: 283366) are acknowledged. Thanks are also given to two JHE reviewers and I. de la Torre for helpful discussion during this study.

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Figure legends

Figure 1.Location map of Olduvai Gorge (Tanzania) and location within Olduvai Gorge of all study sites included in this analysis (map adapted from Jorayev et al. [2016]), and relative stratigraphy and dates of all Oldowan and Developed Oldowan A (DOA) assemblages studied.

Figure 2. Dimension boxplots for length, width, and thickness quartzite (A), lava (B), and chert (C) cores.

Figure 3. Weight (g) boxplots for all quartzite (A), lava (B), and chert (C) cores at all studied assemblages.

Figure 4. Dimension boxplots for length (mm), width (mm), and thickness (mm) for quartzite (A), lava (B), and chert (C) flakes in all assemblages.

Figure 5. Dimension boxplots for weight (g) for quartzite (A), lava (B), and chert (C)flakes in all assemblages and chert flakes excluding data from MNK CFS (D).

Figure 6. Examples of unifacial exploitation on quartzite, lava, and chert cores from Bed I and II. A) Lava unifacial simple partial exploited core from FLK N 1–2. B) Quartzite unifacial abrupt unidirectional exploited core for FLK Zinj. C) Quartzite unifacial abrupt unidirectional exploited core from FLK Zinj. D)Chert unifacial abrupt unidirectional exploited core from MNK CFS. E) Chert unifacial abrupt unidirectional exploited core from MNK CFS. F) Lavaunifacial simple partial exploited core from HWK E Level 3. (Scale = 5cm.)

Figure 7. Examples of bifacial exploited cores on quartzite, lava, and chert cores from Bed I and II. A) Lava bifacial simple exploited core from FLK Zinj. B) Lava bifacial abrupt exploited core for FLK Zinj. C) Quartzite bifacial simple exploited core from FLK N 1–2. D) Lava bifacial simple exploited core form FLK N SC. E) Lava bifacial abrupt exploited core from FLK N SC. F) Chert bifacial abrupt exploited core from FLK N SC. (Scale = 5cm.)

Figure 8. Examples of structured exploited (bifacial peripheral) cores on quartzite, lava, and chert cores from Bed I and II. A) Quartzite bifacial peripheral exploited core from FLK N 1–2. B) Lava bifacial peripheral exploited core from FLK N SC. C) Chert bifacial peripheral exploited core from FLK N SC. (Scale = 5cm.)

Figure 9. Examples of multifacial exploited cores on quartzite, lava, and chert cores from Bed I and II. A) Quartzite multifacial core from FLK N 1–2. B) Quartzite multifacial core from FLK N SC.C) Lava multifacial core from FLK N 1–2. D) Chert multifacial core form HWK E Level 4. (Scale = 5cm.)

Table 1

Table 1. Stratigraphic position and general information for the sites included in this study.[a]

Assemblage	Stratigraphic position	Underlying tuff	Associated date	Overlying tuff	Associated date	Year studied	Assemblage size
DK	Lower Bed I	Tuff IA	1.88 ± 0.05[1]	Tuff IB	1.848 ± 0.003[2]	2013	65
FLK NN 3	Middle Bed I	Tuff IB	1.848 ± 0.003[2]	Tuff ID	1.839[1]	2013	62
FLK NN 1	Middle Bed I	Tuff IB	1.848 ± 0.003[2]	Tuff ID	1.839[1]	2015 + 2014	31
FLK Zinj	Middle Bed I	Tuff IB	1.848 ± 0.003[2]	Tuff ID	1.839[1]	2015 + 2014	2418
FLK N 1-2	Upper Bed I	Tuff ID	1.839[1]	Tuff IF	1.803 ± 0.002[1]	2014 + 2014	1366
HWK E Level 1	Lower Bed II	Tuff IF	1.803 ± 0.002[1]	Tuff IIA	1.68–1.76	2013 + 2014	630
HWK E Level 2	Lower Bed II	Tuff IF	1.803 ± 0.002[1]	Tuff IIA	1.68–1.76	2012 + 2014	342
HWK E Level 3	Middle Bed II	Tuff IIA	1.68–1.76[4]	Tuff IIB*	1.66 ± 0.19[3, 4]	2013	1378
HWK E Level 4	Middle Bed II	Tuff IIA	1.68–1.76[4]	Tuff IIB *	1.66 ± 0.19[3, 4]	2014	611
HWK E Level 5	Middle Bed II	Tuff IIA	1.68–1.76[4]	Tuff IIB *	1.66 ± 0.19[3, 4]	2014	140
FLK N SC	Middle Bed II	Tuff IIA	1.68–1.76[4]	Tuff IIB *	1.66 ± 0.19[3, 4]	2014	250
MNK CFS	Middle Bed II	Tuff IIA	1.68–1.76[4]	Tuff IIB *	1.66 ± 0.19[3, 4]	2014	1780

[a] Dates derive from (1) Deino, 2012; (2) Blumenschine et al, 2003; (3) Uribelarrea et al, in press; (4) McHenry, this volume.

* As there is no clear date for Tuff IIB, the overlying tuff used in this study is the overlying tuff identified by Uribelarrea et al. (in press), dated to 1.66 ± 0.19 Ma.

Table 2

Table 2. Absolute, relative, and adjusted residual (A.R.) values of all technological categories for all assemblages.[a]

Stratigraphic position	Site	Cores and core fragments			Complete flakes			Retouched pieces			Fragmented flakes			Hammerstones			Anvils and anvil fragments			Spheroids and subspheroids			Angular chunks		
		n	%	A.R	*n*	%	A.R	*n*	%	A.R	*n*	%	A.R	*n*	%	A.R	*n*	%	A.R	*n*	%	A.R	*n*	%	A.R
Middle Bed I	**FLKNN 3**	4	10.3	0.2	9	23.1	0.2	0	0.0	-1.0	17	43.6	-1.1	1	2.6	-0.5	0	0.0	-0.4	0	0.0	-0.5	8	20.5	**2.4**
Middle Bed I	**FLKNN 1**	7	63.6	**6.3**	2	18.2	-0.3	1	9.1	1.5	0	0.0	**-3.5**	1	9.1	0.8	0	0.0	-0.2	0	0.0	-0.3	0	0.0	-1.1
Middle Bed I	**FLK Zinj**	37	2.3	**-11.0**	172	10.5	**-12.6**	7	0.4	**-5.9**	1283	78.2	**24.1**	19	1.2	**-6.9**	4	0.2	-1.3	0	0.0	**-4.0**	118	7.2	**-3.3**
Upper Bed I	**FLK N 1-2**	98	9.2	0.1	161	15.1	**-5.8**	6	0.6	**-4.2**	600	56.2	**2.9**	80	7.5	**6.0**	15	1.4	**5.4**	0	0.0	**-3.1**	108	10.1	1.1
Lower Bed II	**HWK E Level 1**	55	17.5	**5.3**	46	14.6	**-3.1**	1	0.3	**-2.5**	44	14.0	**-13.8**	21	6.7	**2.3**	1	0.3	-0.3	0	0.0	-1.6	146	46.5	**23.3**
Lower Bed II	**HWK E Level 2**	69	22.2	**8.2**	60	19.3	-1.1	5	1.6	-0.9	118	37.9	**-5.1**	19	6.1	1.8	0	0.0	-1.2	1	0.3	-0.9	39	12.5	**2.1**
Middle Bed II	**HWK E Level 3**	196	18.0	**11.0**	159	14.6	**-6.3**	35	3.2	1.9	478	43.8	**-6.0**	58	5.3	**2.1**	5	0.5	0.2	32	2.9	**9.0**	128	11.7	**3.1**
Middle Bed II	**HWK E Level 4**	83	15.5	**5.4**	107	20.0	-1.0	33	6.2	**6.0**	207	38.8	**-6.4**	38	7.1	**3.6**	1	0.2	-0.9	8	1.5	**2.1**	57	10.7	1.2
Middle Bed II	**HWK E Level 5**	19	21.6	**4.1**	20	22.7	0.2	0	0.0	-1.5	21	23.9	**-5.3**	17	19.3	**7.2**	2	2.3	**2.7**	1	1.1	0.4	8	9.1	-0.1
Middle Bed II	**FLK N SC**	46	20.9	**6.2**	48	21.8	0.0	20	9.1	**6.6**	36	16.4	**-10.8**	39	17.7	**10.3**	1	0.5	0.1	12	5.5	**8.2**	18	8.2	-0.6
Middle Bed II	**MNK CFS**	36	2.0	**-12.2**	769	42.4	**24.7**	62	3.4	**3.3**	913	50.4	-1.7	2	0.1	**-10.0**	1	0.1	**-2.8**	0	0.0	**-4.3**	29	1.6	**-13.0**

[a] All raw material grouped. Bold = significant at 0.05.

Table 3

Table 3. Absolute and relative frequencies and adjusted residual (A.R.) values of number and total weight of artifacts for each fully analyzed assemblage separated by raw material groups.[a]

			Chert			Lava			Quartzite		
			n	%	A.R	n	%	A.R	n	%	A.R
Middle Bed I	Tuff ID	**FLK Zinj**	0	0%	**-36.17**	146	6%	**-9.85**	2207	94%	**39.72**
Upper Bed I	Tuff IF	**FLK N 1-2**	0	0%	**-22.91**	320	28%	**18.50**	822	72%	**8.92**
Lower Bed II	Tuff IIA	**HWKE Level 1**	2	1%	**-12.24**	114	30%	**11.50**	260	69%	**3.71**
Lower Bed II	Tuff IIA	**HWKE Level 2**	23	7%	**-8.30**	61	20%	**4.48**	225	73%	**4.69**
Middle Bed II	Tuff IIB	**HWKE Level 3**	310	26%	**-2.10**	164	14%	**2.26**	728	61%	0.44
Middle Bed II	Tuff IIB	**HWKE Level 4**	160	28%	-0.02	54	10%	-1.66	352	62%	1.11
Middle Bed II	Tuff IIB	**HWKE Level 5**	2	2%	**-5.45**	27	31%	**5.57**	59	67%	1.36
Middle Bed II	Tuff IIB	**FLK N SC**	72	33%	1.48	44	20%	**3.88**	104	47%	**-3.90**
Middle Bed II	Tuff IIB	**MNK CFS**	1728	93%	**70.47**	20	1%	**-16.24**	111	6%	**-54.14**
			Weight (g)	**%**	**A.R**	**Weight (g)**	**%**	**A.R**	**Weight (g)**	**%**	**A.R**
Middle Bed I	Tuff ID	**FLK Zinj**	0	0%	**-67.4**	13723	47%	**-18.2**	15602	53%	**65.7**
Upper Bed I	Tuff IF	**FLK N 1-2**	0	0%	**-121.7**	59072	72%	**128.5**	23062	28%	**-49.8**
Lower Bed II	Tuff IIA	**HWKE Level 1**	8.1	0%	**-71.2**	26994.6	83%	**117.1**	5511.8	17%	**-72.9**
Lower Bed II	Tuff IIA	**HWKE Level 2**	417.6	1%	**-61.7**	17668.2	57%	**20.4**	12642.3	41%	**21.4**
Middle Bed II	Tuff IIB	**HWKE Level 3**	4776.1	5%	**-82.8**	49304.4	51%	**-9.2**	43316.4	44%	**67.0**
Middle Bed II	Tuff IIB	**HWKE Level 4**	2569.7	7%	**-34.3**	18313	49%	**-9.8**	16125	44%	**34.0**
Middle Bed II	Tuff IIB	**HWKE Level 5**	43.8	0%	**-43.4**	7301.9	55%	**6.4**	6017.8	45%	**23.4**
Middle Bed II	Tuff IIB	**FLK N SC**	1398	3%	**-57.8**	16796.4	42%	**-42.4**	21919.7	55%	**84.3**
Middle Bed II	Tuff IIB	**MNK CFS**	42059.7	93%	**548.6**	2381.4	5%	**-209.8**	558.9	1%	**-161.1**

[a] Bold = significant at 0.05.

Table 4

Table 4. Absolute and relative frequencies and adjusted residuals (A.R) of exploitation types for all raw materials grouped in all assemblages.

	DK	FLK NN 3	FLK NN 1	FLK Zinj	FLK N 1-2	HWK E Level 1	HWK E Level 2	HWK E Level 3	HWK E Level 4	HWK E Level 5	FLK N SC	MNK CFS
	Count	**Count**	**Count**	**Count**	**Count**	**Count**	**Count**	**Count**	**Count**	**Count**	**Count**	**Count**
Unifacial	14	1	4	19	13	16	29	76	27	9	9	17
Bifacial	37	2	3	18	77	34	27	89	40	6	31	10
Multifacial	10	1	0	0	6	5	11	24	15	1	6	7
Total	61	4	7	37	96	55	67	189	82	16	46	34
	%	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
Unifacial	23%	25%	57%	51%	14%	29%	43%	40%	33%	56%	20%	50%
Bifacial	61%	50%	43%	49%	80%	62%	40%	47%	49%	38%	67%	29%
Multifacial	16%	25%	0%	0%	6%	9%	16%	13%	18%	6%	13%	21%
	A.R	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**
Unifacial	-1.9	-0.4	1.3	**2.3**	**-4.5**	-0.8	1.7	**2.2**	-0.2	1.9	**-2.1**	**2.1**
Bifacial	1.1	-0.2	-0.6	-0.7	**5.6**	1.2	**-2.3**	**-2.2**	-1.0	-1.3	1.9	**-2.9**
Multifacial	1.0	0.8	-1.0	**-2.4**	**-2.0**	-0.8	1.1	0.1	1.7	-0.8	0.1	1.5

Table 5

Table 5. Absolute and relative frequencies and adjusted residuals (A.R) of exploitation strategies for all raw materials grouped in all assemblages.

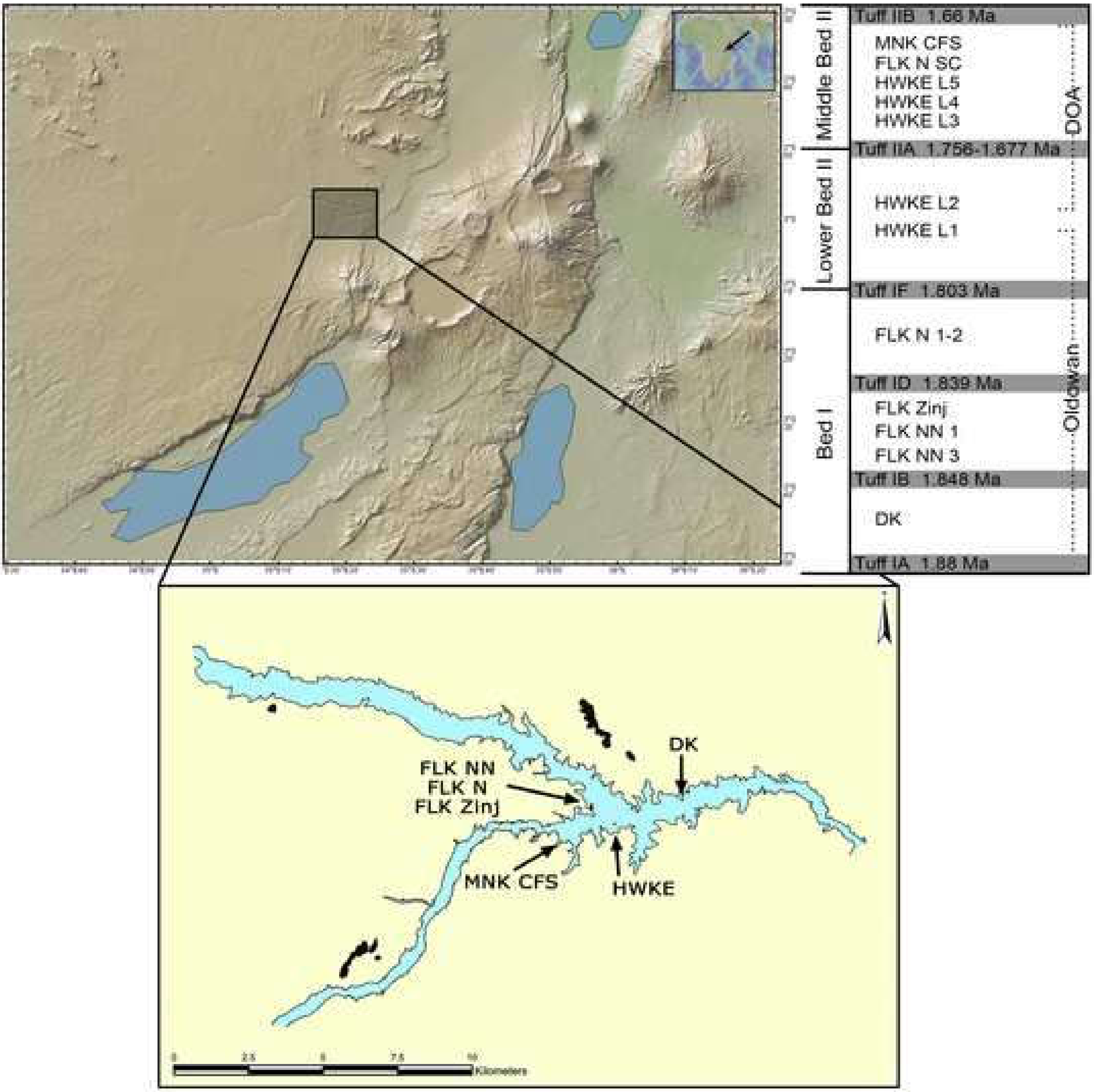
	DK	FLK NN 3	FLK NN 1	FLK Zinj	FLK N 1-2	HWKE Level 1	HWKE Level 2	HWKE Level 3	HWKE Level 4	HWKE Level 5	FLK N SC	MNK CFS
	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count
Unifacial Abrupt	9	1	3	16	7	8	18	56	22	5	7	7
Unifacial Centripetal	1	0	0	0	0	0	0	0	0	0	0	0
Unifacial Peripheral	1	0	0	0	0	0	0	2	0	0	0	0
Unifacial Simple	3	0	1	3	6	8	11	18	5	4	2	10
Bifacial Abrupt	18	2	1	11	32	10	7	36	11	4	15	1
Bifacial Alternate	0	0	1	4	0	11	6	23	13	0	1	1
Bifacial Peripheral	10	0	0	0	6	1	0	6	4	2	11	0
Bifacial Simple	9	0	1	3	39	12	14	24	12	0	4	8
Multifacial	6	1	0	0	4	5	11	24	14	1	6	7
Polyhedral	4	0	0	0	2	0	0	0	1	0	0	0
Total	47	3	3	18	83	39	38	113	55	7	37	17
	%	%	%	%	%	%	%	%	%	%	%	%
Unifacial Abrupt	14.8%	25.0%	42.9%	43.2%	7.3%	14.5%	26.9%	29.6%	26.8%	31.3%	15.2%	20.6%
Unifacial Centripetal	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Unifacial Peripheral	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	0.0%	0.0%	0.0%
Unifacial Simple	4.9%	0.0%	14.3%	8.1%	6.3%	14.5%	16.4%	9.5%	6.1%	25.0%	4.3%	29.4%
Bifacial Abrupt	29.5%	50.0%	14.3%	29.7%	33.3%	18.2%	10.4%	19.0%	13.4%	25.0%	32.6%	2.9%
Bifacial Alternate	0.0%	0.0%	14.3%	10.8%	0.0%	20.0%	9.0%	12.2%	15.9%	0.0%	2.2%	2.9%
Bifacial Peripheral	16.4%	0.0%	0.0%	0.0%	6.3%	1.8%	0.0%	3.2%	4.9%	12.5%	23.9%	0.0%
Bifacial Simple	14.8%	0.0%	14.3%	8.1%	40.6%	21.8%	20.9%	12.7%	14.6%	0.0%	8.7%	23.5%
Multifacial	9.8%	25.0%	0.0%	0.0%	4.2%	9.1%	16.4%	12.7%	17.1%	6.3%	13.0%	20.6%
Polyhedral	6.6%	0.0%	0.0%	0.0%	2.1%	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%	0.0%
	A.R	A.R	A.R	A.R	A.R	A.R	A.R	A.R	A.R	A.R	A.R	A.R
Unifacial Abrupt	-1.6	0.1	1.3	**3.0**	**-3.9**	-1.5	0.8	**2.6**	0.9	0.8	-1.3	-0.3
Unifacial Centripetal	**3.2**	-0.1	-0.1	-0.2	-0.4	-0.3	-0.3	-0.6	-0.4	-0.2	-0.3	-0.2
Unifacial Peripheral	1.5	-0.1	-0.2	-0.4	-0.7	-0.5	-0.6	1.5	-0.6	-0.3	-0.5	-0.4
Unifacial Simple	-1.4	-0.7	0.4	-0.4	-1.4	1.1	1.8	-0.4	-1.3	2.0	-1.4	**3.8**
Bifacial Abrupt	1.6	1.4	-0.5	1.3	**3.1**	-0.6	**-2.3**	-0.9	-1.9	0.4	1.9	**-2.7**
Bifacial Alternate	**-2.5**	-0.6	0.5	0.5	**-3.2**	**3.1**	0.1	**2.0**	**2.5**	-1.2	-1.6	-1.2
Bifacial Peripheral	**3.7**	-0.5	-0.7	-1.5	0.2	-1.3	**-2.1**	-1.8	-0.4	1.2	**5.5**	-1.5
Bifacial Simple	-0.7	-0.9	-0.3	-1.6	**6.2**	0.7	0.6	**-2.3**	-0.9	-1.9	-1.7	0.8
Multifacial	-0.4	0.9	-1.0	**-2.2**	**-2.4**	-0.6	1.4	0.7	1.7	-0.7	0.4	1.7
Polyhedral	**4.5**	-0.2	-0.3	-0.6	1.1	-0.8	-0.9	-1.6	0.2	-0.4	-0.7	-0.6

Table 6

Table 6. Absolute and relative frequencies of all retouch types, and adjusted residual (A.R.) values for all assemblages.

		FLK NN 3	FLK NN 1	FLK Zinj	FLK N 1-2	HWK E Level 1	HWK E Level 2	HWK E Level 3	HWK E Level 4	HWK E Level 5	FLK N SC	MNK CFS
Retouch Types		N	N	N	N	N	N	N	N	N	N	N
	Abrupt Retouch	-	0	0	0	0	0	0	1	-	0	3
	Denticulate	-	0	3	6	1	3	14	15	-	4	19
	Scraper	-	1	2	0	0	2	12	5	-	14	18
	Side Scraper	-	0	2	0	0	0	9	12	-	2	22
	Total	0	1	7	6	1	5	35	33	0	20	62
		%	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
	Abrupt Retouch	-	0%	0%	0%	0%	0%	0%	3%	-	0%	5%
	Denticulate	-	0%	43%	100%	100%	60%	40%	45%	-	20%	31%
	Scraper	-	100%	29%	0%	0%	40%	34%	15%	-	70%	29%
	Side Scraper	-	0%	29%	0%	0%	0%	26%	36%	-	10%	35%
		A.R	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**	**A.R**
	Abrupt Retouch	-	-0.2	-0.4	-0.4	-0.2	-0.4	-1.0	0.3	-	-0.7	1.6
	Denticulate	-	-0.8	0.3	**3.2**	1.3	1.0	0.2	1.0	-	-1.8	-1.5
	Scraper	-	1.5	-0.2	-1.7	-0.7	0.4	0.4	**-2.3**	-	**3.9**	-0.6
	Side Scraper	-	-0.6	0.1	-1.5	-0.6	-1.4	-0.3	1.2	-	-1.9	1.7

Figure 1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Lower Bed II
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FLK N SC
HWKE L5
HWKE L4
HWKE L3
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HWKE L2
HWKE L1
Tuff IF 1.803 Ma
FLK N 1-2
Tuff ID 1.839 Ma
FLK Zinj
FLK NN 1
FLK NN 3
Tuff IB 1.848 Ma
DK
Tuff IA 1.88 Ma
DOA
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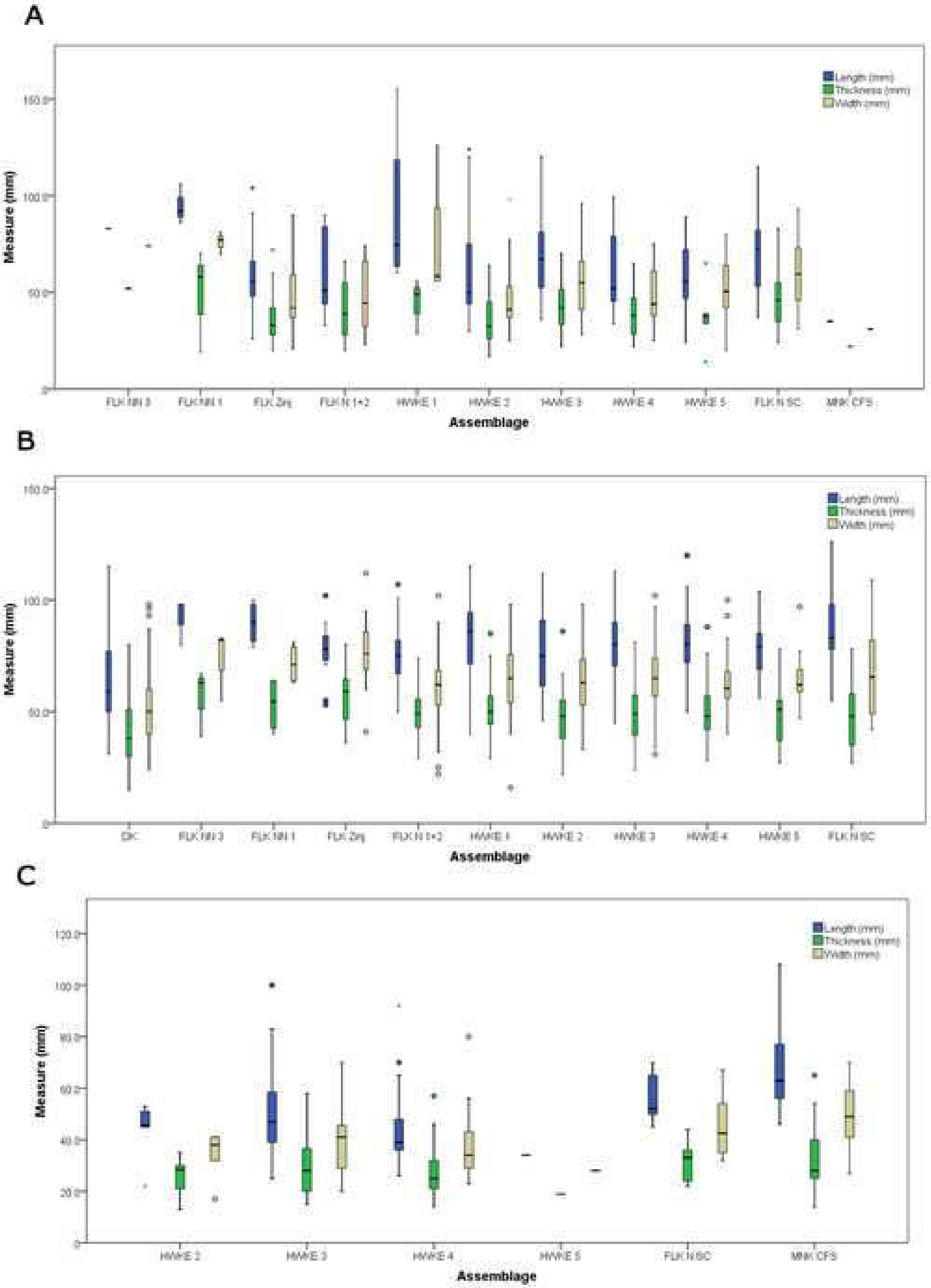
5
7.5
10
Kilometers

Figure 2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Width (mm)
Measure (mm)
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FLK NN 3
FLK NN 1
FLK Zinj
FLK N 1+2
HWKE 1
HWKE 2
HWKE 3
HWKE 4
HWKE 5
FLK N SC
MNK CFS
Assemblage
B
Length (mm)
Thickness (mm)
Width (mm)
Measure (mm)
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100.0
50.0
0
DK
FLK NN 3
FLK NN 1
FLK Zinj
FLK N 1+2
HWKE 1
HWKE 2
HWKE 3
HWKE 4
HWKE 5
FLK N SC
Assemblage
C
Length (mm)
Thickness (mm)
Width (mm)
Measure (mm)
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100.0
80.0
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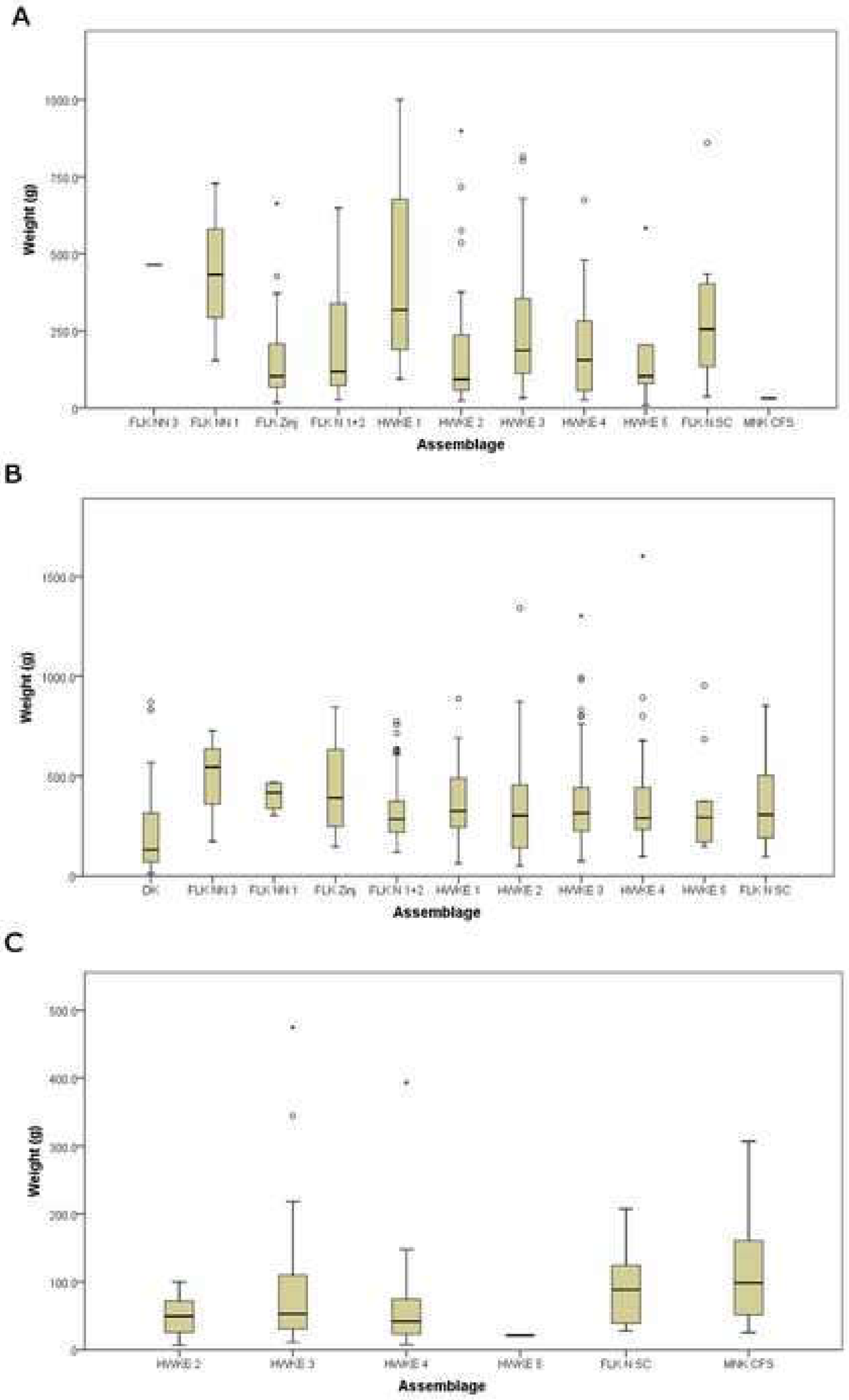
HWKE 3
HWKE 4
HWKE 5
FLK N SC
MNK CFS
Assemblage

Figure 3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FLK NN 1
FLK Zinj
FLK N 1+2
HWKE 1
HWKE 2
HWKE 3
HWKE 4
HWKE 5
FLK N SC
MNK CFS
Assemblage
B
Weight (g)
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1000.0
1500.0
DK
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FLK NN 1
FLK Zinj
FLK N 1+2
HWKE 1
HWKE 2
HWKE 3
HWKE 4
HWKE 5
FLK N SC
Assemblage
C
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HWKE 3
HWKE 4
HWKE 5
FLK N SC
MNK CFS
Assemblage

Figure 4

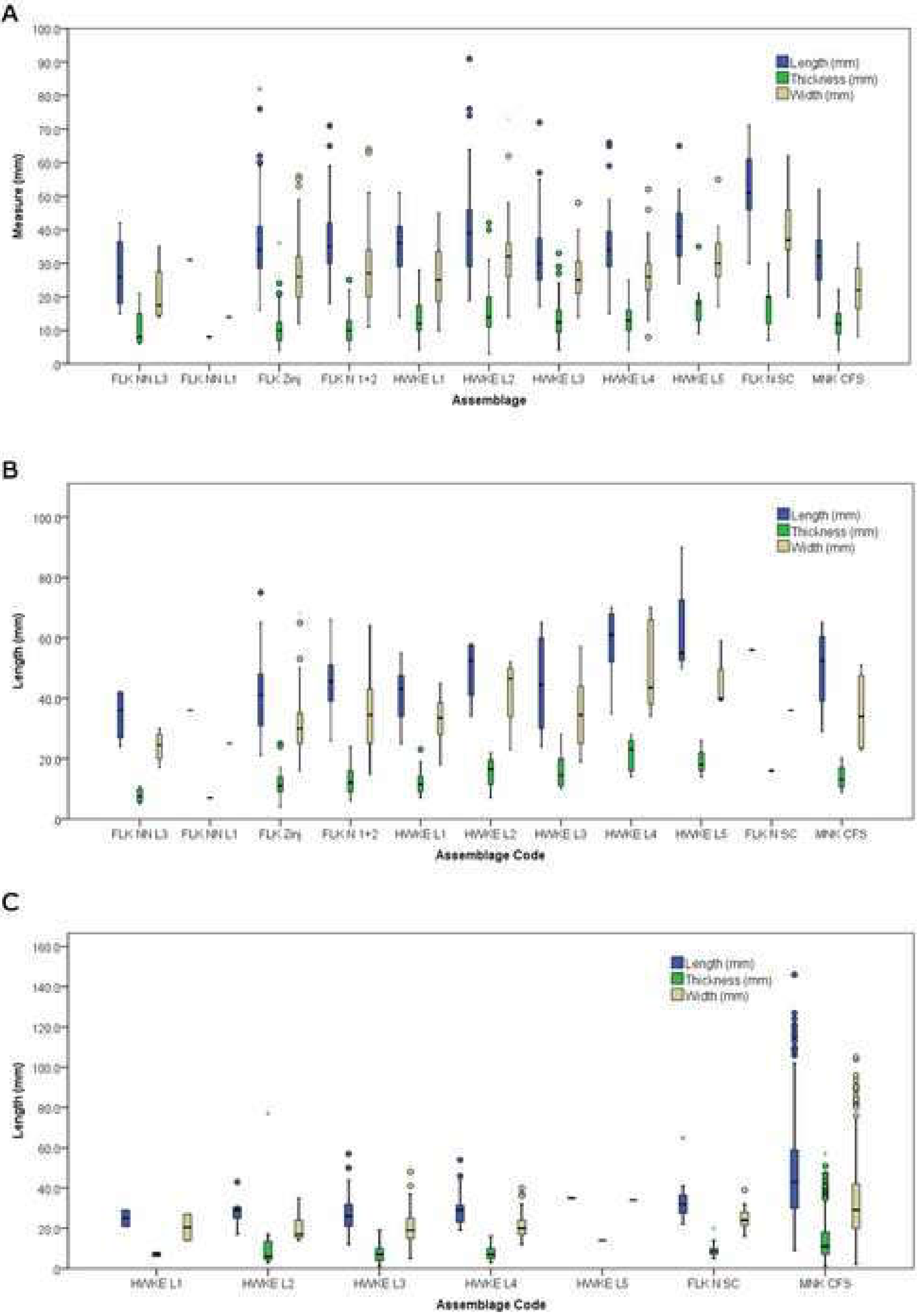
A
Measure (mm)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
FLK NN L3
FLK NN L1
FLK Zinj
FLK N 1+2
HWKE L1
HWKE L2
HWKE L3
HWKE L4
HWKE L5
FLK N SC
MNK CFS
Assemblage
Length (mm)
Thickness (mm)
Width (mm)
B
Length (mm)
100.0
80.0
60.0
40.0
20.0
0
FLK NN L3
FLK NN L1
FLK Zinj
FLK N 1+2
HWKE L1
HWKE L2
HWKE L3
HWKE L4
HWKE L5
FLK N SC
MNK CFS
Assemblage Code
Length (mm)
Thickness (mm)
Width (mm)
C
Length (mm)
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0
HWKE L1
HWKE L2
HWKE L3
HWKE L4
HWKE L5
FLK N SC
MNK CFS
Assemblage Code
Length (mm)
Thickness (mm)
Width (mm)

Figure 5

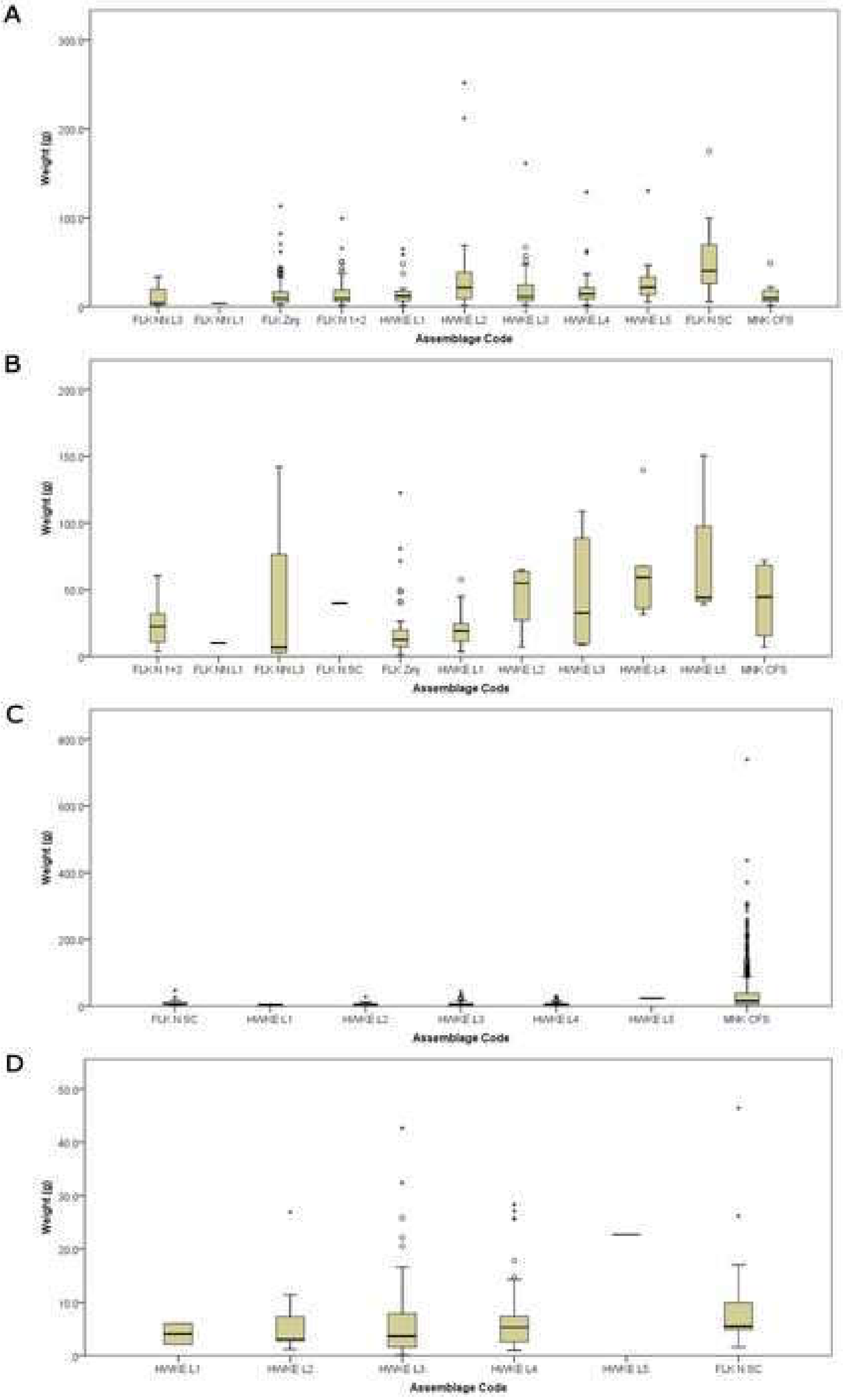
A
Weight (g)
0
100.0
200.0
300.0
FLK NN L3
FLK NN L1
FLK Zinj
FLK N 1+2
HWK E L1
HWK E L2
HWK E L3
HWK E L4
HWK E L5
FLK N SC
MNK CFS
Assemblage Code
B
Weight (g)
0
50.0
100.0
150.0
200.0
FLK N 1+2
FLK NN L1
FLK NN L3
FLK N SC
FLK Zinj
HWK E L1
HWK E L2
HWK E L3
HWK E L4
HWK E L5
MNK CFS
Assemblage Code
C
Weight (g)
0
200.0
400.0
600.0
800.0
FLK N SC
HWK E L1
HWK E L2
HWK E L3
HWK E L4
HWK E L5
MNK CFS
Assemblage Code
D
Weight (g)
0
10.0
20.0
30.0
40.0
50.0
HWK E L1
HWK E L2
HWK E L3
HWK E L4
HWK E L5
FLK N SC
Assemblage Code

Figure 6

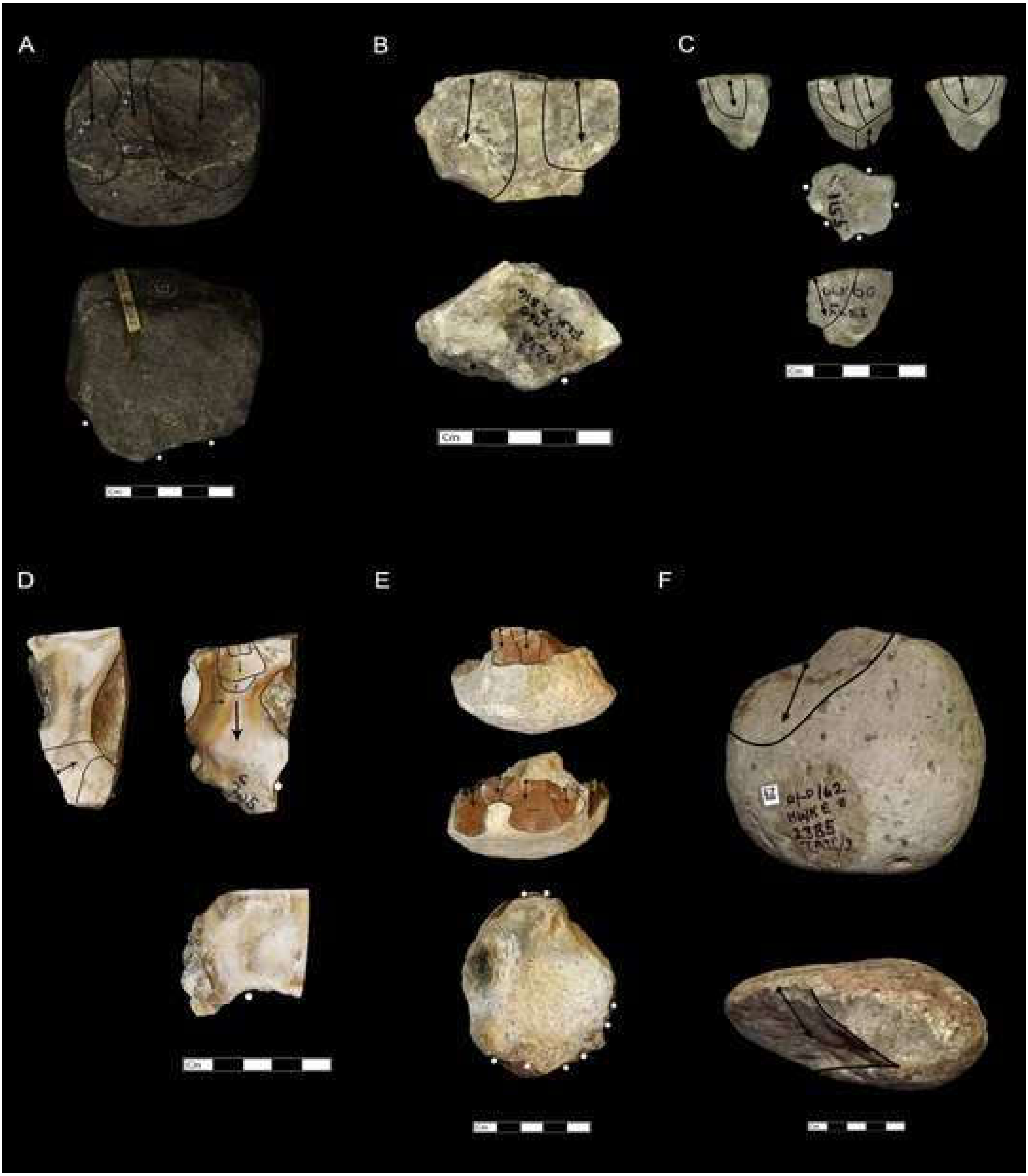

Figure 7

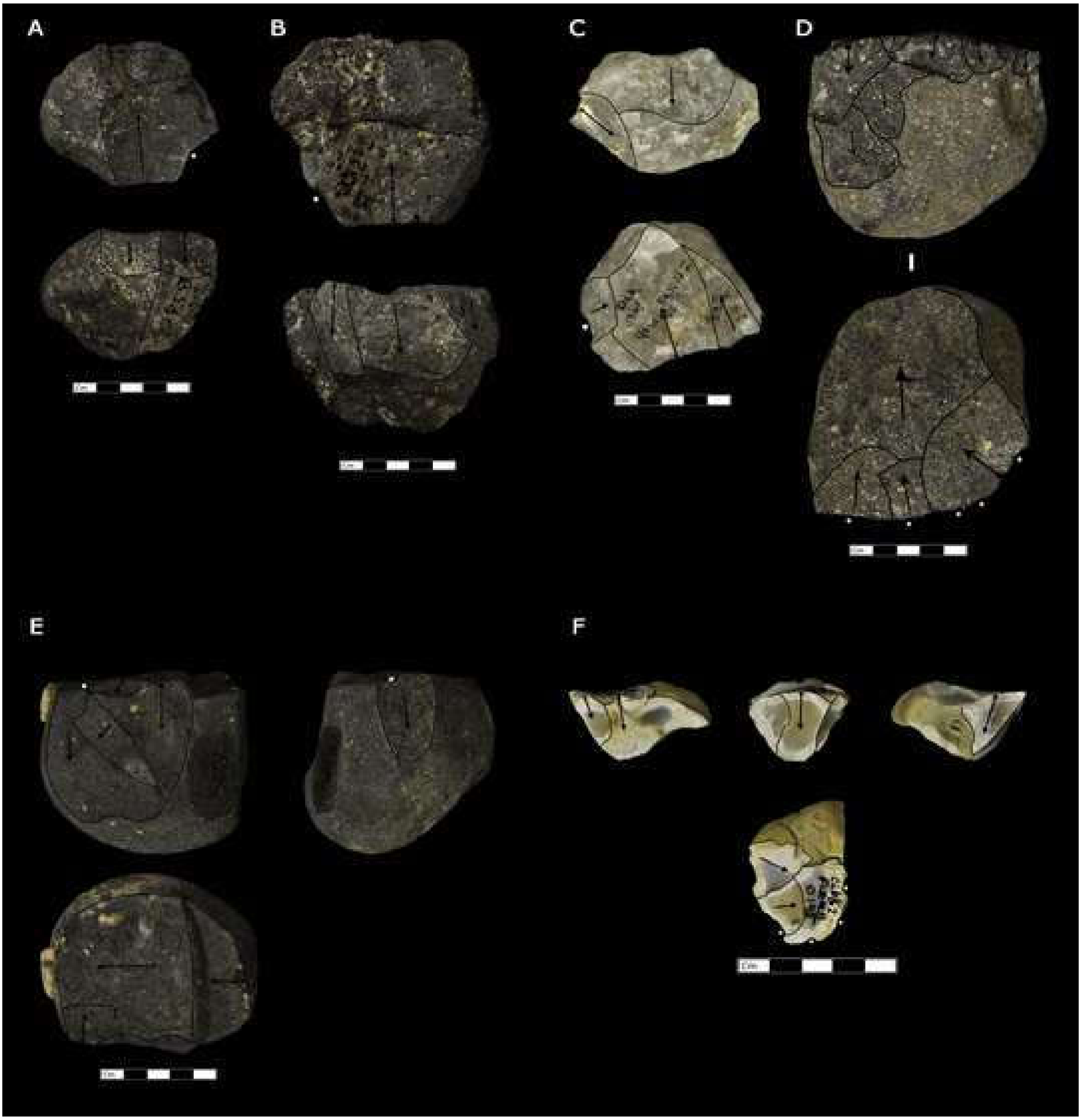

Figure 8

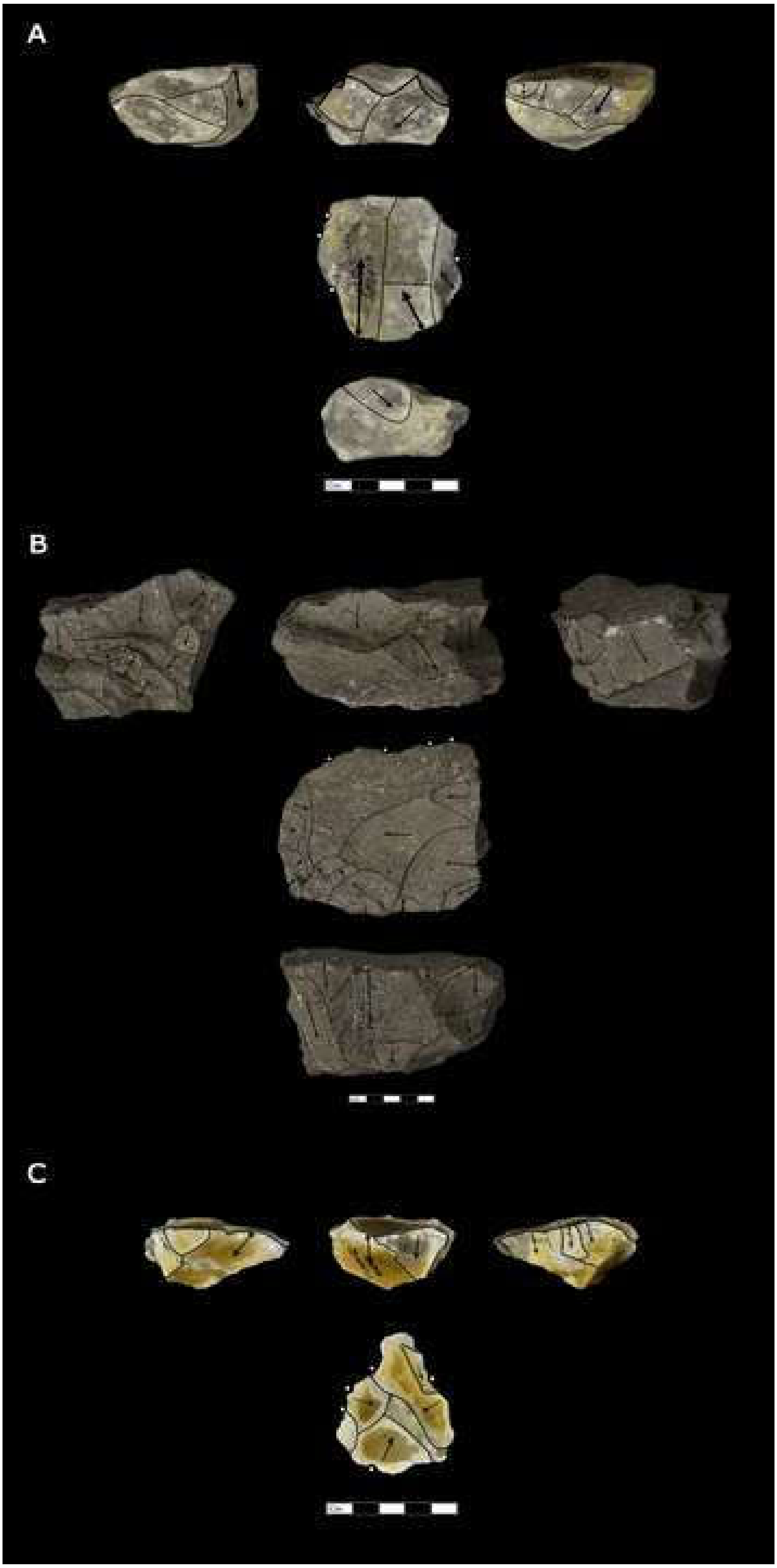

Figure 9

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