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Autochthony and orientation patterns in Olduvai Bed I: a re-examination of the status of post-depositional biasing of archaeological assemblages from FLK North (FLKN)

M. Domínguez-Rodrigo [a,b,*], H.T. Bunn [c], T.R. Pickering [c,d,e], A.Z.P. Mabulla [f], C.M. Musiba [a,g], E. Baquedano [a,h], G.M. Ashley [i], F. Diez-Martin [j], M. Santonja [k], D. Uribelarrea [l], R. Barba [b], J. Yravedra [b], D. Barboni [m], C. Arriaza [a], A. Gidna [a]

[a] IDEA (Instituto de Evolución en África), Museo de los Orígenes, Plaza de San Andrés 2, 28005 Madrid, Spain
[b] Department of Prehistory, Complutense University, Prof. Aranguren s/n, 28040 Madrid, Spain
[c] Department of Anthropology, University of Wisconsin-Madison, 1180 Observatory Drive, Madison, WI 53706, USA
[d] Institute for Human Evolution, University of the Witwatersrand, WITS 2050, Johannesburg, South Africa
[e] Plio-Pleistocene Palaeontology Section, Department of Vertebrates, Ditsong National Museum of Natural History (Transvaal Museum), Pretoria 0002, South Africa
[f] Archaeology Unit, University of Dar es Salaam, Dar es Salaam, P.O. Box 35050, Tanzania
[g] Department of Anthropology, University of Colorado Denver, 1201 5th Avenue, Suite 270, Denver, CO 80217, USA
[h] Museo Arqueológico Regional, Plaza de las Bernardas s/n, 28801 Alcalá de Henares, Madrid, Spain
[i] Department of Geological Sciences, Rutgers University, 610 Taylor Road, Piscataway, NJ 08854, USA
[j] Department of Prehistory and Archaeology, University of Valladolid, Plaza del Campus s/n, 47011 Valladolid, Spain
[k] CENIEH (Centro Nacional de Investigación sobre la Evolución Humana), Paseo Sierra de Atapuerca s/n, 9002 Burgos, Spain
[l] Department of Geodynamics, Complutense University, Prof. Aranguren s/n, 28040 Madrid, Spain
[m] CEREGE (Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement), Aix-Marseille Université AMU/CNRS/IRD/Collège de France, BP80, F-13545 Aix-en-Provence Cedex 4, France

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ABSTRACT

Recent excavations at FLK North (Olduvai Gorge, Tanzania) have produced new information on the orientation of archaeological materials at various levels of the site. This information includes the uniform distribution of material azimuths, which contrasts with previous inferences of highly patterned orientations of materials in the Bed I archaeological sites. Those previous inferences of patterned material orientations are based on Mary Leakey's 50-year-old drawings of artifact and fossil bone distribution, but are not verified by our precise measurements of archaeological objects made *in situ*. Nor do those previous results agree with the general lack of geological, geomorphological, and/or taphonomic data that would indicate significant post-depositional movement of archaeological materials in the sites. We argue here that Leakey's drawings are incomplete (only portions of each assemblage were drawn) and inaccurate in their representation of the original locations, shapes and orientations of most archaeological specimens. This argument is supported by several important mismatches in object representations between a photograph taken of a small portion of the FLK 22 *Zinjanthropus* site floor before the removal of the archaeological items, and the sketch of the same area drawn by Leakey. Thus, we conclude that primary orientation data of excavations (i.e., direct measurements taken from items) generated prior to object removal are the only valid indicators of the relative isotropy or anisotropy of these important paleoanthropological assemblages.

1. Introduction

A reasonable way to understand Pleistocene paleoanthropological sites is that each exhibits varying degrees of integrity or disturbance (Binford, 1981; Andouze and Enloe, 1997). Hydraulic and aeolian sedimentary processes frequently have enough force to "transport" small artifacts and bones across space

* Corresponding author. IDEA (Instituto de Evolución en África), Museo de los Orígenes, Plaza de San Andrés 2, 28005 Madrid, Spain. Tel./fax: +34 91 394 60 08.
E-mail addresses: manueldr@ghis.ucm.es, m.dominguez.rodrigo@gmail.com (M. Domínguez-Rodrigo).

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at the millimetric, centimetric and metric scale, but sometimes with the spatial arrangement of the resulting excavated assemblages preserving its isotropic nature. Other times, major transporting forces by these or other processes affect variously-sized archaeological items to such an extent that anisotropy results. Until a consensus is reached on how many millimeters or centimeters archaeological items can move before they qualify as being in a derived context, the most parsimonious approach is to call an assemblage derived only when its relational and spatial properties that were created during deposition have been subsequently disturbed by post-depositional processes. If, instead, movement of materials was so minimal at a given site that those materials retain a centimetric proximity to their original points of deposition, then that site is potentially of high integrity and high resolution (*sensu* Binford, 1981). Thus, archaeologists commonly distinguish between "primary" and "secondary" positions of sites, with the terms "primary" and "secondary" referring to the location and *not orientations* of materials. Secondary position implies transport of the materials from their original locations of deposition to derived ones (e.g., Drewett, 2001). As long as the original relational properties of all archaeological materials are preserved, the value of the site for providing behavioral interpretations is virtually the same as if each item had preserved its original position and orientation. In this case, the determination that a site is in primary position is justified because the term "primary position" is commonly used to refer to material location and not orientation.

In contrast to archaeologists, taphonomists and paleontologists prefer to designate fossil sites as autochthonous or allochthonous, because, in most cases, one can more accurately infer whether site materials occur in their original depositional *loci* rather than whether they retain their original spatial configuration (Fernández-López, 2000). Further, to practitioners of these historical sciences "primary position" typically implies a "Pompeian scenario", a most rare situation given that the vast majority of known sites show various degrees of disturbance, even those that are autochthonous. Autochthony is thus defined as occurring in the same location where deposited, whereas allochthony implies significant post-depositional modification, with embedding or burial of items in a different location than where initially deposited (Callender and Powellm, 1992; Jacobs and Winkler, 1992; Jenkins, 1992; Callender et al., 1994; Darrah, 1995; Farinati and Zavala, 1995; Rasser and Nebelsick, 2003; Allen and Gastaldo, 2006; Jones, 2006; Martin, 2006). More precisely, autochthonous entities are defined as located within the area of production (deposition), even though, in some cases, they may have been subsequently rearranged within this area (Fernández-López, 1990; Alcalá, 1994). Preferred orientation patterns of materials may, therefore, exist in both autochthonous and allochthonous assemblages.

When material orientation is uniform (i.e., spatial arrangement of materials evenly spanning all orientations), the orientation pattern is referred to as isotropic. In contrast, when measurements of objects do "not vary equally in all directions but may have trends that are directionally dependent" the orientation pattern is referred to as anisotropic (Bevan and Connolly, 2009: 958) or non-uniform (Fisher, 1995). It should be emphasized, for the purpose of understanding archaeological site formation processes, that anisotropy is completely independent from allochthony and autochthony, and may not always imply transport.

Various researchers have argued that several sites in Bed I of Olduvai Gorge (Tanzania) show preferential orientations of their archaeological materials that might be the result of significant post-depositional disturbance (Leakey, 1971; Davis, 1975; Potts, 1988; Petraglia and Potts, 1994; Benito-Calvo and de la Torre, 2011). However, the interpretation of these orientation patterns vary from autochthony (Potts, 1988; Petraglia and Potts, 1994) to allochthony (Benito-Calvo and de la Torre, 2011), the latter interpretation based on modern analogical data from observations of sheet erosion, mass wasting, mass flows, fluvial flooding and solifluction, all of which imply significant transport of materials. Most authors who suggest preferential material orientations in Bed I sites do not provide any data that could distinguish among various equifinal processes that might have potentially led to the purported object orientations. Based on these largely unsupported suppositions, we are unable to gauge the intensity of the potential orienting processes that could have impacted the Bed I assemblages. In turn, this means we do not know if the assemblages are highly altered with regard to their original relational and spatial properties, such as re-deposited allochthonous assemblages or highly altered autochthonous lag deposits. We must be able to distinguish between these and other choices for site formation and alteration in order to assess the fidelity of the Bed I paleoanthropological evidence, and thus, the ultimate veracity of the hominin behavioral scenarios we construct based on that evidence.

Further, several of the various inferences of post-depositional disturbance of the Bed I sites rest exclusively or mostly on the assumption that Leakey's (1971) drawings are accurate reflections of the original positions and orientations of objects (Potts, 1988; Benito-Calvo and de la Torre, 2011), an assumption that we demonstrate is invalid. According to published photographs, Leakey's Bed I site drawings were made without proper x–y reference (usually one-square-meter) grids and are thus subjective records of item orientations and locations. Corroborating this assertion, are data we generated from recent excavations at some of the Bed I assemblages, which were then compared to data derived Leakey's original drawings. We also provide a comparison of a detailed photograph and a drawing of a small portion of the FLK 22 *Zinjanthropus* (FLK Zinj) level, an important Bed I site, and orientation patterns inferred from these two documents, which further demonstrates that Leakey's drawings, while highly informative about other aspects of the archaeology of FLK Zinj, are unsuitable for studying orientation patterns at this and probably other Bed I sites.

It has been argued that most archaeological levels at FLK North (FLKN), as well as other Bed I sites, show a bimodal longitudinal-oblique anisotropic material orientation pattern (Benito-Calvo and de la Torre, 2011). Using compasses and clinometers, we collected horizontal and vertical orientation data directly from archaeological materials during recent excavations of The Olduvai Paleoanthropology and Paleoecology Project (TOPPP) conducted at FLKN. This was the first time in the history of field research in the Bed I sites that item orientation was documented directly (see Domínguez-Rodrigo et al., 2010a).

In total, our work highlighting discrepancies between Leakey's original site drawing and excavation photographs and providing new, accurately collected orientation data from Bed I sites, falsifies the contention that Leakey's pictorial representations are a "superb mapping(s) of archaeological items" (Benito-Calvo and de la Torre, 2011: 51). More importantly, our research demonstrates that the formational histories of the Bed I sites involved a significant degree of allochthony. In sum, this study concludes that some of Leakey's original distribution maps from the Bed I sites, drawn half a century ago, do not show degree of accuracy necessary to inform accurately about post-depositional processes and the formational history of the Bed I sites, and also demonstrates that isotropy is the most common material orientation pattern documented at FLKN.

2. Materials and methods

2.1. Materials

FLKN, situated in uppermost Bed I at Olduvai Gorge (Tanzania), is the thickest early Pleistocene archaeological deposit currently known (Domínguez-Rodrigo et al., 2010a). FLK N includes several archaeological levels below and above the marker Tuff IF, which is dated 1.79 Ma (Hay, 1976; Hay and Kayser, 2001). Leakey (1971) uncovered three archaeological levels overlying Tuff IF, two in lowermost Bed II (FLKN clay with root casts and FLKN *Deinotherium* level) and one situated in the middle of Bed II (FLKN sandy conglomerate). Underlying Tuff IF, she excavated six archaeological levels (FLKN 1–6), which she interpreted as hominin "living floors" (levels 1-2 to 5) and the lowermost one (level 6) as an elephant butchery site (Leakey, 1971). Three additional levels were uncovered by TOPPP (Domínguez-Rodrigo et al., 2010a). Leakey (1971) and Domínguez-Rodrigo et al., 2010a provide a geological description of these levels.

When Leakey excavated FLKN in 1960, she opened five trenches of variable dimensions according to level (no level was exposed for more than 100 m^2). TOPPP had initially opened two archaeological trenches, separated by a 1 m wall, at the back of Leakey's trenches, continuing from near the back wall of Leakey's trenches IV, III and a small part of II (Domínguez-Rodrigo et al., 2010a). In 2011, a third trench was opened continuing to the south of Leakey's trenches II and I. Trench 1 measures 2 × 3 m. Trench 2 measures 4 × 2 m. Trench 3 is 2 × 2 m. TOPPP also opened a 1 m wide geological step-trench ~25 m to the east of the site to expose its eastern boundary (Domínguez-Rodrigo et al., 2010a), which is described in more detail in Ashley et al. (2010a). Trench 1 was excavated throughout levels 1–9. However, level 1–2 is currently being excavated in trenches 2 and 3, due to the wealth of materials and larger size of the area exposed compared to Trench 1.

Here we provide orientation data for levels 1–5, since the sample sizes from TOPPP's excavations for levels underlying level 5 are currently too small to be informative. Further, previous orientation data available for comparisons come only for levels 1–6 (Leakey, 1971). Because of the potential of intra-site spatial variation, one could contend that material orientation patterns in the old and new excavations might not be expected mirror each other. However, given that our new excavations were not restricted to the site margin (sensu, Leakey, 1971), but instead sample and expand four of Leakey's five original trenches, we argue that this is a very unlikely situation. Thus, it is most likely that our results are the most accurate representation of material orientation patterning in FLKN. The new sampled area expands longitudinally by 80% the trenches excavated by Leakey, and comprises >20 m^2, which represents >20% (in some levels even more) of the original surface excavated by Leakey at FLKN.

2.2. Method

Spatial information of each archaeological item was collected with total stations (Top Con and Leica). Total stations can also be used to document the projection of the axis of each object, but we preferred not to use this tool for this purpose, since the orientation of each item would have to be derived graphically after plotting all the information. Given the amount of materials, a combined display of each of the level sets would have obscured the reading of the orientation of several objects. For this reason, we preferred to collect orientation information directly from each item prior to removal. Orientation data for the horizontal and vertical planes were collected with the aid of compasses and clinometers (Voorhies, 1969; Fiorillo, 1991; Alcalá, 1994; Howard, 2007), with an accuracy of one-degree. These measurements were taken along an A-axis consisting of the longitudinal plane of each item, whereby the axis divides the item more or less symmetrically. This symmetry axis is taphonomically sound, since experiments show that long objects tend to orient according to their longitudinal axes (Toots, 1965; Voorhies, 1969; work in progress). This produces different orientations than A-axes taken as maximum length and these remain the same regardless of the geometric outlines of the objects (Fig. 1). Benito-Calvo & de la Torre's A-axes do not reflect the true orientation of those objects under taphonomic processes. By focusing on maximum-length A-axes of plotted objects, they might likely have oriented differently specimens whose longitudinal axes are parallel and *vice-versa* (Fig. 1).

Measurements were taken for each item with a longitudinal A-axis whose length was a minimum of twice the width of the specimen (i.e. of the B-axis). This allowed the collection of orientation data from specimens regardless of their size. Thus, measurements were taken on any specimen >20 mm showing a well-defined longitudinal axis. In the present study, the bulk of orientation data comes for bones and a significantly smaller portion of stone tools (those showing a clear A-axis). Most lithics at the site consist of unmodified cobbles, nodular artifacts and detached products, many of which show oval or irregular morphologies where longitudinal symmetry axes are frequently not objectively identifiable. These are not included in the present analysis. Given that the orientation data from Leakey's (1971) drawings for lithics and bones show a similar bimodal pattern throughout the FLKN sequence, we will use the data collected only from specimens with a well-defined A-axis to test the accuracy of the information drawn from these drawings.

Orientation data were graphically displayed with rose diagrams (using Rockworks 15.0 software) and stereograms (using OpenStereo software). Data were statistically treated by using R software (http://www.r-project.org). Isotropy (or randomness in orientation) can be statistically assessed by using *omnibus* tests, which can detect any trend towards non-uniformity. For this purpose, Kuiper's test (V) was used. However, general omnibus

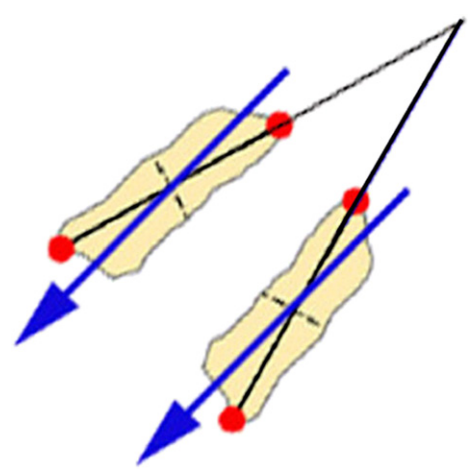

Fig. 1. Contrast between the A-axis (black lines) used by Benito-Calvo and de la Torre (2011) for estimating bone orientation from Leakey's (1971) maps and the longitudinal axis of bones (blue arrows, indicating a theoretical direction or re-orienting force). Notice how two parallel specimens with identical longitudinal axes show divergent A-axes of 30°. By using A-axes, Benito-Calvo and de la Torre (2011) are not documenting the real bone orientation as produced by any physical process. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

tests are not very effective in detecting unimodal orientations. To test uniform distributions against unimodal distributions, Rayleigh's (R) test was applied (Fisher, 1995). This test is very efficient in detecting unimodal patterns in a sample of vectors or bipolar patterns in axes prior to their conversion in vectors (Fisher, 1995). A model for assessing the normal distribution of circular data is the von Mises distribution. For this distribution, the dispersion is quantified by a concentration parameter k, with a $k = 0$ corresponding to an isotropic distribution and increasing values with a trend towards anisotropy. The Watson (U^2) test is a goodness-of-fit statistic for the von Mises distribution. Values with $p = >0.05$ indicate that the null hypothesis of isotropy cannot be rejected. The three tests were applied in the present study and the R functions used were "rayleigh.test", "kuiper.test" and "watson.test" from the R "circular" library. These tests are stronger when sample size is large (Fisher, 1995). For this reason, the different levels were analyzed in two sets (level 1–2 and levels 3–5), which does not distort their assemblage-specific orientation, since according to previous orientation analyses, all levels show similar bimodal orientation patterns (Benito-Calvo and de la Torre, 2011). Since, data from levels underlying FLKN 1–2 were only obtained from Trench 1, splitting each level would have produced fairly small samples, which would have not been statistically reliable.

It is often desirable to supplement tests with graphical procedures (Fisher, 1995). For this purpose, Woodcock's diagrams where linear, planar and isotropic fabrics can be displayed were also used (Woodcock, 1977; Lenoble and Bertran, 2004).

Confirmation of results was obtained by using bootstrapped samples of the original data. A randomized bootstrap method was selected over permutation or other approaches (e.g., Monte Carlo) because it was assumed that each sample was representative of different populations. A non-parametric bootstrapping approach using an alternative model was carried out (Zieffler et al., 2011). Data were randomly resampled 1000 times because given the characteristics of data, that number of replicates provided accuracy in prediction of sample dispersion, standard error of mean values and power (Pattengale et al., 2010) and a higher number of replicates would not necessarily provide more accurate results (Chernick, 1999). Bootstrapped samples were then analyzed through the same omnibus tests as the original data (Rayleigh's, Kuiper's and Watson's tests).

In order to contextualize our analysis of FLKN material patterning, we present comparative data from a portion of the penecontemporaneous Bed I site, FLK Zinj, also first excavated by Leakey (1971). We do not provide *in situ* measurements of newly excavated archaeological material from this site, but instead analyze comparatively a detailed photograph and drawing by Leakey of the same small portion of the site. Specifically, we derived orientation data for the same fossil bones and stone tools visible on the photograph and depicted in the drawing in order to evaluate the accuracy of Leakey's drawings and thus gauge their usefulness for studying orientation patterns. We also provide here a summary of the empirical evidences, which attest for the lack of post-depositional transport in agreement with the anisotropy of the archaeological assemblages.

3. Results

For the orientation analysis, a total of 531 specimens (with A-axes being at least twice the length of B-axes) were used for FLKN 1–2, and 183 specimens for FLKN 3–5. Rose diagrams of horizontal orientations and the stereograms of azimuths of vertical/horizontal orientations show an isotropic pattern of materials in FLKN (Figs. 2 and 3). These results agree with the statistical tests, which indicate uniform random distributions of the orientations and, therefore, attest that the documented fabric for FLKN 1–2 and FLKN 3–5 is isotropic. Probability values for Rayleigh's, Kuiper's and Watson's tests are very high, supporting that the null hypothesis of isotropy at FLKN cannot be rejected (Table 1). Woodcock's statistical graphs show that for both FLKN assemblages, the k value is very low, as would be expected in fairly uniform random distributions (Figs. 2 and 3). These results are robust, as confirmed by the probability values of the bootstrapped samples. Although the p-values are somewhat lower for the bootstrapped samples than those obtained when using raw data, they are similar to the non-bootstrapped samples and well above the alpha level that determines the significance of the rejection of the null hypothesis of isotropy (Table 1). These results contrast with those documented previously (Benito-Calvo and de la Torre, 2011). A comparison of the rose diagrams in Figs. 2 and 3 shows a sharp contrast between the random patterns documented in the present study and the clear bimodal patterns inferred from Leakey's drawings. This questions that Leakey's drawings are accurate representations of fossil bones and stone tools as originally found at FLKN.

This latter claim is further supported by the contrast in the orientation patterns reported from FLK Zinj. In the only published photograph of the Zinj excavation where a match can be made between archaeological items as they appeared in

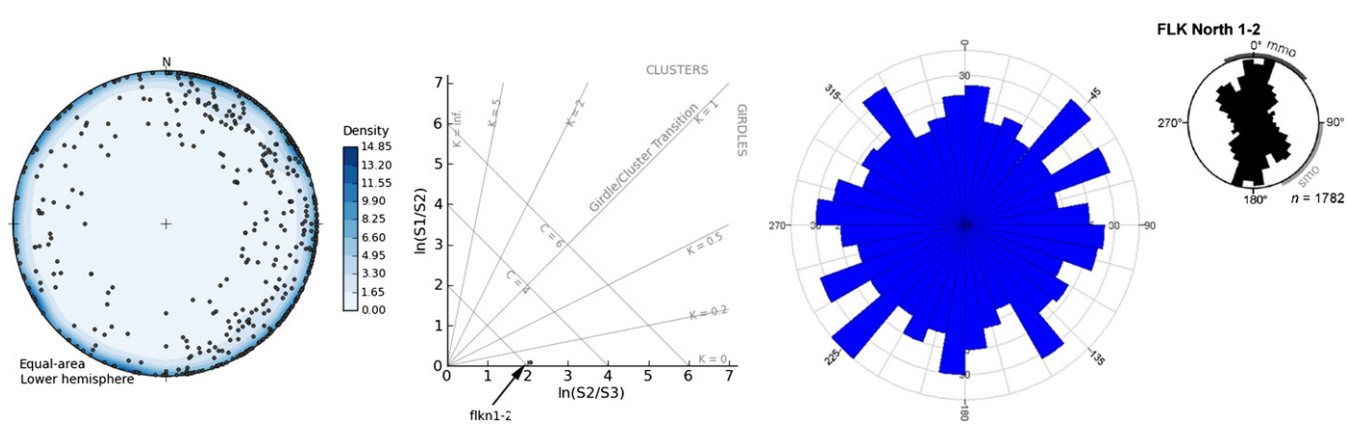

Fig. 2. From left to right: Stereogram showing the azimuth orientation of all the specimens with longitudinal axis at the Olduvai Bed I site of FLKN 1–2. To the right of it, a Woodcock diagram shows an isotropic fabric for the assemblage, with von Misses distribution k concentration values under 0.2. To its right, a rose diagram shows uniform bone orientation, which contrasts with the bimodal pattern (upper right corner) reconstructed by Benito-Calvo and de la Torre (2011) using Leakey's drawings.

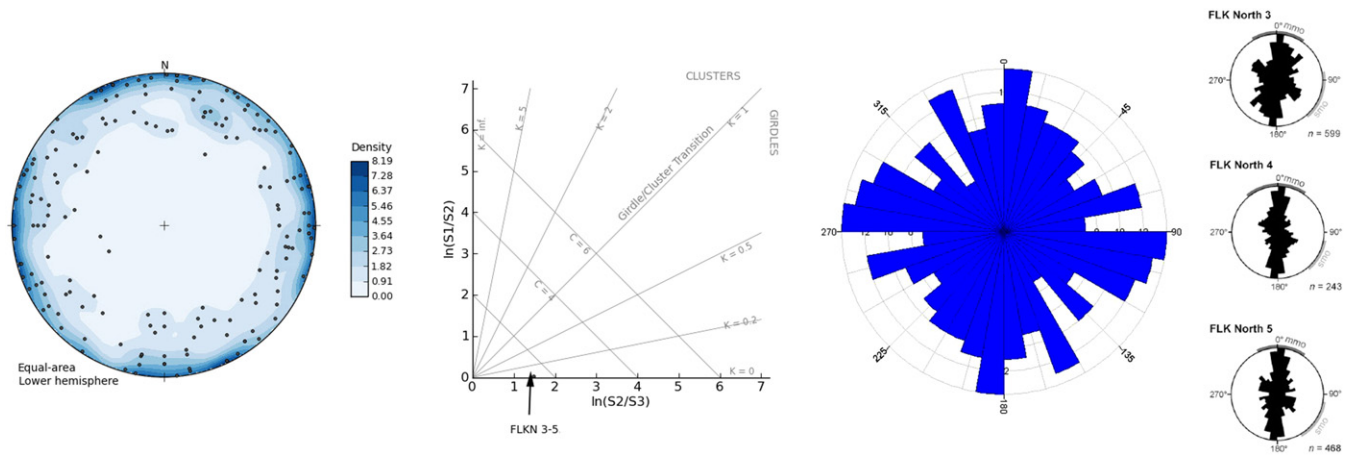

Fig. 3. From left to right: Stereogram showing the azimuth orientation of all the specimens with longitudinal axis at the Olduvai Bed I site of FLKN 3–5, where azimuth orientation data can be observed (Domínguez-Rodrigo et al., 2010a). To the right of it, a Woodcock diagram shows an isotropic fabric for the assemblage, with von Misses distribution *k* concentration values under 0.2. To its right, a rose diagram shows uniform bone orientation, which contrasts with the bimodal pattern for each level (far right) reconstructed by Benito-Calvo and de la Torre (2011) using Leakey's drawings.

excavation and how they were drawn, substantial distortion in item shapes and proportions, locations and orientations can be observed in the drawing that was used by to estimate orientation patterns at the site (Fig. 4). For example, some items that are visible on the photograph were not drawn. Others are visible on the drawing, but difficult to identify in the photograph, probably because they represent items that occurred beyond the upper limit of the level that was photographed. Also, several lithics and bones were drawn with different proportions and shapes (and, hence, different orientation axes). Several other objects were drawn in different positions, with different distances between the objects. The *Parmularius* skull, for example, was drawn with a NNE–SSW orientation while its original position is N–S. Other items were drawn perpendicular to each whereas their original angle in the excavation is oblique. We argue that this significant degree of mismatch over just a small portion of site likely indicates even greater non-alignment between photographically captured reality and artistically rendered approximation of item orientation when considering the much larger whole site.

4. Discussion

The study of orientation patterns in the components of geological structures or fabric is a developing field in structural geology (Twiss and Moores, 2007; Peternell et al., 2011). Thus far, most of the experimental work carried out in this emerging discipline has been conducted in glacial environments, work dealing with the movement and orientation of objects on thawing slopes (Harris et al., 2001) or due to solifluction processes, which cause an anisotropic diffusion of materials (Harris et al., 1997; Todisco et al., 2000; Hugenholtz and Lewkowicz, 2002; Lenoble et al., 2008). Geomorphic observations and experiments in glacial contexts have also focused on sorted patterned grounds, regarding the formation of polygons, stripes and stone-banked solifluction lobes (Washburn, 1979; Williams and Smith, 1989; Harris et al., 1993; Todisco et al., 2000; Matsuoka et al., 2003; Kessler and Werner, 2003; Bertran et al., 2010), as well as on documenting these processes in archaeological contexts (Wilson and Clark, 1991; Lenoble et al., 2008; Bertran et al., 2010). The orientation of till fabric has received a substantial amount of attention in structural geological studies. Till fabric analysis, as the study of the orientation and dip of sedimentary particles or components within a till matrix, includes only deposits of glacial origin. However, the methods derived from the study of these deposits can be applied to a variety of deposits in other contexts (Glen et al., 1957; Krüger, 1970; Andrews, 1971; Mark, 1973; Lawson, 1979; Kjær et al., 2001). These studies have been used as referents when analyzing material orientation patterns caused by mudflow (Lindsay, 1968), debris flow (Rappol, 1985; Major, 1998) and hillslope colluvium (Mills, 1983); the last producing similar patterns to those documented in periglacial colluvium (Millar and Nelson, 2001; Millar, 2006). Several methods have been developed to study mechanical interactions on the development of preferred orientations (Ildefonse et al., 1992), plane sampling (Iachan, 1985), and identification of anisotropy, including the use of eigenvalues (Woodcock and Naylor, 1983).

Still, all of these important studies and their findings are of limited applicability to the interpretation of material patterning on relatively flat lacustrine surfaces, such as the Olduvai paleolacustrine basin, where glacial processes (producing solifluction and sorted patterned grounds) never occurred. Likewise, understanding of slope-induced movement and orientation of materials, such as those produced by rainwash or run-off (Bertran et al., 1997), mudflow or hillslope colluvium does not provide adequate models for the Olduvai Bed I sites, which occupied fairly flatter surfaces than those used for modern experiments on hillslopes.

Instead, the physical forces capable of moving, transporting and orientating material in tropical alluvial contexts, like that reconstructed for Olduvai Bed I, are more likely to be caused

Table 1
Statistical tests of isotropy applied to FLKN 1–2 and FLKN 3–5 and their significance (*p*). *P* values <0.05 indicate anisotropy.

Raw data	Rayleigh's test		Kuiper's test		Watson's test	
	R	*p*	*V*	*p*	U^2	*p*
FLKN 1–2	0.0202	0.805	1.1147	>0.15	0.0453	>0.10
FLKN 3–5	0.0642	0.4705	1.2469	>0.15	0.071	>0.10
Bootstrapped data						
FLKN 1–2	0.0212	0.6385	1.2841	>0.15	0.0936	>0.10
FLKN 3–5	0.0761	0.2021	1.3012	>0.15	0.0921	>0.10

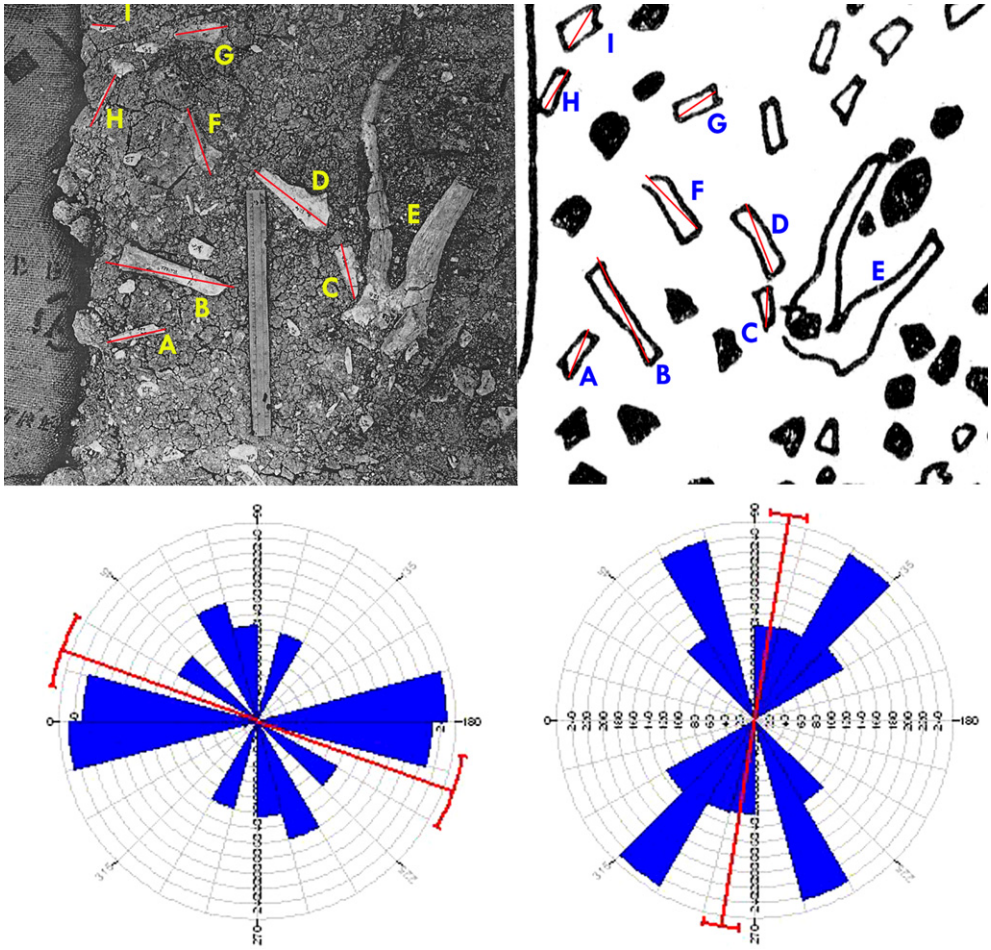

Fig. 4. Comparison of a detailed photograph of a small portion of the FLK Zinj floor before the removal of the archaeological pieces (left) and the same area as drawn by Leakey (1971) (right). Notice the lack of match between both images; several items in the photo were not drawn and others in the drawing are difficult to identify, probably because they represent items that occur beyond the upper limit of the photo. Several lithics and bones are drawn with different proportions and shapes from the photographic image. Further, several objects were drawn with different positions from those observed in the photo and the distance among objects is also different. Notice this to a moderate extent in bones C, D, F and to a bigger extent in the upper left corner where H,G & I cluster. As a result, the different location and shapes of the drawn pieces produce different orientations. Notice how the drawn *Parmularius* skull shows parallel NE orientation to several other drawn pieces whereas its original orientation is different. The most noticeable case is the orientation of A and B, with a perpendicular orientation to each other whereas their original angle in the excavation is oblique. When using A-axes as defined by Benito-Calvo and de la Torre (2011) (red lines), two bootstrapped samples (1000 times) of the bones identified in the photo (left rose diagram) and the same bones drawn in the map (right rose diagram) result in quite divergent orientations: a bimodal pattern with orientation very similar to that documented by Benito-Calvo and de la Torre (2011) in the latter but a unimodal pattern for the former. The unimodal orientation pattern produced for the photographed bones even shows radically different direction than any of the two predominant longitudinal-oblique bimodal orientations produced in the drawing. This clearly shows that the original orientations of items and the orientations as drawn by Leakey produce very different orientation results, casting doubts that the latter is an accurate reflection of the former, but a biased estimation at best. Rose diagrams were artificially oriented to the West and shows approximate North values at 90°. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

by hydraulic processes. Referents created in structural geology based on clast-fabric analyses (Kjaer and Krueger, 1998) or pebble orientation (Rust, 1972) are more informative for these contexts; however, only experiments based on fluvial processes are appropriate for modelling physical agents creating anisotropy in alluvial plains. Thus, experiments on water flows and hydraulic jumbles (e.g., Toots, 1965; Voorhies, 1969; Boaz and Behrensmeyer, 1976; Hanson, 1980; Schick, 1984; Coard and Dennell, 1995; Coard, 1999) and overland flow (Poesen, 1987; Lenoble, 2005) are more adequate proxies for the orientation of materials at the Olduvai sites.

Previous studies on the orientation of the Olduvai materials presented two questions: are materials in the sites oriented anisotropically? If so, do analogical frameworks suggest that they are assemblages so post-depositionally disturbed that they should be considered derived? Some authors hint this could be the case when they describe the sites by employing analogies involving dynamic transport processes, in which terms like "*in situ*" and "autochthony"[1] are used as synonyms (Benito-Calvo and de la Torre, 2011).

[1] Although the term *in situ* is often employed ambiguously by some archaeologists as "within a context" or in its "original place", its original paleobiological and taphonomic meaning concerned items, whose stratigraphic/geological provenience is known, irrespective of whether they are in primary (autochthonous) or secondary (allochthonous) position in such contexts (Fernández-López, 1990, 2000). Hence, all Bed I sites are *in situ*. Some archaeological definitions of *in situ* follow its original meaning: it is a term used to describe an artifact at the point of discovery, when it has not been removed from its surrounding soil matrix (http://archaeology.about.com/library/glossary/bldef_insitu.htm). See also the definition of the term by the Society for American Archaeology.

4.1. Analogies, autochthony and allochthony

Since unimodal orientation patterns are documented under intense creep and solifluction, a bimodal longitudinal-oblique distribution of item orientation is not necessarily caused by downslope erosion or rainwash (Bertran et al., 2010). However, some downslope erosion processes (e.g., items lying on a slope exposed to wind and rain) are different from solifluction and debris flows and need not necessarily be intense. In such cases of gentle downslope erosion, minimal movement of bones and other materials occurs, resulting potentially in the bimodal orientation of those materials.[2] A modern example of this phenomenon was documented in a spotted hyena (*Crocuta crocuta*) den, with a floor showing downslope inclination, in the Maasai Mara (Kenya) (Kerbis-Peterhans, 1990). The observed orientation pattern of bones in the Maasai Mara den was similar to that reported for the Bed I sites, with a bimodal longitudinal-oblique distribution (Fig. 5a). Further, the preferential N–S item orientation previously documented at Bed I site FLKN 1–2 could also be explained as the gravity effect (aided by wind or rain water) of non-horizontal ground, since items were deposited at the site on a downslope surface tilting towards the north and the east (Domínguez-Rodrigo et al., 2010a; Fig. 4). That direction in the inclination of the FLKN slope is documented in most layers across the exposed sequence (Domínguez-Rodrigo et al., 2010a; Figs. 2 and 3) and in some parts of the sequence (e.g., between levels 1–3 and 4–5 and levels 6–7) the inclination is very pronounced ($>10°$). Preferential orientation under trampling has also been documented (Krajcarz and Krajcarz, in press).

Aeolian processes could have also played a role in creating bimodal object orientation patterns. Prendergast and Domínguez-Rodrigo, 2008 monitored the remains of five cattle (*Bos taurus*), which died on the floodplain of Lake Eyasi (Tanzania), for several months. No biotic taphonomic agents nor hydraulic process affected the remains (the lake was dry for most of that year and the rainy season brought virtually no rain), but nonetheless the cattle bones reoriented simply by the action of strong N–S winds that course over the lake during the dry season (Fig. 5b).

Based on Leakey's (1971) drawings, the FLK Zinj site also appears to show an anisotropic orientation pattern of stone tools and fossils. With regard to inferences of early hominin behavior, FLK Zinj has long been considered one of the most important Bed I sites (summarized in Domínguez-Rodrigo et al., 2007). Table 2 summarizes various taphonomic data from FLK Zinj that contradict a hypothesis that the site was significantly modified post-depositionally (see also Kroll and Isaac, 1984; Potts, 1988) (Fig. 6). In addition, taphonomic data do not indicate that any of the paleoanthropological assemblages from the Bed I sites of FLKN or FLKN-North (FLKNN) are allochthonous either. Highly skewed bone specimen size sorting, low representation of easily transported bone types and the presence of bone surface microabrasion typical of flowing water dragging bones across sediment are all missing in most of the Bed I archaeological assemblages. Refitting of bone pieces and biometric matching of skeletal elements in spatial connection of potentially the same individuals (recent work at FLKN) all provide further support for the interpretation of autochthonous Bed I assemblages (Domínguez-Rodrigo et al., 2010a).

The deficit of the smallest-size fraction of bones at some Bed I sites (e.g., FLKN, FLKNN) might be seen as evidence that these items were removed from the sites by the current action of water. But, evaluating this hypothesis within a broader, and thus, more realistic, actualistic framework suggests otherwise. With regard to small bone fragments, the FLKN and FLKNN assemblages are anomalous only when compared to human-generated, experimental faunas, in which marrow-bearing bones were intensively fragmented with hammerstones. In contrast, bone size distribution in the FLKN and FLKNN assemblages matches closely that in faunas modified mostly or exclusively by carnivores (e.g., Castel, 2004) (Fig. 7). More specifically, the fossil assemblage pattern agrees most precisely with that of faunas generated by large felids. Bone assemblages accumulated by felids, such as leopards (*Panthera pardus*), are characterized by a large proportion of complete prey bones and very low levels of bone fragmentation (summarized in Domínguez-Rodrigo and Pickering, 2010; see also, de Ruiter and Berger, 2000; Pickering et al., 2011). Taphonomic studies of FLKN and FLKNN demonstrate that large felids were the dominant carcass accumulators and bone modifiers at those sites in the early Pleistocene (Bunn et al., 2010; Domínguez-Rodrigo et al., 2007). Thus, it is very reasonable to suggest that bone specimen size distribution in the faunas from those sites may have little or nothing to do with water sorting and winnowing.

4.2. Are previously documented orientation patterns at Bed I sites an artifact of method?

A methodological assumption made by Benito-Calvo and de la Torre (2011) about the Olduvai Bed I sites, against taphonomic evidence to the contrary (Frostick and Reid, 1983), is that all bones with a longitudinal axis, irrespective of their size and shape, are equally transported and oriented under the same force. In contrast, Nagle (1967) showed that under the same wave or flow processes, shells oriented differently according to their shape. More elongated shells were oriented parallel to the waves or flows, whereas others adopted either a transversal or an oblique orientation. This finding, instead of recurrent disturbing post-depositional processes, has the potential to explain bimodal longitudinal-oblique orientation materials patterns in the Bed I sites and other sites.

The results of the present study on FLKN shows an important mismatch between orientation data directly collected at the sites and those indirectly derived from some of Leakey's drawings. These results question the assumption that all Leakey's (1971) Bed I site plans are *precisely* accurate representations of the original excavated assemblages. This is obviously not the case, as a simple count of the number of objects plotted on any particular site plan is compared to the actual number of curated objects from that site (e.g., for FLKN4, 260 bone specimens are plotted on Leakey's (1971) plan, versus the actual number of 685 curated bone specimens from the excavated assemblage). This will cause researchers to take serious pause about just how informative are Leakey's (1971) published site plans for reflecting the *actual* original orientation of paleoanthropological collections in those sites. This precaution could probably be applied to orientation patterns derived from all archaeological drawings made by hand, ours included (Domínguez-Rodrigo et al., 2010a), which are made as a rough reference to the location of items, but there are probably substantial errors regarding orientation (certainly more than those derived from total station reconstructions), because either orientation is approximate or because the item shape is not faithfully reproduced, with serious repercussions for the orientation of

[2] Benito-Calvo and de la Torre (2011) argue that longtitudinal unimodal or bimodal longitudinal-transverse object orientation patterns characterize the spatial effects of water transport, creep and downslope movement. Isaac (1967) remarked that some of these and other criteria are good for extreme cases, but that they were not good models for marginal cases, such as local rearrangement without transport. One of his experiments (plot 2), situated in a small channel with sandy substrate, underwent re-orientation after a mild flow of water, with pieces showing a predominant orientation (transverse to the current) and some showing a secondary oblique orientation to it.

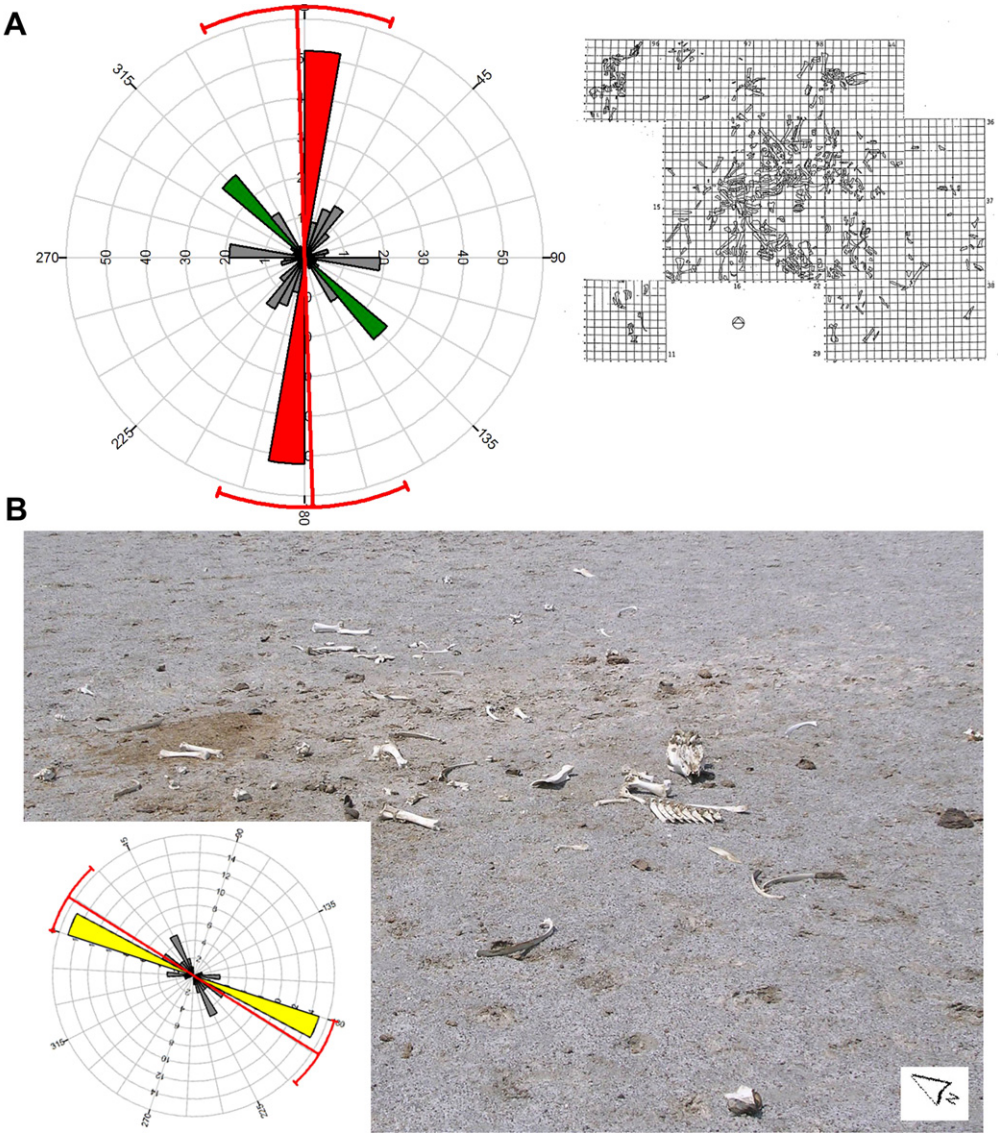

Fig. 5. A, Rose diagram (left) showing the bimodal longitudinal-oblique orientation documented for bones with long axes in a Maasai Mara (Kenya) hyena den (right) (den plan from Kerbis-Peterhans, 1990). Preferential orientation is shown by Rayleigh ($R = 0.2719$, $p = .001$), Kuiper ($V = 3.2644$, $p = <0.01$) and Watson ($U^2 = 0.917$, $p = <0.01$) tests. B, Rose diagram (left) showing the bimodal longitudinal-oblique orientation documented for the bones of one cow on the dry Lake Eyasi (Tanzania) floodplain (Prendergast and Domínguez-Rodrigo, 2008) (right). Preferential orientation is shown on a bootstrapped sample (1000 times) by Rayleigh ($R = 0.187$, $p = .001$), Kuiper ($V = 5.561$, $p = <0.01$) and Watson ($U^2 = 1.155$, $p = <0.01$) tests. Statistical intervals are shown in different colors of the petals. Key: Gray (isotropic): Magnitude < Mean Percentage + Standard Deviation. Green (moderately anisotropic): Mean Percentage + Standard Deviation < Magnitude < Mean Percentage + (Standard Deviation × 2). Yellow (fairly anisotropic): Mean Percentage + (Standard Deviation × 2) < Magnitude < Mean Percentage + (Standard Deviation × 3). Red (Strongly anisotropic): Direction >Mean Percentage + (Standard Deviation × 3). Red diameter and arcs indicate 95% confidence intervals of anisotropy; that is, the confidence interval around the vector mean that most likely contains the true population mean direction.

A-axes. This emphasizes that such drawings cannot replace the accuracy derived from orientation data collected with compass and clinometer.

We have argued previously that one can successfully reconstruct post-depositional site processes only when a multivariate approach is employed (Domínguez-Rodrigo et al., 2007). With that in mind, we stress here that item orientation is just one relevant site variable, a single variable that is subject to equifinal taphonomic processes. To wit, objects with an A-axis can be easily oriented locally under the influence of low-energy forces. To overcome this equifinality, and, from a taphonomic perspective, in order to properly assess the potential array of post-depositional processes affecting any given site, attention must be given to other variables, as well. In this light, we have suggested that the Olduvai Bed I sites preserve autochthonous material assemblages, which experienced limited post-depositional disturbance that was mostly caused by biotic actors (Domínguez-Rodrigo et al., 2007).

4.3. A summary of other taphonomic analyses and their bearing on the documented orientation pattern at FLKN

Taphonomic research on the FLKN fauna concludes that carnivores were responsible for accumulating the bones found at FLKN 1–2 and FLKN 3–5 (Domínguez-Rodrigo et al., 2007, 2010a). This conclusion is based on: (1) tooth-marking on ungulate long limb bone diaphyseal specimens; (2) the types and frequencies of notches on long limb bone specimens; (3) notch ratios and

Table 2
Several arguments documenting the autochthony of the FLK Zinj assemblage.

Variable	Arguments
Bone abrasion and rounding	Benito-Calvo and de la Torre (2011) (B&T) use Pott's (1988) estimates of abrasion indices to evaluate the importance of item movement by the effect of water. However, they misinterpret Potts' conclusions. Potts used bone rounding and edge abrasion as a proxy for hydraulic transport, but he stressed that these modifications could also be caused by plant roots, soil chemistry and even hyena bone gnawing (p. 65). Potts admitted that the interpretation of surface rounding was not clear (p. 69). Domínguez-Rodrigo et al., (2007) recognized that, when considered in isolation, it is impossible to infer sometimes if bone rounding is the result of partial digestion by carnivores or the effects of soil chemical processes. Sediment abrasion by bone movement not only produces polishing but also microabrasion (regardless of sediment type) on most cortical surface (Thompson et al., 2011) (*contra* Benito-Calvo and de la Torre's assertion that bone transported on clay does not create any modifications). This is not detectable in most of the Bed I assemblages, such as FLK Zinj. Rounding of a few bones from FLK Zinj (<2%) is frequently accompanied by conspicuous evidence of biochemical modification of cortical surfaces, probably caused by the same diagenetic process (Domínguez-Rodrigo et al., 2007). The virtual lack of polished or rounded bone with typical microabrasion associated with water transport at FLK Zinj argues against any meaningful influence of water in the movement of bones over metric distances at or into the site.
Bone hydraulic groups	Reference to bone hydraulic transport groups must proceed with caution because carnivore post-depositional ravaging of bone accumulations affects those skeletal elements in the transport group most prone to be transported by water. However, despite this, Potts (1988) remarked that between 35 and 45% of elements at sites were easily transported bones (32% at FLK Zinj), which attests to the negligible impact of water movement on the Bed I assemblages. This suggests that if carnivore ravaging had not been a taphonomic issue at the Bed I sites, as it strongly is (Domínguez-Rodrigo et al., 2007), the easily transported elements could potentially have been predominantly represented.
Anisotropic distribution of microfauna	Potts (1988) emphasized that the abundance of microfaunal remains in connection with macrofaunal specimens also suggested to minimal post-depositional disturbance. It could be argued that the deposition of microfauna could have occurred after water disturbance. However, if that had been the case, one would expect an isotropic distribution of microfaunal remains when compared to the macrofaunal ones. Instead, most microfaunal remains found at FLK Zinj occur in the small area that comprises the bulk of the macrofaunal accumulation documented on the north-eastern corner of the site. Leakey (1971) even singled out a dense patch of it.
Abundance of small fragments	Bone specimen size distribution at FLK Zinj is the same as in experimental hammerstone-broken assemblages unmodified by post-depositional disturbance (Blumenschine, 1995; Domínguez-Rodrigo et al., 2007). Potts (1988) stresses that 38% of all lithics at the site are <2 cm. The abundance of small bone fragments and the high amount of lithic debris contradict a hypothesis of significant disturbing water flow or transport processes at the site.
Flat topography of the FLK Zinj paleosol	Despite their discussion of orientation of plants and possible irregularities on the FLK Zinj surface that contained depressions flooded by ponds, B&T fail to provide any empirical evidence of these features. We are in a position to address this issue, since we have opened the only trench (other than Leakey's excavation) exposing more than 4 m^2 of the FLK Zinj paleosurface and the closest one to the densest accumulation excavated by Leakey at the site (argued by B&T to be a pond) (Fig. 6). Plant remains documented in this trench cannot be determined as either branches or roots. Their orientation was highly variable, but their small size indicates that if any water flow existed at the site, it must have been low-energy; otherwise these plant remains would have been transported away. Furthermore, the site surface, exposed over 12 m^2 is completely horizontal and lacking any depressions susceptible of becoming ponds (Fig. 6b). A further way to test the pond hypothesis is to follow the outline of the FLK Zinj floor in the stratigraphic profile (Fig. 6a; arrow). This reveals fairly horizontal surfaces both at the site and even across the gully (see Ashley et al., 2010a: Fig. 5b; Domínguez-Rodrigo et al., 2010b, Fig. 8). Further, ongoing research on soil micromorphology at FLK Zinj will definitely confirm whether the surface was at any point covered with pond water when the assemblage was formed.
Sedimentation	A pond as well as any other important water disturbing process would have covered archaeological items with sediment. Instead, the paleosol and its overlying items are covered directly by an airborne tuff.
Refitting and conjoining of artifacts and bones	FLK Zinj contains one of the largest sets of refitted bones and stones in the Early Pleistocene archaeological record. The refitting of green-fractured bone, with some specimens so close to each other despite their differences in size (Kroll and Isaac, 1984) is a further proof that post-depositional disturbance was minimal. Further, the clustering of most hominin-modified bones and most-carnivore gnawed bones attests that the assemblage did not undergo any significant transport.
Spatial patterns according to item types and lag deposits	Davis (1975) documented a statistically-supported pattern at FLK Zinj consisting of the main cluster containing all the small bones and detached lithics and a secondary scatter containing the largest (complete) bones and the largest flaked pieces and manuports, occupying a southern peripheral position. The largest materials occur most distally to the small channel (<two feet) reported by Leakey (1971) to the north of the site. This is the opposite of what should be expected if this distribution was caused by fluvial transport (Schick, 1984). This has not been experimentally shown to be feasible in any of the water-transporting models proposed by Benito-Calvo and de la Torre (2011). These authors consider the bimodal object orientation pattern without paying attention to the characteristic elongated lag deposit typical of a water current dragging materials in one direction. Accumulations at the densest parts of FLK Zinj and FLKN 1-2 have been described as oval/circular structures instead of elongated deposits organized in the same direction as the main orientation mode (Ohel, 1977; Leakey, 1971). Furthermore, the small channel reported by Leakey is of the size and dimensions of a hippo trail (expected in the wetlands). So it has never been documented to be a proper channel, specially because it was not filled with sands, as typically documented in channels, but with clay (Leakey, 1971).

breakage plane angles on bones; (4) ungulate skeletal part representation. In addition, despite good cortical bone surface condition—ideal for the preservation of butchery marks had any been imparted by prehistoric hominins—in the FLKN 1–2 and FLKN 3–5 faunas, there are very few stone tool cut and percussion marks on bone specimens from those assemblages.

More specifically, our taphonomic studies, in conjunction with zooarchaeological data, indicate that, over most of the time that the site was forming, felids were the primary agents of carcass accumulation at FLKN (see data in Domínguez-Rodrigo et al., 2007). First, the FLKN 1–2 and 3–5 bone assemblages are dominated by just two bovid taxa, *Parmularius altidens* and *Antidorcas recki*, indicating the activities of a specialized hunter and carcass collector. In contrast, hyenas are more eclectic, typically preying on and scavenging a wider range of animals. Second, the high representation of complete bones in the FLKN faunas, including, prominently, those from small sized animals, indicates that hyenas were unlikely major contributors to the formation of the preserved samples. Third, in contrast to hyena-generated assemblages, the FLKN faunas show an absence of digested bone specimens, coprolites and subadult hyena remains. Fourth, tooth mark frequencies in the FLKN faunas are much lower than those reported in

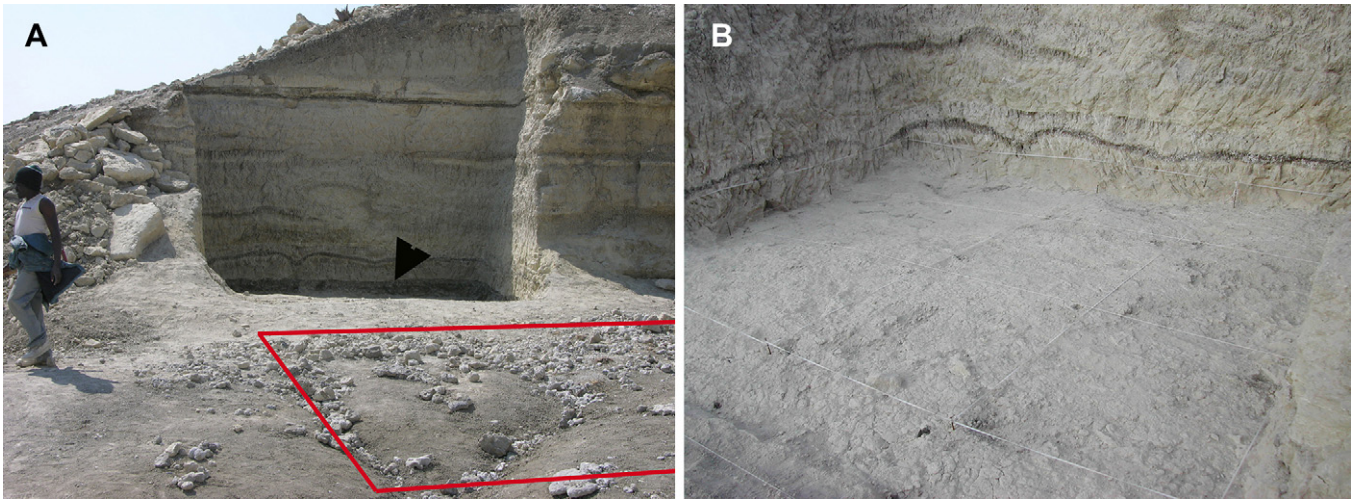

Fig. 6. A, Trench (4 × 3 m) excavated in 2007 on the north-eastern wall of Leakey's excavation at the Olduvai Bed I site of FLK Zinj. Red rectangle delimits the area of the densest accumulation of materials (with the smaller stone artifacts tools and highly fragmented pieces of bones) exposed by Leakey. Arrow shows the linear outline of the horizontal surface of the FLK Zinj paleosol. B, FLK Zinj paleosol exposed after the removal of the overlying Tuff IC and prior to excavation. Notice the absence of depressions or relief that could be attributed to ponds or water puddles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

hyena-generated assemblages, whereas the presence of ungulate axial skeletal elements in FLKN is much higher than seen in modern hyena assemblages.

In sum, the only indications of hyena involvement in the formation of the FLKN faunas are the large size of tooth marks on fragmented bone specimens, which suggest that they intermittently scavenged from felid-generated kills and/or natural ungulate deaths deposited at the site. More frequently, though, it seems that hyenas did not interact with carcasses at the site, many of which are preserved in semi-complete states. Bones from this type of common occurrence at FLKN bear modifications typically documented on remains from experiments with modern felid as the carcass consumers (Domínguez-Rodrigo et al., 2007). In fact, the FLKN 1–2, FLKN 3–5 faunas are among the best examples from Olduvai Bed I of felid-accumulated and modified bone assemblages.

In sum, FLKN, in the form of a vertically dispersed archaeological deposit, is time-averaged and indicates very extensive spans between depositional events (Ashley et al., 2010b). The long period of time represented at the site samples a variety of taphonomic fauna-forming processes, including periods of intense felid carcass accumulation (occasionally with secondary scavenging by hyenas) and alternating phases in which animals (especially megafauna) appear to have died naturally at the site. This kind of taphonomic heterogeneity is not unexpected in a palimpsest, like FLKN, which spans a vast period of total accumulation.

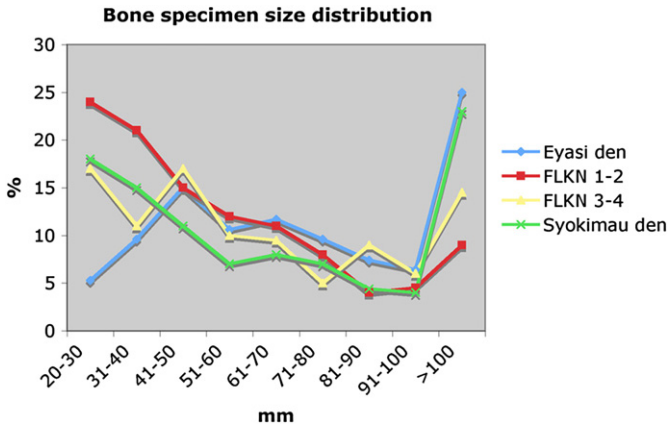

Fig. 7. Bone specimen size distribution in the Olduvai Bed I FLKN 1–2 and FLKN 3–4 fossil faunas compared to bone specimen size distribution in two modern spotted hyena-collected faunas from Eyasi, Tanzania (Prendergast and Domínguez-Rodrigo, 2008), and Syokimau, Kenya (Egeland et al., 2008). Note that the smallest-size fraction (20–50 mm) is better represented in the fossil assemblages than in the modern hyena-generated assemblages.

In contrast to this complicated historical reality, Leakey's original drawings of the site plans, with similar material orientations across all levels, suggest instead that the physical processes responsible for such orientation patterns must have been extremely regular over the entirety of site formation. In addition to the taphonomic points we stress above, clay deposits at FLKN indicate that the slow-energy processes responsible for sedimentation of the site operated on a fluctuating topography and as a result of the interplay between sedimentation and erosion. Indeed, the lower and upper levels of the site must have been exposed differentially to potential hydraulic processes and their directionality, as well as to the potential effects of wind.

A hypothesis of allochthony cannot be reconciled with the completeness of the taphonomic entities deposited at FLKN (sensu Fernández-López, 2006). Several ungulate carcasses are represented by various antimeric skeletal elements (Domínguez-Rodrigo et al., 2007, 2010a). Bone specimen size distribution does not match that of analogical samples formed in transported assemblages or lag deposits (see above). Skeletal part representation at the site is also at odds with these processes. There is lack of polishing and abrasion typical of bone transport by hydraulic jumbles or fluvial currents. Overall, taphonomic analyses suggest that the FLKN assemblage is basically autochthonous. The material orientation patterns at the site, demonstrated by our recent excavations, are predominantly isotropic. The predominance of isotropy supports the hypothesis that the assemblage is autochthonous in character, as is also corroborated by our previous taphonomic research.

5. Conclusions

There is a sharp contrast between the object orientations reconstructed from Leakey's (1971) drawings for the FLKN assemblages compared to our direct orientations recorded for *all* specimens with a longitudinal axis using a compass and

clinometer on a recently excavated sample from the same site (Domínguez-Rodrigo et al., 2010a) (Figs. 2 and 3). In contrast to the orientation patterns reported by Benito-Calvo and de la Torre (2011), the complete recently excavated sample does not show a predominant orientation of items. This is a spatial arrangement of objects indicative of autochthonous assemblages. This finding calls into question inferences of post-depositional processes at FLKN, which are based on material orientation data alone and which are derived from secondary sources (such as drawings). TOPPP's excavations of FLK Zinj and FLKNN did not produce a sample sufficient to statistically analyze orientation patterns. However, data and arguments summarized in Table 2 support that FLK Zinj is also an autochthonous assemblage.

The main conclusion of our analysis is that Leakey's (1971) drawings of the Bed I sites are incomplete and inaccurate representations of items (in terms of orientation and, probably, in terms of specimen shape and inter-relation) as found during excavation. Potts (1988: 69) argued that "the excavated assemblages [at Olduvai Bed I] reflect quiet water flow acting for a short period of time, having the potential to move some objects within the accumulation at each site." This interpretation is not contradicted by any of the aforementioned arguments, and might even be supported by the object orientation data we present above. As described in Domínguez-Rodrigo et al. (2007), the complexity in the formational histories of the Olduvai Bed I sites does not involve, in a significant way, physical post-depositional processes, but is rather primarily patterned by the diversity and interactions of intervening biological actors.

Acknowledgments

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