Site formation processes of the early Acheulean assemblage at EF-HR (Olduvai Gorge, Tanzania)

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Abstract

This paper investigates the formation history of the early Acheulean site of EF-HR (Olduvai Gorge, Tanzania). Our study focuses on the main site (T2-Main Trench) and adjacent trenches (T12 and T9), which constitute the bulk of the archaeological assemblage recently excavated in the EF-HR area (de la Torre et al., submitted). Site formation processes are investigated through taphonomic proxies and spatial analysis, and consider artefact features, orientation patterns, and topographic data retrieved during archaeological excavation. This enables an assessment of the impact of natural agents on the assemblage and a discussion of the relevance of water disturbance in shaping the structure of the EF-HR archaeological record. Our results indicate that fluvial action over the assemblage was significant, although it is likely that EF-HR still preserves areas marginally affected by water sorting and rearrangement. In summary, by applying a novel approach that combines a systematic analysis of artefact attributes with GIS spatial analysis of archaeological remains and topographic features, our study aims to provide a fresh look at the interaction of human and natural agents in the formation of Early Stone Age assemblages at Olduvai Gorge.

Introduction

Understanding site formation processes is essential for inferences on human behaviour based on archaeological assemblages. Early Stone Age (ESA) sites are often palimpsests resulting from a number of overlapping events (e.g., Isaac, 1983; Malinsky-Buller et al., 2011), where human behaviour is juxtaposed with various biological and abiotic agents. Pioneered by Isaac (1967), study of the role of abiotic agents in the formation of East African assemblages has received considerable attention in the last few decades (e.g., Harris, 1978; Potts, 1982; Schick, 1984, 2001; Dechant-Boaz, 1994; Petraglia and Potts, 1994; Morton, 2004; Delagnes et al., 2006; Pante and Blumenschine, 2010; Benito-Calvo and de la Torre, 2011; de la Torre et al., 2017).

This paper aims to make a contribution to this topic by studying the formation processes of the early Acheulean site of EF-HR (Olduvai, Tanzania). EF-HR was originally excavated by Mary Leakey (1971), who unearthed a substantial lithic assemblage at the time considered as the earliest example of Acheulean technology in Olduvai Bed II and one of the oldest in East Africa. While the technology of Leakey's EF-HR assemblage has been restudied on numerous occasions (e.g., Ludwig, 1999; Kimura, 2002; de la Torre and Mora, 2005), formation processes of the site have never been revisited. This is due both to the very poor preservation of fossils (and as a result EF-HR has been systematically neglected in all taphonomic revisions of Bed II faunas) and a lack of spatial data; EF-HR was one of the few sites for which Leakey (1971) did not publish a distribution map of remains, thus preventing spatial analyses such as those conducted on other Bed II assemblages excavated by Leakey (de la Torre and Benito-Calvo, 2013).

Our study of EF-HR formation processes is based on data from recent excavations by the Olduvai Geochronology Archaeology Project (OGAP). Between 2009 and 2013, OGAP conducted renewed fieldwork at EF-HR, and details of trenches excavated, their stratigraphic position, and sedimentary and archaeological features are presented elsewhere (de la Torre et al., submitted). The present paper describes the archaeological context of the main excavation (T2-Main Trench) and immediately adjacent trenches (T9 and T12), which contain the largest accumulation of archaeological remains across the EF-HR exposures. Our study is centred on a discussion of the role of abiotic agents (in this particular case water action) in the formation of assemblages and relies on a taphonomic and spatial analysis of the EF-HR archaeological context.

Taphonomic attributes of artefacts have long been used to assess post-depositional disturbance (e.g., Schick, 1984; Petraglia and Potts, 1994; Lenoble, 2005; Bertran et al., 2006; Lotter et al., 2016; de la Torre et al., 2017), and in recent years, GIS spatial analysis has become more common in ESA and Lower Palaeolithic archaeology (e.g., Alperson-Afil et al., 2009; Boschian and Sacca, 2010; Benito-Calvo and de la Torre, 2011; Gallotti et al., 2011; Bohner et al., 2015). By combining both proxies, our objectives are two-fold: to introduce methodological innovations that can help assess the impact of human and natural agents on the formation of ESA sites, and to provide a contextual framework to decipher hominin behaviour captured in the EF-HR assemblage.

Materials and methods

Materials

Out of the 12 trenches excavated in the EF-HR wider area (de la Torre et al., submitted), three were selected for the study of site formation processes. These are (from west to east) T12, T2-Main site, and T9 (Fig. 1A), which contain the highest concentration of artefacts across all trenches and can confidently be attributed to the same archaeological assemblage (see details in de la Torre et al., submitted). T12 (Fig. 1B-D) is the densest trench of the EF-HR complex and presents sedimentary and archaeological features identical to those of the largest excavation at T2-Main Trench (Fig. 2). Such features (e.g., a clay paleosurface overlain by diamictite and conglomerate units filled with weathered fossils and abundant early Acheulean artefacts) are also found in T9, which serves to project the extension of the main concentration eastwards.

Due to post-depositional fragmentation and overall poor preservation of the bone assemblage (Fig. 3A; see details in de la Torre et al., submitted), our taphonomic analysis focused on features of the stone tools from trenches T12, T2-Main Trench, and T9. The study centred on artefacts from the main archaeological unit (Interval 1 as defined by de la Torre et al., submitted), and thus considered a total of 2097 stone tools from T12 (n = 232), T2-Main Trench (n = 1826), and T9 (n = 39), although sample sizes were adjusted according to each analysed feature.

Although the limited excavation area of T12 and T9 (8 m^2 each) precludes a systematic spatial analysis of these test trenches, T2-Main Trench was excavated across a larger area of 76 m^2 (Fig. 2) and, therefore, our study of spatial patterns focused on this trench. Three archaeological units (from top to bottom: L1E, L1, and L2) were differentiated during excavation at T2-Main Trench; L1 and L2 are vertically close and undistinguishable in most cross-sections, and are attributed by de la Torre et al. (submitted) to Interval 1 (Fig. 2D-E), while the higher unit of L1E corresponds to Interval 2. Fieldwork observations led to identification of particular areas across T2-Main Trench according to distinct features, such as the presence of incision surfaces eroding the clay topography or the documentation of carbonate clusters over the clay (Fig. 2B-C). As detailed elsewhere (de la Torre et al., submitted), data on the paleo-topography of the clay surface underlying the archaeological unit was recorded during excavation; this enabled use of spatial statistics to classify the excavated area independent of fieldwork observation, and correlate resulting datasets with spatial and taphonomic features of artefacts. The spatial analysis of T2-Main Trench considered the entire assemblage of this site (n=2470), including bones (n=603) and stone tools (n=1867), although for some particular tests (see sections below), our study focused on materials from Interval 1 (Fig. 4) (Supplementary Online Material [SOM] S1), particularly the stone tools.

Methods

<u>Lithic taphonomy</u> Stone tool taphonomy was investigated through the study of edge damage and artefact size distribution. While microscopic inspection of post-depositional edge modification is desirable (Levi Sala, 1986), macroscopic analysis of lithic artefacts has often been used in ESA archaeology to assess site integrity (Petraglia and Potts, 1994; Shea, 1999; de la Torre, 2011), and such an approach is followed here. Two variables were recorded when analysing edge damage macroscopically: rounding (or abrasion, e.g., Shea, 1999) and

microfracturing (sensu Levi Sala, 1986; small-scale chipping sensu Petraglia and Potts, 1994).

Rounding refers to the degree of bluntness of lithic edges, and four stages of roundness (fresh/unabraded, slightly rounded, medium and severe) were used to classify stone artefacts (*n* = 2032) irrespective of size. While rounding is mostly linked to fluvial abrasion, it has been noted elsewhere (e.g., de la Torre and Mora, 2004) that weathering of lavas unrelated to water traction (but linked instead to chemical diagenesis) might obscure representativeness of rounding classes. Therefore, although most EF-HR lava artefacts are in a relatively stable weathering condition, given that most of the EF-HR assemblage is made of trachytes, phonolites, and basalts (see McHenry and de la Torre, submitted), diagenesis rather than fluvial action may have contributed to some of the abrasion patterns observed.

Microfracturing mechanics are, to some extent, also subject to equifinality; while microscopic analysis may be able to distinguish use-wear from edge chipping caused by post-depositional processes (e.g., trampling, sediment pressure, or fluvial action), such distinction is more arbitrary at the macroscopic scale. Therefore, this study considered the presence/absence of microfracturing irrespective of their potential origin and recorded this variable for all artefacts that are over 2 cm in length (*n* = 1117).

Artefact size distribution is particularly informative in assessing post-depositional disturbance of Palaeolithic sites (Schick, 1984; Petraglia and Potts, 1994; Bertran et al., 2006; Sitzia et al., 2012; de la Torre et al., 2017). Our analysis included the entire assemblage (*n* = 2097) of lithic artefacts recovered in situ during excavation and from dry sieving (6 mm mesh). Artefacts were measured tri-dimensionally (longest axis taken as length and the two complementary dimensions as width and thickness) with callipers and weighed with a mg-resolution scale. Maximum dimension and weight classes followed 'standard' size ranges used in previous archaeological studies (e.g., Schick, 1984; Petraglia and Potts, 1994; de la Torre, 2011), but also Jenks' method of natural breaks optimization (Jenks and Caspall, 1971; Slocum, 1998), which statistically classifies the sample according to the best arrangement of clusters. Considering lithic artefacts also as sedimentary particles, stone tool shape was calculated following Sneed and Folk's (1958) classes and plotted in Tri-plot (Graham and Midgley, 2000). Chi-square tests were used to assess whether there were statistically significant associations between artefact variables.

The potential of refit data for taphonomic analysis is well known in Palaeolithic studies (e.g., Villa, 1982, 2004; Collcutt, 1990; Bordes, 2003) and was systematically applied to the entire EF-HR assemblage (i.e., the 12 trenches presented in de la Torre et al., submitted), although refitting was successful only in T12 and T2-Main Trench. Refit analysis has a well attested decreasing return of effort (e.g., Cziesla, 1990), so considering the number of analysts involved (*n* = 4) and their time spent on refitting, it was decided to invest 100 hours in total for the conjoin study.

<u>Spatial analysis</u> Artefact density and the basic analysis of point patterns started with visual identification of the density of artefact distribution on the excavation surface. In order to produce kernel density surfaces, we used a geo-algorithm to create a raster surface of artefact intensity, through the placing of a two-dimensional probability density function (kernel) across the observed data points (Conolly and Lake, 2006). The optimal bandwidth was

calculated in a statistical package –function *bw.diggle* in R (Ihaka and Gentleman, 1996)– and used to ensure that the actual distribution was represented.

Cluster analysis included nearest neighbour analysis and Ripley's K-function to investigate presence/absence of clustering. Where clustering was confirmed, cluster membership was identified via k-means analysis, as EF-HR datasets are too large (>100) for traditional, hierarchical cluster analysis. Since the k-means method requires a set number of clusters, optimal numbers of clusters were obtained by comparing k-means optimum cluster and PAM (partitioning around medoids) methods with kernel density maps. K-means optimum examines the rate of decrease in the sum of squared distances over increasing number of clusters; the optimum number of clusters is when a significant decrease in the total sum of squares can no longer be observed (MacQueen, 1967; Ripley, 1976, 1981; Kaufman and Rousseeuw, 1990).

A digital elevation model (DEM) of T2-Main Trench was calculated with kriging from field recorded points on the surface of clays in Trench 2, with 20 mm cell size and smoothened by focal statistics in a circular window of five cells. Five elevation ranges were defined following Jenks' natural breaks method. The slope map was developed from the surface of the DEM and divided into five ranges with Jenks' natural breaks method. A flow direction map was also extracted from the DEM, by assigning a value to each cell depending on the direction water would flow if dropped on the cell. A probability surface model was calculated by considering kernel density in conjunction with four other variables (i.e. elevation, slope, flow direction, and flow accumulation [number of upstream cells draining into each cell]). This model was then tested against spatial randomness (Poisson) with K-means function, as well as a pair correlation function (within the multivariate bounds of the model), and compared to an envelope of 99 Monte Carlo simulation runs (Robert and Casella, 2004).

Orientation and dip were recorded during fieldwork with a compass and clinometer, respectively, on lithic and fossil remains larger than 2 cm that showed a recognizable longer than width axis. The sample was further adjusted for analysis to include only those artefacts whose elongation index (Ie = length/ width) was greater than 1.6 (n = 227) (Bertran and Lenoble, 2002; Benito-Calvo and de la Torre, 2011). Analysis of orientation patterns followed sample size and statistical protocols outlined by Bertran and Lenoble (2002) and Benito-Calvo and de la Torre (2011), and statistics and rose diagrams were produced using R (upper and lower closed intervals, comparative histograms) and Stereo32 software (linear and equal area scaling, circular histograms). Stereographic projections were produced using Stereo32. Fabric analysis followed the method proposed by Bertran and Lenoble (2002) and Benito-Calvo et al. (2009), and used a modified version of Tri-plot (Graham and Midgley, 2000) for calculations.

Orientation and fabrics of the clay surface were calculated from topographic surveys conducted during fieldwork. Dip was calculated for the surface model from the slope map and azimuth from the aspect map. For best results, two groups of watershed datasets were created. The first (underlying surface) was a dataset created by sampling the slope and aspect map of each watershed at the exact location of each artefact on the XY plane. The second (random sample) sampled each watershed at 50 random locations. Such an approach was employed to give an idea of how fabrics of the surface underlying each artefact dataset differed from archaeological fabrics and how that related to fabrics of entire watersheds.

Results

Stone tool taphonomy

Edge damage Roundness was analysed in 2032 stone tools, constituting 96.9% (n = 2097) of the combined assemblages of T12 (n = 232), T2-Main Trench (n = 1826), and T9 (n = 39) for Interval 1 (see breakdown of technological categories in de la Torre et al., submitted). Table 1 shows that artefacts are predominantly fresh (65.4%), although a small sample (2.6%) are severely rounded (Fig. 5A). Fig. 5B suggests uneven frequencies of roundness in each trench and the Chi-square test confirms a higher proportion of fresh artefacts in T12 (X^2 (6) = 20.41, $p < 0.05$) than T2-Main Trench and T9. Likewise, Fig. 5E shows a higher percentage of fresh material associated with the diamictite unit (see lithological description in de la Torre et al., submitted), which is statistically significant (X^2 (6) = 20.6, $p < 0.05$).

Significant statistical association (X^2 (6) = 74.57, $p < 0.05$) also exists between degrees of rounding and raw materials (Fig. 5C); most lavas preserve fresh (72%) or slightly rounded (18.3%) edges. Frequency of fresh metamorphic artefacts is lower (59.1%), while stone tools with slight (25.7%) or medium (12.4%) roundness are more abundant. In contrast, only 16.6% of chert edges are fresh and most rolled artefacts are chert; thus, when chert is removed from the sample (Fig. 5D), 87.7% of the remaining assemblage (n = 2008) is fresh (n = 1326) or slightly (n = 435) rounded.

Classifying artefact roundness into three length categories (Table 1 and Fig. 5F) indicates that 86% of artefacts >100 mm are fresh as opposed to 56% of stone tools <20 mm, with statistically significant differences (X^2 (6) = 57.87, $p < 0.05$). The same pattern is observed when roundness is considered according to weight classes (Fig. 5G): 81.8% of artefacts heavier than 50 g are fresh in contrast to only 57.6% of those <5 g. The Chi-square test (X^2 (6) = 106.57, $p < 0.05$) confirms higher than expected proportions of slightly rounded artefacts less than 5 g and fresh tools >50 g. Similarly, statistical comparisons of roundness according to general technological groups (X^2 (6) = 45.37, $p < 0.05$) also show that larger artefacts (e.g., large cutting tools [LCT]) are consistently fresh (91.9%), while frequency of fresh edged debitage is reduced to 63.7% (see also Fig. 5H).

Presence/absence of edge microfracturing was recorded in 1117 artefacts (53.2% of the assemblage). The Chi-square test (X^2 (2) = 2.4, p <0.05) found no significant differences across the three trenches, although the T9 sample is considerably smaller (see values in Table 1) and the comparison in Fig. 6A is focused on T2-Main Trench and T9. Fig. 6B illustrates the presence/absence of microfracturing in relation to raw material type, and clear differences can be observed between chert versus metamorphic and lava artefacts; thus, a significantly higher number than expected (X^2 (2) = 21.6, $p < 0.05$) of chert artefacts show edge wear when compared to the other raw materials. Although it might be reasonable to expect that presence of microfracturing was associated with the lithology in which artefacts were embedded, Chi-square (X^2 (2) = 2, $p < 0.05$) found no significant differences between artefacts in the conglomerate, diamictite, and clay (see also Fig. 6C and SOM S2).

Size distribution Average dimensions of the entire T12, T2-Main Trench, and T9 lithic assemblage (*n* = 2097) are listed in Table 2, which also indicates the absence of stone tools smaller than 5 mm and a significant size variability (as shown by the large standard deviation of maximum length). Fig. 6D considers the metric relationship between length, width, and thickness, and shows the very bladed (24.3%) to bladed (19.7%) dominance of artefact shapes (see values in Table 2). Distribution of weight classes according to Jenks' optimisation method shows that 81% of stone tools are <133.6 g (Fig. 6F). In parallel, incremental weight classes (Fig. 6E) indicate a clear bimodal pattern, with 27.9% of artefacts in the 1–5 g interval and 28% heavier than 50 g (see data in Table 3).

Maximum artefact length was classed in 10 (Fig. 7A-B) and 20 (Fig. 7C, E, G) mm intervals, using Jenks' natural breaks (Fig. 7D, F, H; see also Table 3 and SOM S3). 54% of stone tools are <40 mm (Fig. 7A-B, SOM S3), with predominance of artefacts <33 mm (46.4%, Fig. 7D) and of those in the 20–39 mm interval (36.6%, Fig. 7C, also Table 3). T12 contains a substantially higher frequency (30.1%) of artefacts <20 mm than T2 (15.8%) and T9 (12.8%). Conversely, the percentage of stone tools 40 mm or larger is very similar in T2 (47.4%) and T9 (46.1%), in contrast to T12 (34.9%, Table 3 and Fig. 7E and 6G).

Raw material patterns are also distinctive (Fig. 7I and 7J); only 6.7% of lava artefacts are smaller than 20 mm, as opposed to 29.5% of the quartzite assemblage. This pattern becomes more accentuated when the next size class (20–39 mm) is considered, showing that quartzite artefacts <40 mm are proportionally much more abundant (74%) than lava pieces (36.9%, see raw data in Table 3).

Refitting Only five refit sets were identified in the entire EF-HR assemblage (four sets from T2 and one set from T12), all consisting exclusively of two conjoining pieces (i.e., total refitted artefacts = 10). This results in a considerably low proportion of refits—i.e., 0.3% of the whole collection (*n* = 2317), 0.3% of Interval 1 at T2 (*n* = 1826), 0.8% in T12 (*n* = 232)—and a low yield rate—i.e., one refit every 20 hours (total time of refit analysis = 100 hours).

All refits are fractured artefacts. The mean direction of conjoining lines is 122–302°, and the average horizontal distance between conjoining artefacts in T2 is 3.32 m (min = 38 cm, max = 6.46 m, std dev = 2.69 m). Despite this considerably long horizontal distance between conjoining artefacts (see Fig. 8), all sets are well constrained vertically and are within similar elevation ranges as classed by the DEM (Fig. 9).

Spatial analysis of T2-Main Trench

Artefact density and clustering The kernel density estimation (non-parametric) produced a smooth approximation of data point distribution across the surface of T2-Main Trench (Fig. 10 and SOM S4). As visual examination suggests distinctive density peaks of remains (mostly in the NW and W parts of the trench), several tests were applied to examine whether or not the distribution is random or regular, and thus whether clustering exists. The nearest neighbour analysis (Clark and Evans' test) for all remains (R = 0.8699, $p < 2.2e^{-16}$), stone tools (R = 0.8681, $p < 2.2e^{-16}$), and fossils (R = 0.8221, $p = 7.42e^{-12}$) suggests clustering (R < 1 at a high confidence level) of archaeological materials at T2-Main Trench, a pattern that was supported by the Ripley's K-function test (SOM S5A-C).

Once clustering was confirmed, cluster membership was assigned through k-means analysis, and the results of k-means optimum cluster numbers (four clusters for all data and lithics, and five for fossils; see SOM S5D-F) and PAM (eight clusters for all data and lithics, and seven for fossils) compared with kernel density maps. Thus, clusters best reflecting density of remains were established at six for the entire assemblage and for the stone tools, and five for fossils (SOM S5G-I).

Statistical confirmation of clustering also enabled us to examine the spatial distribution of lithic artefacts according to particular attributes such as edge roundness, chaîne opératoire technological category, and raw material. These attributes were tested with Clark and Evans' nearest neighbour test and K-function (SOM S6) to establish whether artefacts are distributed following the Poisson process or if there is any type of clustering or regularity (Table 4). This allowed identification of those attributes where both tests indicate non-randomness, and clustered datasets were then plotted as kernel density estimates (Fig. 11).

<u>Artefact distribution</u> Clustering patterns observed in T2-Main Trench may be due potentially to a genuine spatial attraction between particular artefact attributes (Fig. 9A), but may also be influenced by the surface (i.e., topographic properties) where remains were deposited. Three additional analyses (surface properties, hydrology, and probability surface) were performed to investigate this question. The first aimed to establish whether there was a preference in artefact distribution for certain values in properties of the surface (elevation, slope, and flow direction). The second considered the influence of hydrology in T2 (as amenable for study from spatial data recorded during excavation) in the spatial distribution of artefacts across the trench. The probability surface considered first and second order effects by calculating a log-linear regression model that explored artefact density based on all the aforementioned surface variables.

To analyse artefact distribution across several elevation ranges in T2-Main Trench, underlying elevation values from the clay surface DEM were assigned to each artefact, and artefact frequency in each elevation range was then calculated. These values were examined against the statistically expected number of artefacts in each elevation range and a Chi-squared value calculated to determine whether the difference in number is statistically significant.; As shown in SOM S7 and summarised in Table 5, there is a very strong correlation between elevation and density of remains, with lower altitude areas containing significantly more artefacts than expected, a pattern particularly accentuated among stone tools smaller than 34 mm.

Slope values underlying artefacts were also calculated and assigned to several slope ranges. As with elevation, frequencies were then tested against the expected values. Results (Table 5 and SOM S7) show that all archaeological remains tend to concentrate on the lowest gradients. Although overall stone tool distribution does not correlate with slope (but fossils do), a strong correlation is observed between artefacts larger than 33 mm and lowest slopes, particularly those of Jenks' length classes 2, 3, and 5.

The Trench 2 flow direction map (Fig. 9D) was used to investigate the impact of water flow direction on the distribution of artefacts across the site. The number of cells flowing in each of the eight directions from Fig. 9D (N, NE, E, SE, S, SW, W, and NW) was determined, and by calculating the percentage of each direction on the map, it was possible to estimate the expected number of artefacts overlying the flow direction map in an even distribution. There was a significantly larger than expected number of remains (particularly stone tools) in the W and SW flow directions (SOM S8 and Table 5). Correlation is particularly strong between such flow directions and lithic artefacts larger than 33 mm, as well as between stone tools from the small debitage chaîne opératoire and the W flow direction.

The relationship between elevation, slope, flow accumulation, and flow direction was further explored in the probability surface of Fig. 12A. The observed function appears outside the critical envelope of randomness and is, therefore, statistically significant (Fig. 12B). Artefact distribution is thus a product of multiple factors, the strongest of which are elevation, slope, and flow accumulation.

Orientation and fabric patterns

<u>Artefact orientation</u> Rayleigh's and Kuiper's tests to distinguish uniform (i.e., isotropic) distribution from non-uniform (multimodal, bimodal, or unimodal) patterns of T2-Main Trench artefacts are shown in Table 6. This includes the entire assemblage (lithics and fossils) and a series of subsamples based on artefact characteristics (e.g., stone tool weight classes, abrasion, particular categories such as LCTs), lithological—e.g., sedimentary context (gravels, sands, or clay) or areas with concentration of carbonates—and topographic structures observed during the excavation (see locations in Fig. 2), and spatial features defined by geostatistical methods (see Fig. 9).

Both Table 6 and the rose diagrams in Fig. 13 suggest plurimodal distributions of artefact orientation. Rayleigh's test confirms lack of unimodal distribution in all cases, and Kuiper's results are significantly opposed to uniformity of datasets. Although in some cases (e.g., bones, East channel, Cluster 4 datasets) the main and secondary mode can be distinguished, results are statistically weak due to small sample sizes (see Table 6). In those datasets where the sample is larger (n = 40–50 or above), modes are less pronounced, although patterns can still be distinguished. Thus, the main mode for the whole assemblage (n = 227), stone tools (n = 147), and fossils (n = 80) is on the N-S axis. Smaller datasets are also patterned, as evident in Cluster 3 (NW-SE mode), Cluster 4 (both N-S and NW-SE modes), Cluster 6 (E-W with a strong secondary mode of NW-SE), Northern channel (NW-SE with a secondary mode in N-S), LCTs (N-S mode), stone tools in diamictite/sands/gravels (NE-SW with secondary mode in N-S), and others (see Table 6 and Fig. 13).

Overall, a particular orientation trend for the entire assemblage (all analysed fossils and lithics) does not exist and a plurimodal (but not entirely random) distribution of orientations predominates. The visual investigation of rose diagram patterns (Fig. 13) in specific datasets enables us to distinguish two main directions (N-S and NW-SE); in some cases (e.g., West channel, watershed 5), the main mode is pronounced and indicates a clear orientation pattern in particular spatial locations (e.g., channels, clusters, and watersheds) of the trench (see below).

<u>Artefact fabrics</u> Although Curray's (1956) L values (Table 7A) are unsuitable for studying bi- or plurimodal distribution of orientations, they provide a proxy (particularly where very high p-values are obtained) of no strong linear tendencies in any fabric dataset. The mean vector R% index (also in Table 7A) shows some (weak) indications of linear orientation, although

the higher values correlate with smaller sample sizes and, therefore, results should be considered with caution. The same pattern occurs in K (shape) values (Table 7C), which are usually well <1. When K>1, results (apart from the Watershed 5 dataset) can be linked again to sample size being below the standard (n = 50). The C (strength) parameter shows mainly moderate and low strength fabrics, and it only reaches higher values (within assemblages with an appropriate sample size) in fossil and Cluster 3 datasets (Table 7C).

When isotropy (IS) and elongation (EL) indices (Table 7C) based on the Eigenvectors (Table 7B) are represented on Benn's (1994) diagrams, a strongly planar tendency of fabrics is observed (Fig. 14). Thus, most datasets fit well in the planar fabrics sector, with a considerable degree of isotropy in some cases. The only clear exceptions are stone tools with edge microfracturing on clays, plus Cluster 5, Watershed 5, the area of carbonates, and the Eastern channel, all of which are characterised by higher isotropy and a tendency toward linear (rather than planar) fabrics. Once again, however, sample size is low in some datasets (see Table 7) and, therefore, they cannot be taken as true indicators of the nature of fabrics.

Orientation and fabrics of the T2-Main Trench clay surface The geospatial classification of T2-Main Trench into watersheds (Fig. 9E) provides full coverage of the surface and insights into site hydrology (Fig. 9F), and enables investigation of the relationships between archaeological fabrics and fabrics of the trench surface (Figs. 15 and 16). The two sets of Curray's vector magnitude (L) values (see table in SOM S10) were compared in a linear regression, and results show no strong correlation between L values of artefact datasets and L values of the underlying surface (R^2 correlation coefficient = 0.386, or 0.2325 if adjusted to four degrees of freedom).

As shown in Fig. 16, archaeological fabrics are placed in approximately the same area as watershed fabrics in terms of linearity and isotropy. The only exception is Watershed 5, where archaeological fabrics are considerably more isotropic. A comparison between Watershed 5 fabrics and the other watersheds together (Fig. 16H) confirms singularity of this cluster, and therefore further comparisons including additional variables (stone tool, LCT and fossil frequencies, roundness stages, and length and weight classes) were made; the Kolmogorov-Smirnov test (D = 0.064, p-value = 0.00614) indicates a strong difference between Watershed 5 and the other watersheds combined, and the t-test (p = 0.0003387) supported that the two samples are statistically different (normal distribution confirmed by Shapiro-Wilks test: Watershed 5 p-value = 0.3608, Watersheds 1–4 p-value = 0.7971), which is also sustained by the Mann-Whitney test (W = 26, p-value = 0.001011).

To further investigate relationships between clay topography and artefact distribution, watershed (Fig. 9E), flow accumulation (Fig. 9F), and aspect (Fig. 9G) maps were used to calculate the mean stream direction (i.e., the mean direction of stream vectors for each stream network) and mean aspect (i.e., mean of all cells in the aspect map of each watershed; Fig. 17A, Table 8). Results were then compared to artefact orientation in each watershed and channel (Fig. 17B and D, respectively). Results show a slightly transverse position of the artefact mean mode with regards to the mean direction of each watershed and fieldwork observed incision surfaces. This pattern is particularly evident in the Eastern channel (see location in Fig. 2B-C in this paper and Fig. 8C in de la Torre et al., submitted).

Interpretation of results

Part of the fossil assemblage from EF-HR is clearly derived, as evidenced by the presence of very rounded bone fragments that behaved as clasts within the conglomeratic deposit documented at the site (see details in de la Torre et al., submitted). While other fossil remains can be more confidently related to human action, overall poor bone preservation hinders a systematic taphonomic study, and such analysis relies on an interpretation of the lithic assemblage. As shown above, most EF-HR stone tools are in fresh condition and part of the slight rounding observed on some lithics could be due to weathering, rather than fluvial abrasion. A small fraction of the assemblage is severely abraded, an observation also reported by Leakey (1971) during the original excavations. Heavily abraded artefacts are mostly chert (which is very rare in the EF-HR assemblage) and small in size. Thus, it is very likely that heavily abraded artefacts have no connection with the bulk of the EF-HR assemblage and, like bone clasts, were a component of the conglomerate in which part of the assemblage is embedded.

Leaving the heavily abraded material aside, there are still materials with rounding and microfracturing that clearly indicate fluvial agency in the formation of the site. Results indicate that edge rounding is higher among artefacts embedded in the conglomerate, as opposed to those in clays and the diamictite unit. While lithological features of the site are presented elsewhere (de la Torre et al., submitted; Stanistreet et al., submitted), this all seems to suggest that abrasion is mostly related to the conglomerate unit. A clear pattern is also observed in the presence of edge damage according to artefact type; nearly all LCTs are fresh and virtually none are moderately or severely abraded. Some of these LCTs have very thin and delicate edges that nonetheless are in remarkably mint condition (see example in Fig. 3), so it is unlikely that they underwent any post-depositional modification. On the other hand, frequency of fresh artefacts is lower in smaller and lighter stone tools and, therefore, rearrangement of some of them is more plausible.

Artefact size results are particularly relevant in assessing the extent of such fluvial rearrangement. The smallest artefacts predominate in unsorted experimental assemblages (Schick, 1984; Bertran et al., 2006) but, albeit present in EF-HR, <20 mm debris are outnumbered by larger sized lithics. The virtual absence of microdebitage—i.e., pieces <2 mm (Dunnell and Stein, 1989) or <1 mm (Fladmark, 1982)—and the relatively modest frequency of debitage <20 mm thus suggests sorting processes that washed away the smallest fraction of the stone tool assemblage. This is also consistent with weight distribution; in fluvial contexts, light artefacts (<1 g) travel greater distances and settle at slower rates than heavier ones (Byers et al., 2015). This agrees with the bimodal pattern shown by the EF-HR assemblage, where dominance of the 1–5 g group could be interpreted as the threshold for entrainment of artefacts and where the other peak (artefacts >50 g) may represent the bulk of a lag deposit.

Once it is concluded that the EF-HR assemblage underwent fluvial disturbance, spatial patterns of T2-Main Trench can be used to interpret post-depositional mechanisms. Our geospatial results indicate unambiguously that the archaeological material is clustered (i.e., artefacts are not randomly distributed across the trench). Statistical tests also show strong correlation between density of artefacts and lower altitude and gradient areas. The deepest areas were informally termed ‘channels’ during fieldwork and interpreted as the lowermost parts of an incision surface/s eroding the clay paleosurface beneath the archaeological units. GIS-based hydrology models support such an interpretation of the paleosurface, and geostatistics indicate that artefact density is higher within such depressions. The most plausible interpretation is, therefore, that archaeological material was accumulated preferentially in the deepest areas by natural agents.

Orientation and fabric patterns are essential in developing this interpretation further. Orientations do not show preferential arrangement for the whole EF-HR assemblage, which is not surprising given the intricate paleo-topography of the clay substrate. Thus, when rose diagrams are considered according to spatial clusters, preferential patterns can be discerned (Figs. 13 and 18), with bimodal orientations in particular areas probably associated with fluvial rearrangement of local zones across the trench. Likewise, while fabrics of the entire assemblage are predominantly planar, some differences are observed per area; artefact fabrics in the carbonates area lie almost ideally in the centre of Benn's diagram, with no inclination towards any fabric type. Artefacts in the carbonates area (and in the geostatistically defined Watershed 5) are comparatively less abraded than those in the rest of the trench, which is consistent with fabrics, and thus could suggest this to be the least disturbed part of T2-Main Trench. In contrast, the east channel, which shows the strongest preferred orientation, also shows a strong tendency towards a linear fabric, and its dense concentration of materials is likely due to fluvial accumulation. In this regard, transverse position of artefacts in relation to the mean direction of watersheds (a pattern particularly conspicuous in the east channel) might suggest rolling of artefacts along their shorter axis (Allen, 1984), and potentially indicate water flow with enough energy to move larger artefacts.

Overall, there is enough evidence to confirm fluvial processes played a significant role in shaping the structure of the archaeological record in T2-Main Trench, and some spatial proxies suggest that the densest artefact accumulations across the trench were influenced (or caused) by water action. Variability in the distribution of archaeological occurrences receives further support when T2-Main Trench and T12 patterns are compared. Artefact taphonomic proxies such as rounding (Fig. 5B) and size (Fig. 7G) consistently show lower disturbance in T12, which yields more fresh stone tools and higher frequencies of small lithics than T2-Main Trench. In addition, a brief overview of the main spatial features of T12 (Fig. 19 and SOM S11) indicates a more random distribution of artefacts, a different orientation pattern (with an NE-SW main mode, in contrast to the N-S main mode in T2-Main Trench), and a more linear fabric (mostly planar in T2-Main Trench). All of this essentially supports the conclusion that water rearrangement was not uniform across the main EF-HR exposure and that it operated locally throughout the site, resulting in variable occurrences with disparate degrees of fluvial disturbance.

Discussion

Mary Leakey (1971: 124) proposed that the EF-HR assemblage originally lay on the clay surface and that later some material was caught up in the lower part of the conglomerate. She also identified a fluvial channel cutting across the excavation surface and proposed that the assemblage represented the living floor (Leakey, 1971: 258) of a temporary camp on either side of a shallow water course (Leakey, 1971: 124). Our results partially agree with Leakey's. The remarkably fresh condition of most of the lithic assemblage (which includes many delicate edges sensitive to any post-depositional damage) suggests that most stone artefacts did not undergo substantial transport, nor were they abraded in situ by flowing water sediment. The freshest artefacts at EF-HR are often associated with carbonate growth also found across the clay surface (see details in de la Torre et al., submitted) and there seems to be a different spatial patterning of areas with carbonate clusters when compared to the rest of the trench. Thus, it is probable that artefacts associated with such a context belong to the original primary deposition of the assemblage. Nonetheless, subsequent fluvial disturbance is evident. Leakey (1971) stated that the channel she identified was aligned E-W, and given that we excavated on either side of her trench, it is likely that our east channel (roughly equivalent to Watershed 3.1) and west channel (Watershed 3) are a continuation of both ends of Leakey's channel. In our view, however, the stream bed forms identified are responsible for the rearrangement of the EF-HR remains, i.e., they are posterior to the original deposition of the assemblage. Therefore, hominins did not occupy a floodplain on either side of a channel, but fluvial agents contributed through substantially rearranging an earlier human occupation of the site that, as shown elsewhere (de la Torre et al., submitted), was located at the bottom of a river valley.

Three plausible scenarios could explain the formation history of the EF-HR Interval 1 assemblage. One is that the original assemblage was deposited in primary position on the clay paleosurface, after which carbonates grew over the clay surface and artefacts laying on it. Subsequently, the archaeological assemblage would have been buried by mudflows (diamictites) and potentially by low energy water flow, facilitating the excellent preservation of stone tools. Subsequent fluvial incision removed the smallest lithic artefacts and rearranged part of the larger material, which was accumulated in the more deeply eroded areas of the clay surface. In this scenario, fluvial disturbance operated locally (which would explain the non-random distribution of artefacts in some areas and the pristine stone tool preservation in others) and was moderate (i.e., it did not significantly alter assemblage composition of artefacts >20 mm). A second scenario envisages the archaeological assemblage transported from its original position elsewhere into EF-HR by mudflow processes; as viscous deposits, diamictites could have moved the artefacts without causing abrasion and might also explain the relatively polymodal orientation patterns observed. Since mudflows are characterised by low transport distances, the diamictite could have rearranged archaeological pieces into a near original position. This artefact bearing mudflow deposited over the clays would then be eroded by fluvial processes in essentially the same way as described for the first scenario. Alternatively, a third option would be the total rearrangement of the entire EF-HR assemblage by fluvial processes, placing all of it in secondary position. In this view, water disturbance would have been responsible for dismantling original human occupations elsewhere in the area, and the EF-HR assemblage would be a palimpsest comprising materials from several transportation episodes from long (heavily eroded artefacts) and shorter (fresh artefacts) distances.

The last scenario is highly unlikely, partly because most material is too fresh to have been transported by water for any long distance. More importantly, some of the EF-HR Interval 1 material was clearly embedded in (and sealed by) diamictite deposits, confirming that at least part of the material was deposited before fluvial rearrangement took place. Given that once heavily rolled materials are excluded the lithic assemblage is very consistent in terms of artefact preservation, raw materials, and technological categories irrespective of their lithological context, it is therefore improbable that the entire assemblage represents a secondary deposit. In addition, some refit sets (sets #4 and #5: see Fig. 8) conjoin pieces on top of the clays with others found in sands, which further reinforce Leakey's original idea that some materials were eroded from the top of the clays and caught by the conglomerate. Choice of one of the two other formation scenarios is more ambiguous. The second hypothesis that the assemblage was transported by mudflow processes is certainly possible; the patchy preservation of diamictites could be due entirely to subsequent fluvial incision, as carbonates on top of artefacts next to the clays were probably caused by groundwater precipitation affecting artefacts at the bottom of the mudflow deposit and close to the impermeable clay unit (see details in de la Torre et al., submitted). Nonetheless, we favour the first scenario (materials originally deposited on clays and buried by mudflows), as there are artefacts lying directly on the clay and (more rarely) inside the first few centimetres of clays, the diamictite unit is not pervasive over the excavated area (but the clay surface is), and there is consistency between better preservation, proximity to the clay paleosurface, and carbonate growth over both artefacts and clays.

Considering all the evidence, we propose that hominins occupied the river valley where EF-HR is located and left behind a large assemblage of stone tools and bones deposited on the lacustrine floodplain clay land surface. The assemblage was then buried by mudflows and, potentially, by flowing water, which may have contributed to partially rearranging the site, but which probably did not alter significantly its original configuration. Afterwards, higher energy water flows eroded mudflows and incised the clay paleosurface further, removing the smaller artefacts, redepositing part of the materials within stream shaped depressions, and generally rearranging the original position of a significant part of the assemblage. The extent of such rearrangement is difficult to evaluate and probably varied locally. Water energy was high enough to deposit natural cobbles with a mean size of 8 cm (see details in de la Torre et al., submitted), bone clasts, and some heavily rolled artefacts in EF-HR. Water flow thus explains the lack of microdebitage and the underrepresentation of smaller artefacts, which were washed away from the site. Heavy weathering of bones could partially be explained by water action, but other agents such as subaerial exposure and chemical decay due to particular mineralogical features of the embedding sediment could also have contributed, for most of the stone artefacts show no fluvial abrasion. In fact, the mint condition of many artefacts (including nearly all LCTs) suggest that if rearranged, stone tools were not transported for long distances. On the other hand, the extremely low number of refits may point to partial dismantlement of the assemblage, although it could also be partially explained by behavioural fragmentation of the technological chaînes opératoires (de la Torre and Mora, submitted). Likewise, although refits can exist even in heavily disturbed assemblages (Schick, 1982), long distances of conjoining artefacts across T2-Main Trench hint at least to the cohesion of the archaeological assemblage.

The degree of postdepositional disturbance of T2-Main Trench is also relevant to our interpretation of the wider EF-HR landscape. As discussed elsewhere (de la Torre et al., submitted), there is a conspicuous difference in artefact density across the 12 trenches excavated in the EF-HR area, with nearly all material clustered around T2-Main Trench and immediately adjacent trenches (T9 and T12). Comparisons of the altitude of the clay unit and archaeological units across the EF-HR landscape show that topographically T2-Main Trench is not particularly lower than any other trench and, therefore, it is unlikely that the main outcrop functioned as a local depocenter that accumulated materials from its surrounding area, as the third scenario discussed above would imply. Thus, we conclude that the artefact density peak around T2-Main Trench should have a behavioural meaning; hominins accumulated a considerable number of stone tools in the vicinity of T2-Main Trench and adjacent trenches, regardless of the post-depositional processes that would eventually rearrange the assemblage. This includes an outstanding number of LCTs, which is in fact the largest concentration of Acheulean handaxes so far documented in Olduvai Bed II. The technological behaviour underlying such accumulation is discussed elsewhere (de la Torre and Mora, submitted).

Conclusions

The palimpsest nature of most of the ESA record continues to be widely discussed (e.g., Stern, 1993; Malinsky-Buller et al., 2011) and the impact of post-depositional processes on the formation of Olduvai assemblages has long been recognised (Leakey and Roe, 1994; Petraglia and Potts, 1994; de la Torre and Mora, 2005b; Benito-Calvo and de la Torre, 2011). The aim of this paper has been to contribute to this discussion on the role of natural agents on site formation by analysing the emblematic site of EF-HR. For many years considered one of the earliest Acheulean sites in the world, EF-HR was interpreted by Leakey (1971) as an example of living floors with pristine human occupations. However, our study has concluded that EF-HR is a palimpsest shaped by a number of post-depositional processes and, potentially, also behavioural events. These conclusions are based on a taphonomic analysis of stone tools and study of the spatial patterns of fossils, lithic artefacts, and topographic features of the site. Characteristics of the stone tools suggest that the assemblage did not undergo heavy post-depositional disturbance, but spatial analysis clearly shows that rearrangement of materials took place, with clustering of artefacts caused by water action in incised depressions alongside areas with random (and probably near to) pristine distribution. On this front, our recent fieldwork at EF-HR highlights the opportunities provided by large scale excavations, which enable exploration of spatial patterns of site formation processes that otherwise would be more narrowly understood.

This paper has also contributed to a better understanding of the EF-HR landscape. Although definitely affected by fluvial disturbance, the artefact cluster in the main EF-HR outcrops still seems to represent a density anomaly in the wider landscape. As discussed elsewhere (de la Torre et al., submitted), the large size of the archaeological site sampled in T2-Main Trench and adjacent trenches contrasts sharply with the low density of materials elsewhere. Thus, the main EF-HR outcrop features a large accumulation of handaxes and other stone tools that cannot be explained (at least exclusively) by abiotic causes; hominins were making and discarding a huge number of lithics, amounting to well over 250 kg—OGAP (de la Torre and Mora, submitted) and Leakey collections (de la Torre and Mora, 2005) included. Given the substantial area still unexcavated—and probably equally productive (see de la Torre et al., submitted)—it thus seems necessary to recognise that the input of natural agents to the formation history of EF-HR does not preclude the search for behavioural causes to explain such a remarkable accumulation.

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Figure captions

Figure 1. A) Location of EF-HR at Olduvai Gorge and aerial view of the EF-HR outcrop. B) Plan view of trenches T12, T2-Main Site, and T9 at the main EF-HR outcrop. Off-trench elevation model from aerial photography digital elevation model (DEM) by Jorayev et al. (2016). Elevation models inside trenches refer to clays underlying plotted artefacts (see details in de la Torre et al., submitted). C) Stone tools and fossils from archaeological unit T12L20 plotted on the clay surface of T12. D) East-West cross section of artefacts and artefact density in T12. E-G) Large cutting tools (LCT) and debitage across the T12 excavation area. Arrows point to geographic North.

Figure 2. A) Orthomosaic model of T2-Main and T9, T2-Main Trench artefacts and stratigraphy overlain (see stratigraphic details in Stanistreet at al., submitted; de la Torre et al., submitted). B and C) T2-Main Trench after completion of excavations, with areas named during fieldwork. D-E) Cross sections of all artefacts (D) and artefact density (E) from the L1 and L2 archaeological units in T2-Main Trench.

Figure 3. Fossils and stone tools from Interval 1 at T2-Main Trench. A-B) Examples of heavily weathered fossils. Scale: 10 cm. C) Unabraded LCT during excavation. D-E) Close-ups of LCT in (C). D) Area boxed in (C). E) Detail of LCT tip and adjacent edges.

Figure 4. Plan view of T2-Main Trench Interval 1 artefacts on the clay digital elevation model. An interactive 3D model of this map is available in SOM S1A and a video-clip in SOM S1B.

Figure 5. Edge modification of Interval 1 stone tools in T12, T2-Main Trench, and T9. A) Edge roundness of all material combined. B) Edge roundness per trench. C) Roundness percentages per raw material. D) Edge roundness excluding chert. E) Roundness percentages per lithological context. F) Roundness according to artefact dimensions (three arbitrary maximum length classes). G) Roundness according to three arbitrary weight classes. H) Roundness per general lithic category (debitage: flakes and fragments, flaked/battered: cores and pounding tools, LCT). All data from Table 1.

Figure 6. A) Relative frequencies of edge microfracturing in T12 and T2-Main Trench. B) Microfracturing per raw material. C) Microfracturing per lithology. D) Sneed and Folk’s (1958) diagram of artefact shapes in Tri-plot (Graham and Midgley, 2000). E-F) Incremental (E) and Jenks’ (F) stone tool weight classes from T12, T2-Main Trench, and T9. Figure 6A-C: data sourced from Table 1. Figure 6D: data from Table 2. A shape diagram according to roundness values is available in SOM S2. Figure 6 E-F: data from Table 3.

Figure 7. Maximum dimension (length) of Interval 1 artefacts in T12, T2-Main Trench, and T9. A-B) Absolute (A) and cumulative (B) frequencies of the entire assemblage in one cm intervals. C) Standard length classes of the entire assemblage. D) Length classes of the entire assemblage according to Jenks' natural breaks optimization. E-F) Standard (E) and Jenks' (F) length classes per trench. G-H) Cumulative frequency of standard (G) and Jenks' (H) length classes. I-J) Standard (I) and Jenks' (J) length classes per raw material (chert is excluded due to low counts). All data from Table 3.

Figure 8. Conjoining artefacts in T2-Main Trench. A) Dorsal and platform views of Set #3, refit of two phonolite flake fragments of LCT chaîne opératoire (C.O.). B) Dorsal and ventral views of Set #5, refit of a quartzite flake of LCT C.O. C) Plan view of refit sets in T2-Main Trench. D) Cross sections of refit lines in T2-Main Trench. E) Dorsal and ventral views of Set #4, quartzite flake with transversal fracture.

Figure 9. A-G) GIS maps based on the paleosurface of clays at T2-Main Trench: A) Artefact clusters calculated through k-means and PAM analysis, B) digital elevation model with underlying hillshade and elevation ranges, C) slope and slope ranges used in the analysis, D) flow direction with direction coding, E) watersheds, F) flow accumulation, G) aspect map. H) Areas defined in T2-Main Trench during fieldwork (i.e., not through geostatistics), overlain on the hillshade map (see also Fig. 2).

Figure 10. Kernel density maps of T2-Main Trench per mm^2. Further density plans of other artefact attributes are available in SOM S4.

Figure 11. Kernel density (intensity) with optimal bandwidth of stone tools where there is agreement between the nearest neighbour and K-function tests in artefact clustering (see results in Table 4).

Figure 12. A) Probability surface of T2-Main Trench: a log-linear regression model based on elevation, slope, flow direction, and flow accumulation. Intensity of artefacts is represented by colours from blue (minimum) to yellow (maximum). B) K-function and pair correlation function of the probability model (black) with Poisson line of spatial randomness (red) and the critical envelope of 99 random runs (grey).

Figure 13. Circular histograms of T2-Main Trench (see Table 6 for details of each dataset and SOM S9 for the correspondent stereograms).

Figure 14. Benn’s diagrams of T2-Main Trench. A) Entire assemblage compared with fossil, stone tool, and LCT fabrics. B) Fabrics of stone tool weight classes (as defined in Table 7). Stone tool fabrics according to C) rounding and D) microfracturing. E) Stone tool fabrics by lithology. F) Artefact fabrics according to areas identified through field observations. G) clusters defined geostatistically in Figure 9A and H) watersheds defined geostatistically in Figure 9E.

Figure 15. Circular histograms comparing archaeological fabrics and fabrics of the clay surface at T2-Main Trench.

Figure 16. Comparison of archaeological fabrics and the fabric of the underlying clay surface.

Figure 17. A) Stream networks and mean direction by geostatistically defined watersheds. B) Orientation of artefacts in watersheds, and mean aspect (red) and mean direction of the stream network (blue). C) Main stream networks of channels (identified through field observations). D) Rose diagrams of the strike direction of artefacts in channels compared to mean direction of stream networks (in red). Mean stream direction and aspect values from Table 8.

Figure 18. T2-Main Trench rose diagrams in artefact clusters calculated through k-means and PAM analysis (A) and in deeply incised areas (‘channels’) identified through field observations (B).

Figure 19. Spatial patterns of archaeological remains and fabrics in T12. A) K-function of the entire sample (n = 44), lithics (n = 28, middle), and fossils (n = 16), with theoretical complete spatial randomness (red) and a critical envelope of 999 random runs (grey). Although the functions differ from the Poisson line, they do not lie significantly outside the envelope of random simulations and therefore do not indicate artefact clustering. B) Orientation patterns of T12. Results of Rayleigh’s and Kuiper’s tests (SOM S11) reject uniformity of orientation distribution and the existence of a unimodal distribution. C) T12 fabrics and comparison with T2-Main Trench fabrics (see SOM S11 for statistical tests).