The contexts and early Acheulean archaeology of the EF-HR palaeo-landscape (Olduvai Gorge, Tanzania)

Ignacio de la Torre[1], Rosa M. Albert[2,3], Richard Macphail[1], Lindsay McHenry[4], Michael Pante[5], Ágata Rodríguez-Cintas[3], Ian Stanistreet[6,7] and Harald Stollhofen[8]

[1] Institute of Archaeology, University College London, 31-34 Gordon Square, WC1H 0PY London, United Kingdom

[2] ICREA, Pg. Lluís Companys 23, 08010 Barcelona, Spain

[3] Departament de Historia i Arqueologia, Universitat de Barcelona. Montalegre 6-8, 08001 Barcelona, Spain

[4] Department of Geosciences, University of Wisconsin- Milwaukee, 3209 N. Maryland Ave., Milwaukee, WI 53211 USA

[5] Department of Anthropology, Colorado State University, 1787 Campus Delivery, Fort Collins, CO 80523 USA

[6] Department of Earth, Ocean and Ecological Sciences, University of Liverpool, Brownlow Street, Liverpool L69 3GP, United Kingdom

[7] Stone Age Institute, 1392 W Dittemore Road, Gosport, Indiana 47433, USA.

[8] GeoZentrum Nordbayern, Friedrich-Alexander-University (FAU) Erlangen-Nürnberg, Schloßgarten 5, 91054 Erlangen, Germany

[1]Corresponding author: i.torre@ucl.ac.uk (I. de la Torre)

Abstract

Renewed fieldwork at the early Acheulean site of EF-HR (Olduvai Gorge, Tanzania) has included detailed stratigraphic studies of the sequence, extended excavations in the main site, and has placed eleven additional trenches within an area of nearly 1 km^2, to sample the same stratigraphic interval as in the main trench across the broader palaeo-landscape. Our new stratigraphic work suggests that EF-HR is positioned higher in the Bed II sequence than previously proposed, which has implications for the age of the site and its stratigraphic correlation to other Olduvai Middle Bed II sites. Geological research shows that the main EF-HR site was situated at the deepest part of an incised valley formed through river erosion. Archaeological excavations at the main site and nearby trenches have unearthed a large new assemblage, with more than 3,000 fossils and artefacts, including a hundred handaxes in stratigraphic position. In addition, our test-trenching approach has detected conspicuous differences in the density of artefacts across the landscape, with a large cluster of archaeological material in and around the main trench, and less intense human activity at the same level in the more distant satellite trenches. All of these aspects are discussed in this paper in the light of site formation processes, behavioural contexts, and their implications for our understanding of the early Acheulean at Olduvai Gorge.

Keywords: Early Stone Age; East Africa; Bed II chrono-stratigraphy; Large Cutting Tools; landscape archaeology; Early Pleistocene

Introduction

EF-HR is one of the most emblematic archaeological sites in Olduvai Gorge, Tanzania. Discovered by Evelyn Fuchs and Hans Reck (hence EF-HR) in 1931, the site was originally excavated by Mary Leakey in 1963 (Leakey, 1971), and became the prime example of the early Acheulean at Olduvai. Although the estimated age of the site varied between 0.7–1.0 Ma (Leakey, 1971) and 1.4 Ma (Leakey, 1975), EF-HR was soon considered as paradigmatic in discussions on the emergence of handaxe technology (e.g., Gowlett 1979; Stiles, 1979), also attracting research interest in recent years (e.g., Kimura, 2002; de la Torre and Mora, 2005). Nonetheless, despite frequent references to EF-HR in the literature on early Acheulean origins, no fieldwork was conducted at the site for over four decades.

In 2009, the Olduvai Geochronology Archaeology Project (OGAP) renewed excavations at EF-HR, which continued until 2013. Objectives of the new fieldwork programme included refining the chronostratigraphic position of the site, investigating contexts and site formation processes, exploring the lateral extent of deposits and the wider palaeo-landscape, and retrieving fresh archaeological data to characterise the technological and subsistence strategies of Olduvai Gorge Early Acheulean hominins.

While Leakey (1971) positioned EF-HR as the earliest assemblage in Middle Bed II, Hay (1976) located the site higher up in the sequence, just below Tuff IIC. Revisiting the stratigraphic position of EF-HR was thus deemed essential to contextualise it better among other relevant Middle and Upper Bed II sites; our new results, which contradict earlier reconstructions, will be discussed in this paper. The archaeological context of EF-HR was only briefly touched upon by Leakey (1971), who assumed the site constituted a living floor largely in primary position; this and an accompanying study (de la Torre and Wehr, submitted) will discuss formation processes of EF-HR in the light of renewed excavations, highlighting the complexity of the site's history. Inspired by leading efforts to produce palaeo-landscape data in major palaeoanthropological localities (e.g., Rogers et al., 1994; Potts et al., 1999; Blumenschine et al., 2012a, 2012b), we combined large-scale excavations (sited to extend Leakey's trench at the main EF-HR trench) with test trenches across the same stratigraphic interval. While the large size and relevance of the lithic assemblage warrants a separate account (de la Torre and Mora, submitted), the main features of the fossil and stone tool collection unearthed by OGAP at EF-HR, and the meaning of their distribution, will be another major aspect discussed in this paper.

In summary, trench stratigraphic correlations, landscape reconstructions and a study of site formation processes based on spatial analysis, taphonomic signatures, and sedimentological features are presented in order to understand the dynamics that led to the accumulation of a large assemblage with some of the earliest Acheulean handaxes at Olduvai. Our aim in the present study is to provide a detailed account of the stratigraphic, contextual, and behavioural features of the wider landscape occupied by hominins during early Acheulean times at Olduvai Gorge.

Methods

Archaeological excavation

Based upon relative coordinates, a virtual grid was set up in the area of the main outcrop at EF-HR, and cemented reference stations were placed across the korongos of DK EE, EF-HR and MK W. This coordinate system was aligned with Leakey's trench at the main exposure of EF-HR, and therefore the northing (Y-axis) is at 320°, rather than geographic North. Although the relative coordinate system was used during the excavations, cemented reference stations were positioned with differential GNSS, and then the grid was transformed into absolute coordinates (WGS84), which is the reference for all maps shown here, apart from Figure 9A–C, where a UTM Zone 36S projection is used.

Excavation methodology included three-dimensional (3D) plotting with a total station of all artefacts unearthed and relevant geological features (e.g., lithological contacts and hence lithofacies geometries, claystone palaeo-surface topography, palaeo-environmental samples) and followed protocols detailed by de la Torre et al. (2015). Definition of archaeological levels was based on both the lithofacies context and vertical clustering of artefacts. Thus, some lithological units contained more than one archaeological level because of vertical gaps between artefact aggregations, while lateral changes of facies led on occasions to the inclusion of materials embedded in more than one lithological unit within the same archaeological level.

Stratigraphy and sedimentology

Stratigraphic sections in the vicinity of EF-HR were measured from the Lemuta Member to the base of Bed III where possible. These were initially measured to help identify the target interval so that satellite trenches could be sited. This means that the measured sections made use of natural exposures with minimal scraping, and that they pre-date the excavations. They are thus not always directly associated with a trench, and lack the sedimentological detail later achieved during the measurement of the trench backwalls. They are, however, sufficient to identify the major lithological units and their relative stratigraphic positions, and help to place the EF-HR land surface within the context of Bed II stratigraphy. A rock hammer was used to clear exposures, measurements were made using a Jacob’s staff (with level) and meter stick, and sedimentological observations were made using a hand lens.

Following excavation, the detailed stratigraphy of all trenches excavated in the EF-HR area was mapped on the backwalls and/or sidewalls of each archaeological trench, and lithological contacts were measured at cm-accuracy with a total station and positioned in the same reference system as the archaeological material.

Particular facies types were defined on the basis of grain size, sorting, fabrics, bedding, compositional, and grain characteristics, providing the basis for their process-related sedimentological interpretation. Lithostratigraphic units and facies associations were also classified as to whether they were bounded by conformable or incisional surfaces. Incisional surfaces were differentiated into Type I (pronouncedly incisional) or Type 2 (hiatal or slightly incisional). Time-rock units were then delimited according to the criteria employed by Stanistreet (2012), Blumenschine et al. (2012a, 2012b), and Stanistreet et al. (submitted), who have named such time-slices lake-parasequences.

Micromorphology

Sediment blocks and carbonates encrusted on artefacts were impregnated with a clear polyester resin-acetone mixture; samples were then topped up with resin, ahead of curing and slabbing for 75x50 mm thin sections (Murphy, 1986; Goldberg and Macphail, 2006). These were further polished with 1,000 grit papers and analysed using a petrological microscope under plane polarised light (PPL), crossed polarised light (XPL), oblique incident light (OIL) and using fluorescence microscopy (blue light – BL), at magnifications ranging from x1 to x200/400. Thin sections were described, ascribed soil microfabric types (MFTs), and counted according to established methods (Bullock et al., 1985; Courty et al., 1989; Courty, 2001; Macphail and Cruise, 2001; Stoops, 2003; Stoops et al., 2010).

Phytolith analysis

Eighteen phytolith samples were analysed, following the rapid extraction procedure developed by Katz et al. (2010). Quantitative analysis and morphological identification used an Olympus BX41 optical microscope with magnification of 200x and 400x, respectively. Morphological identification was based on our own reference collection (Albert et al., 2016; www.phytcore.org), as well as on relevant published literature from Africa (Alexandre et al., 1997; Runge, 1999; Bamford et al., 2006; Barboni et al., 2007; Barboni and Bremond, 2009; Mercader et al., 2009).

Artefact and fossil analysis

Bone taphonomy was mostly limited to inspection of cortical surfaces with the naked eye under a 60 W light source due to the overall poor condition of the fossils. However, following Blumenschine et al.'s (1996) methods, a more conventional technique of using a hand lens was employed when bone surfaces were well preserved enough to reveal surface modifications. Taphonomic data collected include bone weathering based on Behrensmeyer's (1978) criteria; the type of breakage – either green (indicated by spiral or feathered breaks), or dry (indicated by transverse breaks); and a general account of the condition of cortical surfaces as measured by exfoliation, rounding, and relative coverage by adhering matrix.

Classification of stone raw materials is based on McHenry and de la Torre (submitted). Technological analysis followed the distinction between detached, flaked and battered tools proposed by Isaac et al. (1997), and the definition of lithic categories is based on de la Torre (2011), and follows the results presented in de la Torre and Mora (submitted).

X-ray diffraction (XRD)

Fourteen sediment samples were collected from the backwall of T2-Main Trench to characterize the mineralogy of the individual units. Each sample was powdered by hand using an agate mortar and pestle, and then mounted as a random powder for analysis using a Bruker D8 Focus X-ray Diffractometer (Cu Kα radiation, 1 s per 0.2°2ϴ, 2°-60° range; methods of McHenry, 2009). Mineral phases were identified by pattern matching using Bruker's EVA software, comparing against the ICDD PDF-2 database. Abundances were qualitatively estimated using relative peak heights, and categorized as abundant (XXX), common (XX), between common and rare (X), rare (+), and absent (-).

Results

Archaeological trenches

Excavations began by extending the Leakey trench at the main EF-HR locality, and most of our fieldwork efforts concentrated there, at the trench named T2-Main Trench (see further details in de la Torre and Wehr, submitted). Regularly-spaced test pits were excavated following the main exposure eastwards (T9 and T13) and westwards (T12 and T15) of T2, and further trenches were randomly positioned in any other outcrops where the targeted stratigraphic unit (i.e., the brown claystone palaeo-surface) could be traced (Fig. 1; Table 1; Supplementary Online Material [SOM] S1). The furthest point where this stratigraphic interval could be followed is slightly less than 200 meters from the Main Trench, at T17 in the east and T10 to the west (Table 2).

In total, 12 trenches were dug between 2009 and 2013, spanning an area of c. 900 m^2, of which 151 m^2 were excavated. Most of the area exposed corresponds to the Main Trench (76 m^2) and immediately adjacent trenches (T15, T12, T9 and T13; each of them with an area of 8m^2), while the size of the outer trenches (see Table 1) was adapted to the local topography.

Trenches were normally deemed as completed when the brown waxy claystone palaeo-surface was fully exposed at the bottom of the excavation, although in some trenches (e.g., T2-Main Trench, T13), excavation continued in test pits to expose lithological units underneath.

Stratigraphic position

The middle to upper Bed II sections in the vicinity of EF-HR sit above the Lemuta Member, which locally consists of a series of cliff-forming orange-coloured aeolian tuffs, with some nodular carbonate and green claystone near the top (Fig. 2). These are followed by sandstones and a diamictite, underlying the 1–2 m thick brown claystone directly beneath the EF-HR archaeological level. The top boundary of this brown claystone is incised to varying degrees in the different exposures and trenches (Fig. 3). At EF-HR, conglomerate and diamictite sit directly on this surface, while to the west (at DK EE), a thin, highly weathered tuff directly overlies the clays, below the level of the diamictite. Based on Hay's (1976) stratigraphic correlations, this tuffaceous interval (which has been cut out at EF-HR by the incision into the top of the claystone) corresponds to the Tuff IIC interval. As most of the archaeological materials sit upon this incision surface, this material therefore likely post-dates the missing Tuff IIC interval, which places the EF-HR site within Leakey's (1971) Upper Bed II. This is in contrast with prior stratigraphic interpretations, which placed the archaeological assemblage below the level of Tuff IIC. Figure 4A shows this position of Tuff IIC.

The archaeological level is capped in some trenches by diamictites, with several stacked sandstone units in the top of the backwall at T2-Main Trench. This sandstone contains blocks of Tuff IID, confirmed by mineralogical and geochemical comparison to in situ Tuff IID compositions (McHenry et al., 2016). Tuff IID is not identified in situ in the local area, though eroded blocks of it are also found near the base of the sandstone body developed between EF-HR and DK EE (Fig. 2). Therefore, the base of the sandstone represents an incision surface cutting down through Tuff IID, a prominent marker in Upper Bed II at nearby sites JK (to the west) and Locality 34a (to the south). The base of the Bed III red beds lies four meters above the level of the Tuff IID-bearing sandstone at EF-HR. This incision surface could correspond to that recorded at Locality 11A (MK) as figured by Hay (1976, his Fig. 19), which also cuts pronouncedly through Tuff IID into the interval below. The disconformity at EF-HR, on which the artefact and bone assemblage lies, is therefore a major incision surface situated between Tuff IIC and Tuff IID.

The lack of quality radiometric dates for Bed II tuffs limits our ability to constrain the EF-HR interval temporally, though it certainly falls between the ages of Tuff IIA (within the Lemuta Member, below, dated to 1.72 ± 0.03 Ma by Manega, 1993) and Tuff IID (above, dated to 1.48 ± 0.05 Ma by Manega, 1993 and to 1.338 ± 0.024 Ma by Domínguez-Rodrigo et al., 2013).

T2-Main Trench was used as the reference for the stratigraphic succession, mineralogical, and particle size characterization (SOM S2, SOM S3), and soil micromorphology of archaeologically relevant units (SOM S4), given its thicker exposed sequence. At T2-Main Trench, the brown claystone unit is around 1.3 m thick and is overlaid by a sandy diamictite, which is then eroded by a conglomerate also incising the underlying claystones (see Fig. 5). Sandy and conglomeratic layers follow for over a meter, and are overlaid by a sequence of claystones and sandy diamictites. The top of the sandy diamictites interfingers with a claystone unit (see palaeo-landscape assessment below).

Sedimentary facies associations and environments of the EF-HR T2-Main Trench

The backwall and sidewall of the main EF-HR trench (i.e., T2) is shown in Figure 5. Sedimentary grain-size varies greatly throughout, ranging from cobble conglomerates to claystones. Individual facies identified are catalogued in Table 3. One type of lithofacies which appears in Table 3, but which has not been recognized previously to any great extent at East African archaeological sites and only recently at Olduvai Gorge (Stanistreet, 2012; Stanistreet et al., submitted), is the diamictite facies. These comprise massive, matrix-supported lithologies characterized by a wide spread of grain sizes from clays, which are dominant, to scattered matrix-supported cobbles and even boulders that were buoyant within the clay or sandy clay matrix. Based on variable contents of matrix volumes and matrix type, we further distinguish three subtypes: clay diamictites, sandy clay diamictites and sandy diamictites. We apply "diamictite" as a purely descriptive, non-generic term. Such facies are commonly interpreted as glacial or mudflow in origin, and the latter depositional mode pertains at Olduvai, although viscosity and flow behaviour vary, depending upon the diamictite type.

There are essentially two types of grain-supported sandstones, which are distinguished on the basis of their clay contents and bedding characteristics. The first type is a medium to very coarse volcaniclastic sandstone, rather free of detrital matrix, and frequently showing plane bedding or trough cross-bedding with gentle erosive basal contacts resulting in flat lenticular sedimentary bodies. This represents shallow ephemeral braided fluvial channel deposits. The second type is similar in detrital grain composition, but more poorly sorted with up to 7 vol. % of clay and silt matrix, and randomly distributed lithic and soft clasts. These sandstones are usually massive or, rarely, faintly flow laminated, which together with grain size and sorting characteristics count for their interpretation as hyper-concentrated streamflow deposits. These involve a transport mechanism transitional between mass flows and normal stream flows, and are characterized by high sediment loads (Pierson and Costa, 1987; Svendsen et al., 2012), common in active explosive volcanic terrains.

Brown waxy claystones are well to moderately sorted, show tabular geometries and are weakly plane bedded. Considering bedding and sorting characteristics and a dominance of smectite and interlayered illite/smectite, they are interpreted to represent suspension fallout in offshore saline alkaline lake settings. Sandy claystones, showing enhanced contents of sand-sized detrital grains are placed in a nearshore lake setting, which is affected by wave reworking and aeolian detrital input. At several levels within claystones, horizons of white micritic and small spherulitic calcite nodules are developed. These cross-cut the bedding planes and are frequently associated with burrowed and/or rooted levels in the host sediment, all together suggesting shallow sub-surface pedogenic overprinting (Bennett et al., 2012; Rushworth, 2012).

Conglomerates are usually clast-supported, erosionally based and form massive, lenticular bodies of granules to cobbles, some of which are incised and became stacked upon each other. They most likely represent multi-storey, braided river channel complexes.

Fine to coarse ash tuffs are very well sorted, and some are normally grain size graded and form rather thin but laterally persistent tabular units that drape underlying topography. Components include euhedral crystals and crystal fragments and compact to vesicular volcanic lithic and vitric grains, including pumice. Considering composition, geometry and contact relationships, the tuffs are related to fallout of volcanic ash in a medial to distal setting of a volcanic source upwind of Olduvai Gorge.

Depositional architecture of EF-HR T2-Main Trench and in situ assemblage preservation

The artefact and bone assemblage itself sits upon a pronounced regional incision surface cut deeply into claystones of Middle Bed II (Figs 2 and 3), but cutting also through horizons of pedogenic limestone nodules developed within that claystone. The first unit to initiate filling of that incision surface was a diamictite deposited by a viscous mudflow, mapped mainly on the sidewall of T2-Main Trench, but extending across the floor of the trench where it covered in situ archaeological materials. The propensity of mudflows, with their low shear stress bases, to preserve archaeological assemblages has been recognized in both Holocene (Harris, 2000) and Pleistocene Olduvai (Stanistreet et al., submitted) sites.

The next processes to affect the site were more destructive fluidal flows of rivers that eroded through the diamictites and, to an extent, into the underlying waxy claystones, locally reworking diamictite materials, limestone nodules, and archaeological items into its clast population. On the sidewall of T2-Main Trench, a pronounced channelform trending ~032°–212° cuts through the assemblage and the incision surface to concentrate both artefacts and natural cobbles in its conglomerate fill. Other channelforms characterize the incision surface along the backwall, but overall the <90 cm thick gravel unit is deposited as a broad braided fluvial channel complex system with width/depth ratio exceeding 13.8. Fluvial coarse to very coarse sands on top of the conglomerate fill the remaining incision surface, accreting to be preserved as a unit <60 cm thick.

At least six phases of fluvial incision and fill are recorded low in the backwall of T2-Main Trench, five of which are covered by gravel deposition, usually with fluvial sand accretion above. The last fluvial gravel is followed by a major shift in depositional style. A broad incision surface with low relief cuts across the underlying fluvials, followed and covered by the first of a series of diamictite and sandy diamictite couplets, each underlain by an incision surface. The highest couplet extends further cyclically to be succeeded by brown waxy claystone, indicating lake flooding of the area. Subsequently two incision-based sandy diamictite and brown waxy claystone couplets complete the cyclic record displayed in the

T2-Main Trench backwall.

We interpret the sequence to represent a series of cycles, each including a phase of lake withdrawal and base-level fall to generate the underlying Type II incision surface. This is followed by lake transgression to provide the rise in base-level (i.e., lake surface) in order to induce accommodation space for deposition of each cycle. Such fundamental time-slice units delimited by a single cycle of lake flooding and withdrawal have been designated lake-parasequences (Blumenschine et al., 2009, 2012a, 2012b; Stanistreet, 2012; Stanistreet et al., in prep.), a set of which might be contained within a "sequence" bounded by more pronounced Type I incision surfaces (see also Stanistreet et al, submitted). Two such sequences are recorded in the EF-HR Trench maps, one characterized mainly by the conglomerate and sandstone facies association (with subordinate diamictite units) below, the other characterized by the diamictite, sandy diamictite and brown claystone facies association above.

Following this interpretation, the conglomerate and sandstone fluvial facies association is linked to enhanced rainfall in the source area, the Ngorongoro Volcanic Highlands to the northeast of EF-HR. This would rapidly break down source rocks and carry clasts and grains into the Olduvai Basin. By contrast, the various diamictite facies and paleosol overprinting of the lake clay facies association indicate a drier phase in this part of East Africa. Hydrothermal alteration and/or chemical weathering within the volcanic source terrain produced voluminous clays, favouring mass flows. Rare heavy rainfall would produce flash-flood discharge of water, mixing with the clays, inducing viscous mudflows or lahars to rapidly inundate the Olduvai Basin.

Micromorphological soil characterization

Micromorphology of the top of the brown claystones (Fig. 6A–C) indicates that these are iron-depleted with approximately 45% mineral grains (poorly sorted coarse silt, fine to coarse sand size feldspar, basalt and volcanic scoria; see also SOM S3). Many thin burrows are observed, and formation features include occasional textural intercalations (associated with embedded grains/grano-striate b-fabric), while secondary features are composed of rare, very fine fissure infillings and void infilling of $CaCO_3$, and rare, impregnative iron-manganese. Thin section analysis of the overlying diamictite features a massive fine sandy clay matrix, with a fine crack microstructure, probably inherent to the sample (Fig. 6D). The diamictite is poorly sorted with fine to coarse silt, fine to very coarse sand, with few small clasts. There are occasional textural intercalations throughout the diamictite and rare clayey infills (~0.4mm wide), abundant thin to very broad (9 mm) burrows mixing less sand-rich clayey sediment and clay clasts (Fig. 6E–F), and excremental fabrics. Many fine impregnative micritic $CaCO_3$ nodules occur (Fig. 6F), within a sediment that is very poorly humic (1.66% LOI) and with a marked phosphate content (see SOM S3).

XRD analysis (SOM S2) shows that volcaniclastic materials (indicated by anorthoclase/sanidine feldspars and/or augite) are present in all units regardless of clast size, and that groundwater conditions were alkaline (indicated by the zeolites chabazite +/- phillipsite or erionite in all samples). Quartz is an unlikely juvenile component of the silica undersaturated Bed II volcanic materials (McHenry et al., 2016), thus its presence in all samples might indicate sediment sourced in part from basement quartzites or granites to the west or recycling of quartz grains from eroded older Bed I sequences. Smectite clay (montmorillonite) is present in all samples regardless of grain size.

Phytoliths

Phytoliths were present in most of the samples collected (T2-Main Trench, T9, T12, T13, T14, T15, T16 and T17), though they show varying degrees of weathering, which in some cases prevented a morphological identification. As a result, none of the samples reached a minimum of 50 recognizable morphotypes (Table 4). The dominant morphotype in most samples is short cells of the rondel type from the Poaceae family (grasses), probably from the C3 Pooideae subfamily (Fig. 7 A–B). These morphotypes are quite resistant to post-depositional and taphonomic processes (Cabanes et al., 2011). Blockys were the next most abundant morphotype, and probably derive from wood/bark of dicotyledonous plants (Fig. 7C). These were associated with other characteristic dicotyledonous plant phytoliths such as ellipsoid with rugose surface. We also identified bulliform morphotypes and trichomes, both from leaves of the Poaceae family (Fig. 7D). Tabular elongates with entire margin were also observed in some samples. These morphotypes appear commonly in the monocotyledonous group. In summary, although poor phytolith preservation hinders a reliable reconstruction of the vegetation, the few phytoliths recovered indicate that plants from both the Poaceae family (probably from the C_3 group) and ligneous dicotyledonous plants were present in the EF-HR area. Phytoliths characteristic of palms, which have been observed at earlier times at Olduvai Gorge sites (Bamford et al., 2006, Albert et al., 2009, Barboni et al., 2010), were not identified at EF-HR.

Position of archaeological remains

The archaeological material appeared in a range of lithological facies from the top of the brown claystone (which forms the bottom of the targeted sequence) through viscous (i.e., diamictite), fluvial (sands and gravels), and again diamictitic units. As shown in Figure 8A, the archaeological material is usually positioned close to the top of the brown claystone, and the elevation is remarkably consistent across all trenches (see Fig. 8C), with the exception of T11 and T17 (where lower elevation of the targeted claystone unit may be caused by down-to-the-east normal faulting). While some artefacts were found embedded within the top part of the brown claystone, these were rare in comparison to archaeological material lying on the clay palaeo-surface, within the overlying diamictite, and (especially) the conglomerate eroding the earlier units (see Tables 5 and 6 and Fig. 8). This conglomerate is normally made of medium to coarse sand-supported gravels (see details in Table 3), but in some areas of T2-Main Trench lava cobbles averaging 81 mm filled up depressions dug into the brown claystone unit (see details in de la Torre and Wehr, submitted). This produced an archaeological accumulation (Interval 1 in Fig. 8) that is vertically clustered but contained within several lithological units. Some trenches (T2-Main Trench, T9, T10 and T15) also yielded archaeological material in fluvial and diamictite units around one meter higher up (Interval 2), which is separated from the assemblage of Interval 1 by an archaeologically-sterile gap (see Fig. 8). The bulk of the collection corresponds to Interval 1, which is the main subject of study in this paper.

As discussed above, the claystone palaeo-surface with which the Interval 1 assemblage is associated was heavily incised across the EF-HR landscape; for instance, in T14 the incision surface cuts over 60 cm down through the claystone unit (Fig. 9A), and T16 presents an uneven clay topography shaped by erosion (Fig. 9B). This is also the case for T2-Main Trench, where sharp channelforms exist as well (Fig. 9C, see also de la Torre and Wehr, submitted, and SOM therein).

Carbonate growth on top of the claystone palaeo-surface was documented in T15, T12, T2-Main Trench, T9, T13, T14, T16 and T17. In some cases (i.e., T2-Main Trench, T9, T17), carbonates also grew over artefacts lying on the clays (see Fig. 10A), demonstrating that carbonates formed after the stone tools were deposited. Micromorphological analysis of carbonates embedding artefacts at T9 (Fig. 10B–E) and T2-Main Trench (Fig. 10F–G) associated with the diamictite above the claystone indicates the formation of massive micritic and microsparitic calcite enclosing poorly sorted sands, small stone, bone and clay clasts. These carbonates contain abundant iron-manganese impregnations and dendritic infillings of fissures within clay clasts, and relict burrows and root channels (e.g., Fig. 10E).

Distribution of archaeological remains across the EF-HR wider palaeo-landscape

As shown in Figure 11, the distribution of materials is sharply uneven across the trenches. Thus, trenches on the periphery of the area yielded very low or nil frequencies, while density of stone tools and fossils increases substantially towards the main EF-HR outcrop. This bell-shaped pattern is consistent in absolute frequencies of both fossils and stone tools (Fig. 11A, B), area and volume densities (Fig. 11C, D), total weight of lithic raw materials (Fig. 11E, F), and in the distribution of the most conspicuous category, i.e., Large Cutting Tools (LCTs) (Fig. 11G, H).

Trenches in the main EF-HR area comprise (from west to east) T15, T12, T2-Main Trench, T9 and T13 (Fig. 1). While T2 sought to extend Mary Leakey's trench northwards, positioning of our other trenches aimed at providing full coverage of the main outcrop, and thus to investigate the lateral extent of the archaeological accumulation. Figure 11 shows the density peak of Interval 1 materials to be at T12 and T2-Main Trench, followed by T9, while T13 and T15 have sparser distribution.

When the consistently higher density of materials in T12 and T2 is considered in the light of the east-west distance between the two trenches and the location of T12 further north into the outcrop (see Fig. 12B), patterning suggests that the main archaeological accumulation may well extend over 220 m^2. This is a minimum estimate that does not take into account the area previously excavated by Leakey to the south of T2-Main Trench, the area lost to erosion to the southwest of T2, or the space separating the eastern limit of T2 from T9 (where artefact density is still high), so the original site's size is likely to have been even larger (see Fig. 12B, D).

Figure 13 shows a compilation of the backwalls and sidewalls of T2-Main Trench and satellite trenches across the EF-HR area between DK EE and MK. The overall picture is one of an incised valley subsequently compacted and slightly tilted to the east by about 8°. The most likely cause of this tilting is the continued subsidence of the Olduvai Basin to the east along 3rd and 2nd Faults in concert with 1st Fault (Stollhofen and Stanistreet, 2012), and their association with the continuing subsidence of the Eastern Branch of the African Rift System. Trenches T10 and T11 mark the opposite sides of the valley, whereas T14 and T16 demarcate an eroded claystone highpoint within the valley (see also Fig. 8C). T16 was only covered by sandy diamictites at a slightly later stage of valley-fill.

Additional pieces of information concerning the lithofacies architecture are revealed in Figure 13, and expanded in Stanistreet et al. (submitted). During the early fluvial phase of valley-fill, in the conglomerate-sandstone couplets that are traced eastwards to Trench T9 and beyond, diamictites are preserved prior to successive downcutting phases (Fig. 4), to complete a cycle comprising: gravel–sandstone–sandy diamictite. The implication is that late in the lake-parasequence cycle, mudflows ran through the fluvial channel systems as conduits for flow and filling them prior to the next fluvial downcut. In T10, T11, T13, T14 and T16, the transgressions depositing the late-phase lake clays are well marked. Good recoveries of in situ artefacts are found in T2-Main Trench and T12 on the incision surface, where mudflow diamictites are the first depositional event covering the assemblage. Subsequent fluvial downcutting incises through this preserving diamictite to disrupt, disperse or eliminate locally the original artefactual and bone assemblage in that area, followed by deposition of the next fluvial channel complex. The fluvial gravels are best developed and concentrated in the middle of the incised valley, as would be predicted if the same river system that cut the valley also started to accrete river sediment as the lake surface base-level rose to accommodate sequence accretion.

Hominin activity and assemblage accumulation was concentrated in the middle and deepest part of the incised valley (Figs. 8C and 13) adjacent to the river system that eroded it, sourced in the Ngorongoro Volcanic Highlands. The first depositional events in the valley-fill were mudflows, also sourced in the Highlands, which also covered and preserved in situ portions of the archaeological assemblage because of the low basal shear stresses exerted by such a viscous flow. Only where the diamictite was eliminated by subsequent fluvial action was the assemblage material disrupted and reworked into the younger fluvial channel systems. This is because of the enhanced basal shear stress and thus heightened erosive capacity generated in such fluidal water flows. It is for these reasons that mudflow-covered parts of T2-Main Trench and T12 proved to be optimal circumstances for stone artefact recovery.

The stone tool assemblage

The twelve EF-HR trenches produced 2317 lithic artefacts (Table 7), with a total weight of 223 kg (Table 8). Most of the assemblage (1826 artefacts weighing 199.8 kg) derives from T2-Main Trench, which is partially due to its larger trench size but also to higher density patterns in the main outcrop (see section above). The sharp contrast in artefact frequencies between T2-Main Trench and the rest of trenches precludes statistical comparisons, although general patterns are described below.

By weight, lava artefacts predominate both in Interval 1 (172 kg, 79.6%) and Interval 2 (3.1 kg, 53.5%) over metamorphic stone tools (Interval 1= 44.1 kg; Interval 2= 2.7 kg), although

Interval 2 shows an increase in quartzite (46.5%) with respect to Interval 1 (20.3%) (Fig. 14A). Some variation is also observed in raw material distribution across trenches with higher artefact weights within Interval 1 (i.e. T12, T2 and T9), with the proportion of lava by weight increasing eastward (66.2%, 80.4% and 89.5% respectively; see Fig. 14B).

Detached pieces dominate across the trenches (Table 7), and in both Interval 1 (82.8%) and Interval 2 (92.1%). As shown in Figure 14C, detached pieces are relatively more abundant in T12 (93.1%) than in T2 (81.3%), which might be related to post-depositional processes (see de la Torre and Wehr, submitted). Figure 14D reinforces a proportional overabundance of the smallest lithic fraction (shatter <20 mm) in T12 (18.5%) when compared to T2-Main Trench (8.9%). Conversely, Figure 14D shows that shaped artefacts (i.e., LCTs and smaller retouched tools) are almost twice as abundant in T2-Main Trench (4.8% and 2.4% respectively) as in T12 (2.5% and 1.3%), a pattern for which post-depositional explanations are more difficult to invoke.

Fossil remains

Mary Leakey's (1971:126) account of the EF-HR fauna was limited, only noting that fossil bones were "scarce and generally in a fragmentary condition". The only exception was a complete cranium of *Giraffa jumae*, which she hypothesized was probably brought to the site by human agency. The bone assemblage unearthed by OGAP is poorly preserved and extremely fragmentary, but fossils were not scarce, with 23,805 specimens recovered across the trenches. The vast majority of the fossils (*n*=23,205) were too small and/ or in too poor a condition (Fig. 15A) to be assigned unique identifications, many of them best described as bone pebbles with the same size and shape as some lithic clasts from the sediment.

Frequencies of plotted bone specimens are shown in Table 5, of which 600 bone and tooth fragments from Interval 1 are summarized in Table 9.

The majority of bones show weathering of stage 2 or greater (Table 10) and many were fragile enough to fall apart during excavation, requiring consolidation on site. Nearly 86% of bone surfaces are exfoliated enough to obscure bone surfaces, while nearly 50% exhibit major rounding (Table 10). Only 7% were well-preserved enough to allow for the identification of bone surface modifications. Figure 15B shows the poor condition of a sample of limb bones from unit L2 at T2-Main Trench. The poor condition of the fossils contrasts with the well-preserved lithic collection and may be the result of sediment chemistry that did not favour bone preservation, as observed elsewhere (e.g., Stiner et al., 2001).

There is evidence of both hominin and carnivore consumption of carcasses at EF-HR, but only the most conspicuous damage was visible due to the poor condition of the cortical surfaces in the assemblage. Despite the poor condition of fossils, the high incidence of green breaks (81.4%) suggests nutrient extraction by hominins or carnivores during the resource life of the carcasses. Figure 15C shows apparent impact marks on a proximal femur of a giraffid likely resulting from hammerstone breakage for marrow extraction, while Figure 15D shows possible cut marks on a size 3 limb bone shaft fragment. The Y-pattern of one of the marks is a feature that has been linked to cut marks made by bifacially flaked tools (de Juana et al., 2010). Hominins at the site may have also been using bone and teeth as tools as suggested by the presence of a hippo incisor that appears to have been shaped either through use or intentional modification (Fig. 15E). However, the poor condition of the surface does not allow for the observation of polish even under high magnification so this interpretation cannot be confirmed. There is also evidence of carnivore activity in the form of notches and tooth marks on bone surfaces, but these traces are not abundant likely due to the poor preservation of the assemblage.

The EF-HR fossil assemblage is taxonomically rich despite the small sample size of identifiable bone (Table 11). There is a minimum of 17 individuals in the assemblage, of which five (29.5%) are bovids. Four of the five bovid individuals are grazers, suggesting the presence of grassland habitats near the site. Equids are represented by two grazing taxa, *Equus* cf. *oldowayensis* and *Eurygnathohippus* cf. *cornelianus*, and giraffids are represented by two genera, *Giraffa* and *Sivatherium*. The only identified primate is represented by a poorly preserved molar tooth that has similarities with a lower M2 of genus *Homo*, but given its thin enamel, gracile roots, and strongly grooved palatal root it may also be a large monkey, such as *Theropithecus* sp. or Colobinae. The presence of both *Hippopotamus* sp. and *Crocodylus* sp. along with Phalacrocoracidae (cormorant) (Prassack et al., submitted), suggests a relatively stable water source near the site.

Discussion

One of the main outcomes of our fieldwork is a reconsideration of the stratigraphic position of EF-HR within the general sequence of Bed II. The recognition of an incised palaeo-landsurface cut into the claystones at EF-HR, upon which the EF-HR assemblages lie, and which is traceable across the broad area from DK-EE to MK-W, requires a reinterpretation of Leakey's (1971) and Hay's (1976) stratigraphic placement of the EF-HR site. At DK-EE, this incision does not penetrate as deeply, and leaves exposed a thin, highly weathered tuff above the claystone and below the incision and infilling diamictite. This exposed interval is provisionally correlated to Hay's (1976) Tuff IIC interval. Hay's (1976) stratigraphic section for Locality 12A (equivalent to DK EE) indicates two tuffs (Brown Tuffaceous Siltstone and

Tuff IIC), each topped by thin conglomerates, in the Lemuta to Tuff IID interval, with the archaeological level indicated above the lower of the two. In contrast, our detailed stratigraphic mapping between DK EE and EH-HR indicates that the EF-HR archaeological level sits between Tuffs IIC and IID, within the lowermost part of Upper Bed II (based on Leakey's 1971 divisions) rather than in Middle Bed II. The reason for the previous misinterpretation is that these erosional surfaces often cut across lithologic boundaries, creating land surfaces for hominins to exploit but which can be difficult to recognize and correlate across the landscape.

Another aspect of discussion is the nature of human occupation across the EF-HR stratigraphic interval. Despite the relatively large area (around 150 m^2) sampled during our excavations, most of the trenches in the wider EF-HR landscape yielded very low densities of material, and the vast majority of fossils and stone tools were concentrated around the T2-Main Trench locus. The main lithological marker (i.e., the brown claystone unit) could be traced across all 12 trenches, and therefore the sharp break in artefact density is not a product of lateral stratigraphic discontinuity. In fact, even though many cubic meters of sediment were removed from various lithological units in order to expose the brown claystone unit across several trenches, such upper deposits were always very poor archaeologically (with the exception of T15), and artefacts, however scarce, were consistently derived from the same stratigraphic position on or near the top of the brown claystone (i.e., Interval 1). Furthermore, it is worth noting that, despite the low frequencies in the satellite excavations, all trenches but one (T16) produced materials in Interval 1 (Table 5). This could indicate the existence of a palaeo-landscape over the clays that was used by early Acheulean hominins across the entire sampling area. However, pervasiveness of human presence does not alone explain the large archaeological concentration unearthed around the T2 outcrop, and the stark contrast in density when compared to outer trenches. As discussed above (see also Fig. 12B, D), the area surrounding T2-Main Trench and T12 is potentially massive in terms of archaeological material, and therefore behavioural and/or natural causes should be sought to explain this dramatically higher density around the main EF-HR site.

Given that T2-Main Trench and adjacent trenches were in the middle part of a river valley, one hypothesis to explain the concentration around the main site is that this area acted as a depocenter that captured materials from topographically higher areas nearby. Although this hypothesis cannot be ruled out completely, no statistical correlation exists between clay elevation and artefact density (SOM S6B), and Figures 8A and C show that the top of the brown claystone unit is not particularly depressed in T2-T12, and lowest elevation values at T11 and T17 (probably tectonically-controlled) do not correlate with higher artefact densities. A similar hypothesis is that artefact density could correlate with clay roughness, under the assumption that unevenness of the claystone (caused by fluvial erosion) was associated with artefact accumulation. This explanation is not satisfactory either, since some of the most uneven clay depressions (e.g., T14) yielded very low artefact frequencies, and spatial tests (i.e., roughness index and Terrain Ruggedness Index) rule out a statistical correlation between artefact density and claystone surface unevenness (SOM S6C) (see also de la Torre and Wehr, submitted).

Since the microbotanical analyses did not yield pollen (Alice Milner, pers. comm.), the few phytoliths identified remain as the main evidence for the vegetation present at EF-HR. Despite the strong dissolution observed, the few phytoliths identified point to the presence of C_3 grasses, which together with bulliforms, indicate a humid environment and soil moisture. These grasses would be associated with trees/bushy vegetation. This is consistent with the faunal taxonomic list (Table 11), and both indicate that T2-Main Trench was probably a relatively open habitat, with affordances that may have included a stable water source (thus supporting our sedimentary facies reconstruction) and possibly tree cover adjacent to the water source.

In addition to these proxies, facies characteristics of archaeological units clearly indicate the presence of tractive agents, be it viscous flows to deposit diamictites or fluvial flows to develop conglomeratic layers. The key point here is ascertaining to what extent such agents were responsible for the archaeological accumulation around the main EF-HR site. In the case of fossils, the extreme rounding of most of the material suggests significant fluvial action, and a great majority of bones are basically clasts like other detrital sediment particles from the conglomeratic units. Unfortunately, there are not sufficient data to determine if the entire assemblage has been reworked, due to the small sample of identifiable bone. Highly transportable skeletal parts, such as vertebrae and carpals/tarsals, are less abundant in the assemblage compared to specimens that are less likely to be transported, such as teeth and mandibles, but this pattern could be the result of differential preservation of lower density elements (Voorhies, 1969; Lyman, 1994; Stiner, 2002).

The case of lithic artefacts is different. EF-HR stone tools are generally in fresh condition and all size ranges are represented (de la Torre and Wehr, submitted), and techno-typological features are consistent and indicate a homogeneous assemblage (de la Torre and Mora, submitted). The presence of carbonate growing in artefacts from T2-Main Trench, T9 and T17 (see Fig. 10), the association of such carbonates with the top of the claystone and the diamictite unit, and the better conservation of artefacts in areas with carbonate concentrations in T12 and T2-Main Trench, may all be related to the formation of the site. Carbonates are of two different generations. The carbonates within the waxy claystones are pedogenic in origin (cf. Bennett et al., 2012; Rushworth, 2012) and formed a long time prior to the incision, because they are cut by the erosion surface that cuts down from a higher stratigraphic level. Carbonate encrusting artefacts from T2-Main Trench, T9, and T17 (see Fig. 10) are of a much younger generation, precipitating after gravel and diamictite deposition. The association of such carbonates above the top of the claystone indicates that the latter was acting as an aquiclude for the precipitating fluids. This explains the poor phytolith preservation – which, as opaline silica, are prone to dissolution under highly alkaline conditions (Piperno, 1988; Karkanas, 2010) –but also the better conservation of artefacts in carbonate-encrusted assemblages at Trenches T12 and T2-Main Trench.

The archaeological assemblage may have originally been deposited over the exposed (i.e., weathered) surface of the lacustrine floodplain (i.e., the brown claystone). Artefacts (and probably some of the fossils) were gently buried by slower moving viscous deposits (as evidenced by diamictites) in pond-like conditions (as suggested by carbonate morphology). These deposits were then truncated and partially reworked by fluvial agents, which eroded the claystone unit further and deposited a conglomerate, but it seems evident that fluvial activity must necessarily account, at least partially, for the higher density of artefacts in the cluster around the EF-HR main outcrop (see discussion in de la Torre and Wehr, submitted).

The lithic and bone assemblage is concentrated on the incision surface, cutting deeply into the underlying stratigraphic sequence as deep as Middle Bed II claystones. The depth of the downcutting implies a major fall in base-level, hence the remaining lake was remote from the site at this time. Instead, the palaeo-landscape comprised a broad valley incised by a river flowing at its centre at the position near Trenches T12 and T2-Main Trench.

The subsequent start of the rise of Palaeo-lake Olduvai engendered the accretion of the incision-fill sequence, initially fluvial gravels, sands and mudflow deposits, and followed by cycles extending from mudflows to lake clays as the lake episodically flooded the site. An initial mudflow potentially rearranged, and covered and preserved the lithic and bone assemblage within the centre of the valley. Subsequent fluvial erosion cut through the resulting diamictite and parts of the assemblage were disrupted and reworked into the fluvial gravels as allochthonous bone clasts alongside volcanic and metamorphic detrital material (sands to cobble size). The extent of these post-depositional processes upon the T2-Main Trench archaeological assemblage is discussed elsewhere (de la Torre and Wehr, submitted).

Conclusions

EF-HR was originally interpreted as a living floor occupied by Olduvai's earliest Acheulean hominins on either side of a shallow water stream (Leakey, 1971: 124). By combining large-scale excavations at the main site with an off-site approach, renewed fieldwork by OGAP has enabled us to expand the original interpretation, and to understand better the wider palaeo-landscape of early Acheulean hominins within their palaeogeographic and chronostratigraphic context. With regards to the latter, Mary Leakey (1971) originally positioned EF-HR close to the top of Tuff IIB, and subsequent work by Hay (1976), although placing this site higher on the sequence, still bracketed it between Tuff IIB and Tuff IIC. However, our results indicate that EF-HR is located above Tuff IIC, rather than below, but is older than Tuff IID, as revealed by the Tuff IID blocks contained on top of a higher incision surface. This placement of the EF-HR assemblage in lowermost Upper Bed II has relevant implications for the understanding of the early Acheulean at Olduvai Gorge and its affiliation to earlier technologies, as discussed elsewhere (de la Torre and Mora, submitted).

This paper has also shown that human presence was pervasive across the EF-HR palaeo-landscape, for nearly all trenches yielded archaeological material within the targeted stratigraphic unit. On the other hand, such ubiquity is accompanied by a sharply uneven distribution of artefacts, which are tightly clustered around the EF-HR main site. High densities in T12 and T2-Main Trench suggest that the space between these trenches should also be heavily packed with archaeological materials, thus pointing to the presence of a massive concentration in this area. Human agency is largely responsible for the accumulation which, at least in the case of stone tools, is mostly unabraded and hence was not subjected to heavy reworking processes (see also de la Torre and Wehr, submitted). Nevertheless, water flow contributed to the rearrangement of part of the stone tools, and to the input of a large fraction of the fossils, represented in the form of bone clasts.

Hominin activities concentrated on the river or stream at the centre of the incised valley near T2-Main Trench and T12, in a relatively open habitat that provided an immediate water resource for hominins and other animals. Potable water would have been available in ephemeral pools within the river channels, in contrast to more distant lake waters, which with their saline alkalinity would not have been fit to drink. Overall, the newly excavated faunal assemblage is large and taxonomically rich, but poorly preserved. The high incidence of green broken fragments and the presence of surface modifications suggest both hominins and carnivores fed upon carcasses at or near the site, but deficient preservation hinders further elaboration on the meaning of the EF-HR bone collection. In contrast, the lithic assemblage is very well preserved and contains most of the elements of the Acheulean chaîne opératoire (de la Torre and Mora, submitted). The stone tool assemblage includes a considerably high quantity of LCTs, becoming one of the largest collections for the early Acheulean in East Africa. Given the low frequencies of handaxes in most earliest Acheulean sites (see review by de la Torre, 2016), their abundance at EF-HR makes this site an exceptionally good case study to explore technological strategies of early Acheulean hominins, and to understand better the origins of the African Acheulean.

Acknowledgements

We are grateful for their contributions to A. Milner (pollen analysis), J. Crowther (sediment bulk analysis), K. Wehr (spatial analysis) and G. Peters (excavation supervision), and members of the OGAP research and field team. We thank Sarah Elton for her invaluable editorial assistance. Fieldwork at EF-HR by OGAP (Olduvai Geochronology Archaeology Project) was authorized by the Commission for Science and Technology (COSTECH) and the Department of Antiquities, Tanzania. Financial support for fieldwork was gratefully received from PAST (Palaeontological Scientific Trust, South Africa) for IGS, from the German Science Foundation (DFG grant STO 275/9-1) to HS, and from the Spanish Ministry of Economy and Competitiveness to RMA (HAR2013-42054-P) and to ARC (BES-2014-067985). Funding by the NSF (BCS-0852292 to LM), British Academy (IP090186 to IdlT), and the European Research Council-Starting Grants (283366 to IdlT) is gratefully acknowledged.

References

Albert, R.M., Bamford, M.K., Cabanes, D., 2009. Palaeoecological significance of palms at Olduvai Gorge, Tanzania, based on phytolith remains. Quatern. Int. 193, 41–48.

Albert, R.M., Ruíz, J.A., Sans, A., 2016. PhytCore ODB: a new tool to improve efficiency in the management and exchange of information on phytoliths. J. Archaeol. Sci. 68, 98-105.

Alexandre, A., Meunier, F.C., Koud, J.M., 1997. Phytoliths: indicators of grassland dynamics during the Late Holocene in intertropical Africa. Palaeogeogr. Palaeoclimatol. Palaeoecol. 136, 213–239.

Bamford, M.K., Albert, R.M., Cabanes, D., 2006. Plio–Pleistocene macroplant fossil remains and phytoliths from Lowermost Bed II in the eastern palaeolake margin of Olduvai Gorge, Tanzania. Quatern. Int. 148, 95-112.

Barboni, D., Bremond, L., 2009. Phytoliths of East African grasses: an assessment of their environmental and taxonomic significance based on floristic data. Rev. Palaeobot. Palynol. 158, 29–41.

Barboni, D., Bremond, L., Bonnefille, R., 2007. Comparative study of modern phytolith assemblages from inter-tropical Africa. Palaeogeogr. Palaeoclimatol. Palaeoecol. 246, 454–470.

Barboni, D., Ashley, G.M., Domínguez-Rodrigo, M., Bunn, H.T., Mabulla, A.Z.P., Baquedano, E., 2010. Phytoliths infer locally dense and heterogeneous paleovegetation at

FLK North and surrounding localities during upper Bed I time, Olduvai Gorge, Tanzania. Quatern. Res. 74, 344–354.

Behrensmeyer, A.K., 1978. Taphonomic and ecologic information from bone weathering. Paleobiology 4, 150 162.

Bennett, C., Marshall, J.D., Stanistreet, I.G., 2012. Carbonate horizons, paleosols, and lake flooding cycles: Beds I and II of Olduvai Gorge, Tanzania. J. Hum. Evol. 63, 328-341.

Blumenschine, R.J., Marean, C.W., Capaldo, S.D., 1996. Blind tests of interanalyst correspondence and accuracy in the identification of cut marks, percussion marks, and carnivore tooth marks on bone surfaces. J. Archaeol. Sci. 23, 493-507.

Blumenschine, R.J., Masao, F.T., Stanistreet, I.G., 2009. Changes in hominin transport of stone for Oldowan tools across the eastern Olduvai Basin during Lower Bed II times. In: Schick, K., Toth, N. (Eds.), The Cutting Edge. Stone Age Institute Press, Gospore, Indiana, USA, pp 1-15.

Blumenschine, R.J., Stanistreet, I.G., Njau, J.K., Bamford, M.K., Masao, F.T., Albert, R. M., Stollhofen, H., Andrews, P., Prassack, K.A., McHenry, L.J., Fernández-Jalvo, Y., Camilli, E. L., Ebert, J.I., 2012a. Environments and hominin activities across the FLK Peninsula during *Zinjanthropus* times (1.84 Ma), Olduvai Gorge, Tanzania. J. Hum. Evol. 63, 364-383.

Blumenschine, R.J., Masao, F.T., Stollhofen, H., Stanistreet, I.G., Bamford, M.K., Albert, R.M., Njau, J.K., Prassack, K.A., 2012b. Landscape distribution of Oldowan stone artifact assemblages across the fault compartments of the eastern Olduvai Lake Basin during early lowermost Bed II times. J. Hum. Evol. 63, 384-394.

Bouma, J., Fox, C.A., Miedema, R., 1990. Micromorphology of hydromorphic soils: applications for soil genesis and land evaluation. In: Douglas, L.A. (Ed.), Soil Micromorphology: A Basic and Applied Science, Volume Developments in Soil Science 19. Elsevier, Amsterdam, pp. 257-278.

Bullock, P., Murphy, C. P., 1979, Evolution of a paleo-argillic brown earth (Paleudalf) from Oxfordshire, England. Geoderma 22, 225-252.

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G., Tursina, T., 1985. Handbook for Soil Thin Section Description. Waine Research Publications, Wolverhampton.

Cabanes, D., Weiner, S., Shahack-Gross, R., 2011. Stability of phytoliths in the archaeological record: a dissolution study of modern and fossil phytoliths. J. Archaeol. Sci. 38, 2480-2490.

Churcher, C.S., 1978. Giraffidae. In: Maglio, V., Cooke, H.B.S. (Eds.), Evolution of African Mammals. Harvard University Press, Cambridge, MA, pp. 509-535.

Courty, M.A., 2001. Microfacies analysis assisting archaeological stratigraphy. In: Goldberg, P., Holliday, V.T., Ferring, C.R. (Eds.), Earth Sciences and Archaeology. Kluwer, New York, pp. 205-239.

Courty, M.A., Goldberg, P., Macphail, R.I., 1989. Soils and Micromorphology in Archaeology (1st Edition). Cambridge University Press, Cambridge.

de la Torre, I., 2011. The Early Stone Age lithic assemblages of Gadeb (Ethiopia) and the Developed Oldowan / early Acheulean in East Africa. J. Hum. Evol. 60, 768-812.

de la Torre, I., 2016. The origins of the Acheulean: past and present perspectives on a major transition in human evolution. Phil. Trans. R. Soc. B, 371, 20150245.

de la Torre, I., Arroyo, A., Proffitt, T., Martín-Ramos, C., Theodoropoulou, A., 2015. Archaeological fieldwork techniques in Stone Age sites. Some case studies. In: Roda, X., Mora, R. (Eds.), Métodos y técnicas para la recuperación del registro arqueológico: una mirada desde el presente. Treballs d'Arqueologia, 20, 21-40.

de la Torre, I., Mora, R., 2005. Technological strategies in the Lower Pleistocene at Olduvai Beds I & II. ERAUL 112, Liege.

de la Torre, I., Mora, R., (submitted). The EF-HR stone tool assemblage and its implications for the emergence of the Acheulean in East Africa. *J. Hum. Evol.*

de la Torre, I., Wehr, K. (submitted). Site formation processes of the early Acheulean assemblage at EF-HR (Olduvai Gorge, Tanzania). *J. Hum. Evol.*

de Juana, S., Galán, A.B., Domínguez-Rodrigo, M., 2010. Taphonomic identification of cut marks made with lithic handaxes: an experimental study. J. Archaeol. Sci. 37, 1841-1850.

Domínguez-Rodrigo, M., Pickering, T. R., Baquedano, E., Mabulla, A., Mark, D. F., Musiba, C., Bunn, H. T., Uribelarrea, D., Smith, V., Diez-Martin, F., Pérez-González, A., Sánchez, P., Santonja, M., Barboni, D., Gidna, A., Ashley, G., Yravedra, J., Heaton, J. L. & Arriaza, M. C. (2013). First Partial Skeleton of a 1.34-Million-Year-Old Paranthropus boisei from Bed II, Olduvai Gorge, Tanzania. PLOS ONE 8, e80347.

Goldberg, P., Macphail, R.I., 2006. Practical and Theoretical Geoarchaeology. Blackwell Publishing, Oxford.

Gowlett, J.A.J., 1979. Complexities of cultural evidence in the Lower and Middle Pleistocene. Nature 278, 14-17.

Harris, J.M., 1976. Pliocene Giraffoidea (Mammalia, Artiodactyla) from the Cape Province. Ann. S. Afr. Mus. 69, 325-353.

Harris, S.L., 2000. Archaeology and volcanism. In: Sigurdsson, H., Houghton, B., Rymer, H., Stix, J., McNutt, S. (Eds.), Encyclopedia of Volcanoes. Academic Press, San Diego, pp. 1301–1314.

Harris, J., Solounias, N., Geraads, D., 2010. Giraffoidea. In: Werdelin, L., Sanders, W.J. (Eds.), Cenozoic Mammals of Africa. University of California Press, Berkeley, pp. 805-819.

Hay, R.L., 1976. Geology of the Olduvai Gorge. University of California Press, Berkeley.

Isaac, G.L., Harris, J.W.K., Kroll, E.M., 1997. The stone artefact assemblages: A comparative study. In: Isaac, G.L. (Ed.), Koobi Fora Research Project. Volume 5: Plio-Pleistocene Archaeology. Oxford University Press, Oxford, pp. 262-362.

Jorayev, G., Wehr, K., Benito-Calvo, A., Njau, J.K., de la Torre, I., 2016. Imaging and photogrammetry models of Olduvai Gorge (Tanzania) by Unmanned Aerial Vehicles: A high-resolution digital database for research and conservation of Early Stone Age sites. J. Archaeol. Sci. 75, 40-56.

Karkanas, P., 2010. Preservation of anthropogenic materials under different geochemical processes: a mineralogical approach. Quatern. Int. 214, 63–69.

Katz, O., Cabanes, D., Weiner, S., Maeira, A.M., Boaretto, E., Shahack-Gross, R., 2010. Rapid phytolith extraction for analysis of phytolith concentrations and assemblages during an excavation: an application at Tell es-Safi/Gath, Israel. J. Archaeol. Sci. 37 , 1557–1563.

Kimura, Y., 2002. Examining time trends in the Oldowan technology at Beds I and II, Olduvai Gorge. J. Hum. Evol. 43, 291-321.

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

Leakey, M.D., 1975. Cultural patterns in the Olduvai Sequence. In: Butzer, K.W., Isaac, G.L. (Eds.), After the Australopithecines. Stratigraphy, Ecology, and Cultural Change in the Middle Pleistocene. Mouton, Chicago, pp. 477-493.

Lindbo, D.L., Stolt, M.H., Vepraskas, M.J., 2010. Redoximorphic features. In: Stoops, G., Marcelino, V., Mees, F. (Eds.), Interpretation of Micromorphological Features of Soils and Regoliths. Elsevier, Amsterdam, pp. 129-147.

Lyman, R.L., 1994. Vertebrate Taphonomy, Cambridge University Press, Cambridge.

Manega, P., 1993. Geochronology, geochemistry and isotopic study of the Plio-Pleistocene hominid sites and the Ngorongoro Volcanic Highland in Northern Tanzania. Ph.D. Dissertation, University of Colorado.

McHenry, L.J., 2009. Element mobility during zeolitic and argillic alteration of volcanic ash in a closed-basin lacustrine environment: Case study Olduvai Gorge, Tanzania. Chem. Geol. 265, 540-552.

McHenry, L.J., Njau, J.K., de la Torre, I., Pante, M.C., 2016. Geochemical “fingerprints” for Olduvai Gorge Bed II tuffs and implications for the Oldowan–Acheulean transition. Quatern. Res. 85**,** 147-158

McHenry, L.J., de la Torre, I. (submitted). Hominin raw material procurement in the Oldowan-Acheulean transition at Olduvai Gorge. *J. Hum. Evol.*

Mercader, J., Bennet, T., Esselmont, C., Simpson, S., Walde, D., 2009. Phytoliths in woody plants from the Miombo woodlands of Mozambique. Ann. Bot. 104, 91–113.

Murphy, C.P., 1986. Thin Section Preparation of Soils and Sediments. A B Academic Publishers, Berkhamsted.

Piperno, D.R., 1988. Phytolith Analysis: An Archaeological and Geological Perspective. Academic Press, San Diego.

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

Prassack, K., Pante, M.C., Njau, J.K., de la Torre, I. (submitted). The Paleoecology of Fossil Birds from Middle Bed II, at Olduvai Gorge, Tanzania *J. Hum. Evol.*

Rogers, M.J., Harris, J.W.K., Feibel, C.S., 1994. Changing patterns of land use by Plio-Pleistocene hominids in the Lake Turkana Basin. J. Hum. Evol. 27, 139-158.

Runge, F., 1999. The opal phytolith inventory of soils in central Africa-quantities, shapes, classification, and spectra. Rev. Palaeobot. Palynol. 107 , 23–53.

Rushworth, E., 2012. Carbonates from Olduvai Gorge, Tanzania: palaeohydrology and geochronology. Ph.D. Dissertation, University of Liverpool.

Scholle, P.A., Ulmer-Scholle, D.S., 2003. A Color Guide to the Petrography of Carbonate Rocks: Grains, Textures, Porosity, Diagenesis. American Association of Petroleum Geologists, Tulsa.

Stanistreet, I.G., 2012. Fine resolution of early hominin time, Beds I and II, Olduvai Gorge, Tanzania. J. Hum. Evol. 63, 300-308.

Stanistreet, I.G., Stollhofen, H., Njau, J.K., Farrugia, P., Pante, M.C., Masao, F.T., Albert, R.M., Bamford, M.K., (in review) Lahar inundated, modified and preserved 1.88 Ma early hominin (OH24 and OH56) Olduvai DK site. J. Hum. Evol.

Stanistreet, I.G., McHenry, L.J., Stollhofen, H., de la Torre, I. (submitted) Bed II Sequence Stratigraphic context of EF-HR and HWK EE archaeological sites, and the Oldowan/ Acheulean succession at Olduvai Gorge, Tanzania. *J. Hum. Evol.*

Stiner, M.C. 2002. On *in situ* attrition and vertebrate body part profiles. J. Archaeol. Sci. 29, 979-991.

Stiner, M.C., Kuhn, S.L., Surovell, T.A., Goldberg, P., Meignen, L., Weiner, S., Bar-Yosef, O., 2001. Bone preservation in Hayonim Cave (Israel): a macroscopic and mineralogical study. J. Archaeol. Sci. 28, 643-659.

Stiles, D., 1979. Early Acheulean and Developed Oldowan. Curr. Anthropol. 20, 126-129.

Stoops, G., 2003. Guidelines for Analysis and Description of Soil and Regolith Thin Sections. Soil Science Society of America, Inc, Madison, Wisconsin.

Stoops, G., Marcelino, V., Mees, F., 2010. Interpretation of Micromorphological Features of Soils and Regoliths. Elsevier, Amsterdam.

Voorhies, M., 1969. Taphonomy and population dynamics of an Early Pliocene vertebrate fauna, Knox County Nebraska. University of Wyoming Contributions to Geology, Special Paper No. 1, Laramie.

Figure captions

Figure 1: A) EF-HR trenches on the orthomosaic produced through Unmanned Aerial Vehicle (UAV) imagery (see details in Jorayev et al., 2016). B) Location of trenches in the EF-HR wider area. Contour map extracted from DEM in SOM S1. C) DEM model of the EF-HR outcrops, extracted from the UAV orthomosaic.

Figure 2: Measured stratigraphic sections for DK EE, EF-HR, MK W, and intermediate sites. The Lemuta Member of Olduvai Bed II (orange) occurs at the base of each section. The base of the claystone (brown) underlying the EF-HR archaeological level was taken as flat, and all sections were positioned accordingly. The top of the claystone (upon which much of the archaeological accumulation lies) differs in height in part because of different levels of incision and erosion above it. The thin tuff (interpreted as Hay's [1976] Tuff IIC interval) and conglomerate above it at DK EE are absent in other sections, where the EF-HR diamictite (yellow) sits directly upon the underlying, incised claystone; this places the EF-HR archaeological level above Tuff IIC stratigraphically, and therefore within Upper Bed II. Blocks of Tuff IID (purple) were identified in sandstone in the upper part of the backwall of T2- Main Trench and in a section between EF-HR and DK EE. See McHenry (submitted) and Stanistreet et al. (submitted) for further details.

Figure 3: Lithofacies maps of all backwalls and/or sidewalls of trenches excavated in the EF-HR area, as far as MK W to the east and DK EE to the west. See also Stanistreet et al. (submitted)

Figure 4. Details of lithofacies unit geometries and incisional or conformable contacts between them: A) Backwall of T10; B) Backwall of T9.

Figure 5. Lithofacies map of the EF-HR T2-Main Trench backwall (left of the vertical line) and sidewall (right of the vertical line). The incisional nature of the artefact-covered claystone surface near the base of the trench reveals it as a pronounced Type I disconformity, which cut out the Tuff IC sequence at EF-HR proper. Artefacts were least disturbed below the diamictite (mudflow) deposit below the lowest conglomerate. The mudflow with low basal shear stress covered and preserved material more in situ compared to the subsequent fluvial conglomeratic units. Erosional surfaces higher in the backwall are Type II disconformities, displaying less pronounced incision.

Figure 6. A) Thin section scan of the brown claystone unit, with clay overlying mixed clay and sand to stone-size clasts and a likely burrow-mixed boundary. Frame width is approximately 50 mm. B) Plane polarised light (PPL) photomicrograph of thin section in A); clast-rich clay, with stone-size volcanics. Frame width is approximately 4.62 mm. C) PPL photomicrograph of the contact between the brown claystone and diamictite unit: detail of clay and possible framboids, relict of pyrite – now FeMn nodules, potentially indicating past rooting in the brown claystone unit. Frame width is approximately 0.90 mm. D) Thin section scan of the diamictite unit above the brown claystone: mixed clay and silt to sand-size clast-rich clay, with very broad burrow fills of clayey material (centre). Frame width is approximately 50 mm. E) PPL photomicrograph of thin section in D); burrow fill of clay clasts and weathered clay. Frame width is approximately 4.62 mm. F) PPL view of the diamictite unit; example of clay inwash and secondary $CaCO_3$ nodular impregnation. Frame width is approximately 4.62 mm. See SOM S4 for more details.

Figure 7: Phytolith microphotographs (400x magnification). A) Short cell rondel from sample T2-Main Trench 19. B) Short cell rondel from sample T17-3. C) Blocky from sample T13-6. D) Trichoma from sample T13-6. Note that the entire phytolith surfaces were pitted by alteration.

Figure 8. A) E-W cross section of Interval 1 (black dots) and Interval 2 (red dots) artefacts plotted in all trenches in relation to the brown claystone unit. Elevation (meters above sea level: m a.s.l.) is absolute, but the x axis contains breaks in order to show all trenches (i.e., horizontal distance is not represented). B) Lithostratigraphic position of archaeological units in the EF-HR trenches. C) Elevation of the top of the brown claystone palaeo-surface across the EF-HR trenches (data from Table 1). D) LCT from T2-Main Trench (level L2) lying on clays and buried by diamictites. E) LCT from T2 (level L2) embedded in coarse sands and gravels. F) Level 2 LCTs, cores and flakes alongside large cobbles within the infilling of one of T2 incision surfaces. G) Giraffe tibia from the T2 level L2 conglomerate.

Figure 9. 3D models of the palaeosurface of the brown claystone at T14 (A), T16 (B), and T2-Main Trench (C). UTM Zone 36S projection (i.e., UTM projection of WGS84) was used for Figures 9A and 9B, due to the small size of areas covered by these models. (C) includes detail of the NE-SE incision surface over the brown claystone in T2-Main Trench. Dots: archaeological material. See de la Torre and Wehr (submitted) for further 3D models and rotating views of T2-Main Trench.

Figure 10. A) Carbonates over handaxes lying on the claystone palaeo-surface at T2-Main Trench (archaeological unit L2). Arrow points to geographic North. Scale: 10 cm. B) Carbonate cemented diamictite matrix around a handaxe from the archaeological unit T9L10. Scale: 5 cm. C) Section through tufa embedding handaxe from B), which includes lava clasts (blue arrow) and shows possible outwards iron migration within the sample (red arrows). D) PPL photomicrograph of section in C), showing FeMn staining and lens of washed-in clay clasts cemented by calcium carbonate. Frame width is approximately 4.62 mm. E) PPL photomicrograph of section in C), which shows micritic and microsparitic material with clay and volcanic clasts and minerals, indicative of contemporaneous burrowing. Frame width is approximately 4.62 mm. F) PPL photomicrograph of carbonate-cemented sediment encrusting a lava core from archaeological unit L2 at T2: common inclusions are iron-depleted clay clasts, which show fissuring and fragmentation before being cemented within a pond tufa. Frame width is approximately 4.62 mm. G) XPL view of F), showing microsparitic cementation of fragmented clay clasts; it is possible that the inwashed clay fragment dried out and became fissured before being sealed within the pond carbonate. See SOM S4 for more details.

Figure 11. A) and B): Absolute frequencies of artefacts and fossils across all EF-HR trenches (A) and within Interval 1 (B). C) and D): density per m^2 (C) and m^3 (D) of artefacts and fossils within Interval 1. E) and F): E) Total weight of stone artefacts per m^2 (E) and m^3 (F). G) and H): density of LCTs per area (G) and volume (H) within Interval 1. Data from Table 1, Table 4, Table 6 and Table 7. Calculations in SOM S5.

Figure 12. A) Composite picture of trenches in the EF-HR main outcrop (2012 and 2013 excavations). B) Plan view of the trenches at the EF-HR main outcrop. DEM and contour lines (20 cm interval) from a DSM based on aerial photogrammetry. Claystone surface for each trench (cell size of 1 cm, created with kriging from elevation points), trench outlines and

artefact shapes recorded with total station and projected onto an absolute grid. C) E-W cross-section of Interval 1 materials in the EF-HR main outcrop over the top of the claystone. D) Aerial view of the EF-HR main outcrop with minimum estimates of the extension of the main archaeological accumulation.

Figure 13. Correlatory diagram of EF-HR T2-Main Trench and satellite trenches. Revealed is an incised valley with fluvial activity concentrated at the centre of the valley. See further discussion in Stanistreet et al. (submitted).

Figure 14. A) Weight percentage of lava versus metamorphic artefacts in Intervals 1 and 2. B) Weight percentage of lava versus metamorphic artefacts in the trenches with more kg of raw materials. Raw data for 11A and B from Table 8. C) Percentages of detached, flaked and pounded pieces in Intervals 1–2, compared to total figures and the two trenches (T2-Main Trench and T12) with higher frequencies of stone tools [T2 includes Interval 1 artefacts only]. D) Relative frequencies of main lithic categories across all trenches and archaeological units, compared to the richest trenches (T2-Main Trench and T12) in Interval 1 (data from Table 7).

Figure 15. Fossils from Interval 1 at T2-Main Trench. A) Sample of rolled bones. B) Limb bones. C) *Giraffa* sp. femur with hammerstone impact mark. While it is tempting to link this femur to the cranium discovered by Leakey (1971), the relatively small size of this specimen suggests that it should not be attributed to *Giraffa jumae*. It is more likely to be part of a smaller giraffid such as *Giraffa stillei* or *Giraffa pygmaea* (Harris, 1976; Churcher, 1978; Harris et al., 2010). D) Size 3 limb bone shaft fragment with possible cut marks. E) Hippo incisor from T2L2 compared with modern hippo incisor (right). The pointed tip suggests it may have been modified through use or intentionally shaped.