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Orientation patterns of wildebeest bones on the lake Masek floodplain (Serengeti, Tanzania) and their relevance to interpret anisotropy in the Olduvai lacustrine floodplain

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ABSTRACT

A study of bone orientation patterns at a wildebeest bonebed deposited in the floodplain of Lake Masek (Tanzania) shows that portions of the assemblage exhibit anisotropy probably caused by the combined action of lake transgression and regression, and the watersheet formed during the rainy season, which is also responsible for a large part of the microtopographical features of the surface where the bonebed was formed. Some taphonomic indicators (absence of polished or abraded bone, similar representation of Voorhies' anatomical groups I and III) show that the anisotropic trend was formed under very low-energy conditions. Anisotropy can be locally produced in autochthonous assemblages. Bone orientation patterns need to be combined with other taphonomic techniques to determine the depositional nature of any given assemblage.

1. Introduction

Mass drownings of wildebeest at Lakes Masek and Ndutu have long been known in ecological studies of the Serengeti (Tanzania) (Sinclair, 1979). Located in the north-west side of the Ngorongoro Conservation Area, Lake Masek is surrounded by the vast plains of Serengeti National Park. These drownings have been documented during the crossing of the lake in the wet season. The recurrent nature of these drownings is linked to the migratory path that wildebeests undertake by crossing Lake Masek in their annual movement towards the northern grassland plains. In 1973, more than 3000 calves were documented to have died during the lake crossing (Sinclair, 1979). This and subsequent death events have enabled the formation of an authentic bonebed, which is characterized by being autochthonous, by having an extremely dense concentration of bones (see Fig. 1) and by displaying a biased skeletal part profile due to the combined action of the lake water, the watersheets formed during the rains and by carnivores consuming and transporting away determined elements.

From a paleontological point of view, this modern assemblage is an opportunity to create an analogical framework, which can contribute to the interpretation of prehistoric bonebeds. A preliminary taphonomic study was carried out on this area by Capaldo and Peters (1995) who quantified the number of individuals and skeletal parts. Despite the large concentration of subadult individuals previously documented (Sinclair, 1979), Capaldo and Peters (1995) found that adults were better represented skeletally. This is accounted for by the accumulation being a palimpsest of multiple depositional events, which respond to mass deaths of hundreds of individuals and sequential deaths of single individuals or small groups. Capaldo and Peters (1995) also documented that most skeletal elements were complete and that axial and long bones were predominant. Previous taphonomic research on a similar bone concentration of wildebeest was carried out by Dechant-Boaz (1982) on the Mara River (Kenya), where even excavation at selected spots was conducted. Rapid sedimentation in this alluvial setting enabled the preservation of large numbers of axial elements as well as fairly complete skeletons.

The extensive accumulation of carcasses in Lake Masek occurs on the lacustrine floodplain, which during the rains becomes a mudflat. Capaldo and Peters (1995) report that most of the accumulation occurred along ∼400 m on a narrow band of ∼20 m. They also documented that the accumulation was highly variable and that the floodplain was affected by several erosion features, such as shallow channels (i.e., rills) and sedimentary fractures/steps as can be observed today. In their study, Capaldo and Peters carried out a selective survey along this dense strip of the bonebed, and an

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Fig. 1. General view of a part of the area where a dense cluster of wildebeest bones was observed in 2012 in the lake Masek floodplain and where sampling for the present study was conducted (Photograph by Javier Trueba). A, cluster with lake in the background. B, setting of the sampling grid. Length of measuring tape = 4 m.

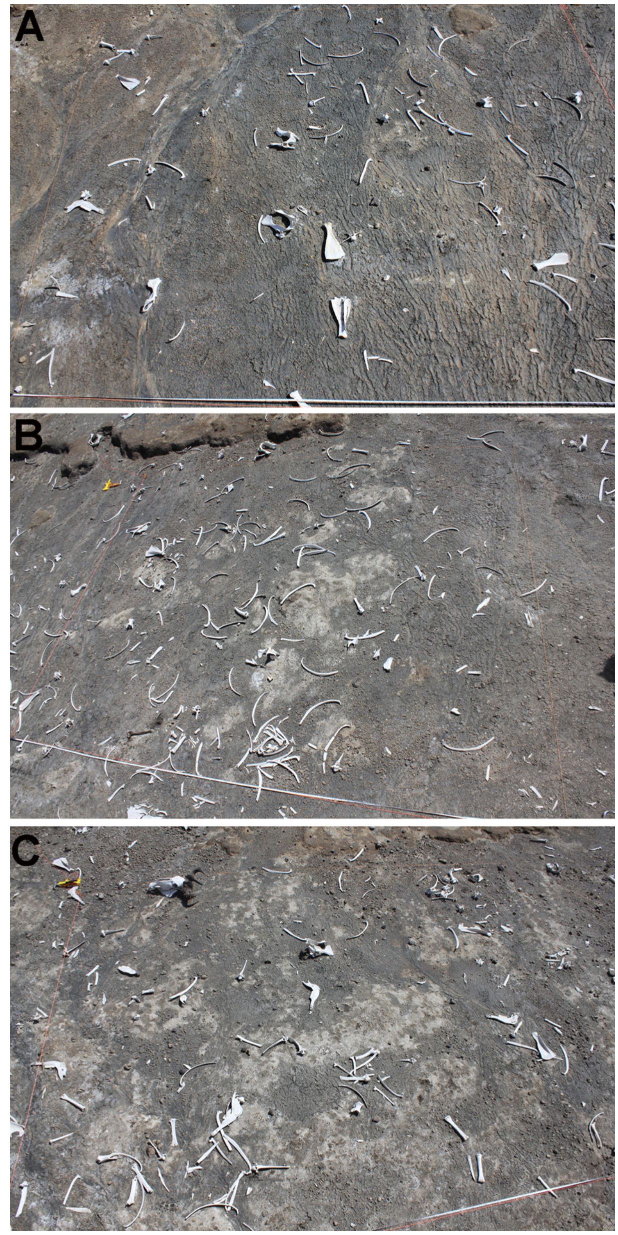

Fig. 2. Bone distribution in three of the sampling units. A; Sampling unit 1; B, Sampling Unit 2; C, Sampling Unit 3.

intensive analysis of a smaller transect (14 × 8 m) where all bones were counted and studied as a control for the selective sampling.

We revisited this dense concentration area and carried out a selective study of bone orientation patterns on a limited number ($n = 5$) of transects. Most carcasses seem to be accumulated here by the combined effect of wind and the lake water depositing them. There is a necrokinesis process in which carcasses are probably moved or transported prior to deposition and accumulation. Therefore, the parallel alignment of carcass remains to the lake water front is not unexpected. Recently, several controversial interpretations have been presented regarding purported orientation patterns on bones documented on the paleo-lake floodplain at Olduvai Gorge and their taphonomic meaning (Benito-Calvo and de la Torre, 2011; Domínguez-Rodrigo et al., 2012, 2013; De la Torre and Benito-Calvo, 2013; Domínguez-Rodrigo and García-Pérez, 2013). No proper referential analog exists reporting how carcass remains deposited on lacustrine floodplains are affected by modifying factors such as wind, trampling, water flows, and sedimentation by various processes, creating anisotropy or isotropy. The location of the Masek bonebed is therefore a heuristic proxy for several Olduvai Bed I localities, as the latter occupied a similar paleoenvironment. Our goal was to document if low-energy processes operating on these mudflats can create anisotropy in autochthonous assemblages, that is, in the absence of bone transport processes after carcass deposition.

Furthermore, most orientation patterns documented archaeologically and paleontologically have been reported at the assemblage level, without specifying how different skeletal element types are affected by these anisotropic processes (e.g., Toots, 1965; Voorhies, 1969). In particular, bone shape has been argued to determine the way elements respond to orientation forces (e.g., Frostick and Reid, 1983), although recent experiments show that different bone shapes align their symmetrical longitudinal axes to the direction of the orientation energy (water flow, gravity, trampling) (e.g., Kerbis-Peterhans, 1990; Domínguez-Rodrigo et al., 2012; Domínguez-Rodrigo and García-Pérez, 2013; Krajcarz and Krajcarz, 2013). Here, we will provide information on the orientation patterns provided by different types of bones and how they contribute to the assemblage isotropic or anisotropic configuration.

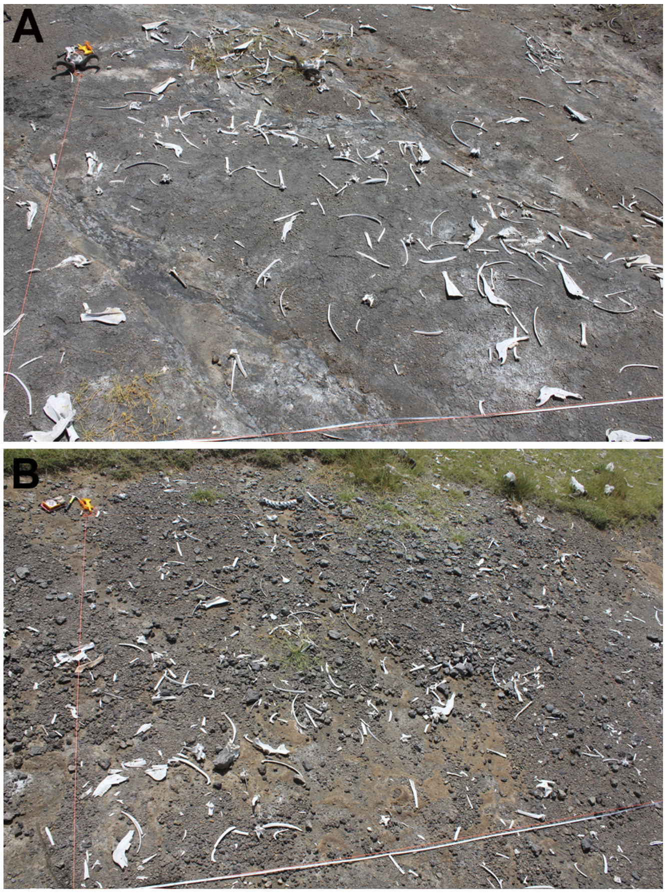

Fig. 3. Bone distribution in two of the sampling units. A, sampling unit 4; B, sampling unit 5.

We show that parts of the Masek lacustrine floodplain where the bonebed is concentrated display anisotropic patterns, whereas others do not. The local characteristics of each depositional setting are discussed vis-à-vis the lacustrine depositional dynamic of the assemblage to determine which process (lake deposition of post-depositional processes intervening locally) are more influential in producing these anisotropic fabrics. We concluded that anisotropy can be produced in autochthonous assemblages deposited in lacustrine settings in the absence of transport processes.

2. Method and sampling

We carried out our analysis in June 2012 on the shores of Lake Masek along the densest part of the bonebed (Fig. 1). Five sampling units of 20 m^2 (5 m $\times$ 4 m) were selected randomly, with their long axis pointing more or less parallel to the lake shore. We selected sampling areas following bone density and topographic variation criteria.

Orientation data for the horizontal and vertical planes of the bones within the boundaries of each sampling unit were directly taken with the aid of a compass and a clinometer, with an accuracy of one-degree, although here only compass azimuths will be provided (Voorhies, 1969; Fiorillo, 1991; Alcalá, 1994; Howard, 2007). Measurements were taken along the A-axis of the bone, which divided each specimen more or less symmetrically through its longitudinal plane. This method is based on experiments that show that long objects actually tend to orient according to their longitudinal symmetry axes when exposed to physical processes (Toots, 1965; Voorhies, 1969; Domínguez-Rodrigo and García-Pérez, 2013; Domínguez-Rodrigo et al., 2013).

Measurements were taken for a total of 686 specimens (Table 1). Axial elements ($n = 519$) make up 75.7% of the sample. Appendicular bones ($n = 133$) comprise 19.4%, of the sample and cranial specimens ($n = 34$; 4.9%) make up the rest. The vast majority of the recorded elements lay on the surface and most of them were almost complete. Only some of them were partly covered by sediment and a few showed a low degree of weathering on their cortical surfaces (Behrensmeyer, 1978) This was observed preferentially in cancellous bones, such as ribs, distal ends of scapulae and vertebral apophyses. In contrast, most of the denser bones, such as metapodials, were complete and did not show any signs of weathering. A detailed description of each sampling unit, containing the inclination of the surface and the topographic features, together with how bones were located with respect to erosive channels and rills is provided in Table 2 (Figs. 2 and 3).

The analysis of the orientation of bones was carried out separately for each sampling unit. Isotropy (or randomness in orientation) can be statistically assessed by using *omnibus* tests. For this purpose, Kuiper's test (V) was used to detect multi-modal

Table 1
Sample size and bone material in each sampling unit.

Sampling unit	Sample size	Total axial elements		Total appendicular elements		Total cranial elements	
1	87	76	48 ribs 20 vertebrae 5 scapulae 3 pelves	10	10 long bones	1	1 mandible
2	183	139	116 ribs 16 vertebrae 3 scapulae 4 pelves	41	34 long bones 4 phalanxes 2 calcanei 1 astragalus	3	2 jaws 1 tooth
3	107	70	43 ribs 21 vertebrae 5 scapulae 1 pelvis	28	28 long bones	9	8 jaws 1 tooth
4	199	146	98 ribs 38 vertebrae 10 scapulae	34	25 long bones 3 phalanxes 2 calcanei 4 astragali	19	17 jaws 2 teeth
5	110	88	51 ribs 27 vertebrae 6 scapulae 4 pelves	20	14 long bones 3 phalanxes 2 calcanei 1 astragalus	2	2 mandibles

Table 2
Description of the sampling units.

Sampling unit	Inclination (°)	Runoff marks of rills	Description
1	4	2	The sampling unit is crossed by two noticeable rills, which run more or less in a north–south direction. One of them forks into two branches and is surrounded by many parallel smaller runoff marks, which follow the same direction. About 26 bones lie in, within, or on the edge of the rills. A total of 22 axial elements (13 ribs, 6 vertebrae, 2 pelves, and 1 scapula) and 4 long bones belong to this group. However, the majority of the specimens tend to concentrate near the runoff marks.
2	1–4	2	The runoff marks of rills are much more superficial and they are concentrated on the eastern side of the quadrant running in a north–south direction. This seems to have an impact on the elements' arrangement, since they lie more dispersed and without following any clear pattern. Here it is common to observe some elements forming smaller accumulations lacking an orientation. There is one remarkable group of elements situated at the south of the quadrant, formed by a cluster of ribs, vertebrae and one metapodial.
3	3–6	3	Three independent runoff marks are perceptible on the surface. However, these are much more superficial than the ones of the first sample. The more noticeable one is on the east half of the quadrant and it is formed by two branches in a north –south direction, which join towards south. Another similarly shaped, but less defined runoff mark, runs from north to south across the west half. Finally, there is a third broader and deeper runoff mark that crosses this sampling unit only at the west-south corner following a northwest–southeast direction. Small bone associations without any particular orientation pattern can also be found here, however they lie outside of the rill channels. About 37 bones are related to the runoff marks (15 ribs, 9 long bones, 7 vertebrae, 3 mandibles, 2 scapulae, and 1 tooth).
4	2–7	2	This sampling unit is clearly crossed in a northwest-southeast direction by two main rill marks. The one on the eastern part of the unit shows two branches that join at the northeast third, forming a strong channel in southeast direction. The one on the west half of the sampling unit forks near the southwest third in two branches that continue their course in a southwest direction. About 17 elements are directly related to the runoff marks. Most of the bones are positioned on the interface between both runoff marks, which lies slightly higher than the rest of the unit.
5	5	–	Contains a wide variety of grain sizes. In general, their diameter varies from 1 cm to more than 10 cm, but there are also some bigger stones, that are 15 cm long. In this case there are no visible surface runoff marks, but two clear corridors that are free from coarse sediment and run in north-south direction are identifiable. They end in a bigger area, which contains fewer grains in comparison to the rest of the sampling unit. North of the limit of this sampling unit lie 10 vertebrae in anatomical position. This is also noteworthy, because it supports the limited disturbance of the accumulation.

orientation patterns. To test uniform distributions against unimodal distributions, Rayleigh's (R) test was applied (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 $k = 0$ corresponding to an isotropic distribution, and increasing values with a trend towards anisotropy. In order to corroborate possible unimodal patterns documented by Rayleigh's test, a distance approach to uniform distribution was carried out by using Rao's Spacing test. The Watson (U^2) test is a goodness-of-fit statistic for the von Mises distribution and is recommended as a general test for uniformity. Values with $p > 0.05$ indicate that the null hypothesis of isotropy cannot be rejected. For the statistical analysis and the graphical display of the statistical results Oriana 4 Software was used.

Bone groups within each sampling unit were also analyzed separately for orientation patterns. Three groups were made, which provided three types of shape-structure bone groups: axial (ribs and vertebrae), scapulae and pelves, and long bones. Since the sample sizes of some of these bones were too small to provide any meaningful statistical results, a bootstrap procedure was implemented. Contrary to standard bootstrapping procedures, which use thousands of permutations, we decided to use a very small number of sampling with replacement units, which were enough to apply and derive meaningful interpretations of the data without distorting too much their original orientation properties. For this reason, each bone group was bootstrapped with replacement 100 times, provided the original sample was ~10 elements or higher. Then omnibus tests were applied.

3. Results

Skeletal part profiles show that axial elements predominate in the Masek bone assemblage (Capaldo and Peters, 1995). Given that these bones constitute Voorhies group I (ribs and vertebrae), together with the high representation of scapulae (Voorhies group I & II), this supports that water flow must have circulated under very low energy, since these bones are easily transported under moderate current force. The orientation patterns documented in the present work must, therefore, have resulted as the effect of these low-energy hydraulic processes.

Orientations were measured for 686 specimens in total, although each sampling unit was treated separately. Table 3 shows the statistical tests of isotropy applied to sampling units 1–5 (Fig. 4). Their p-values show different results for all samples. They

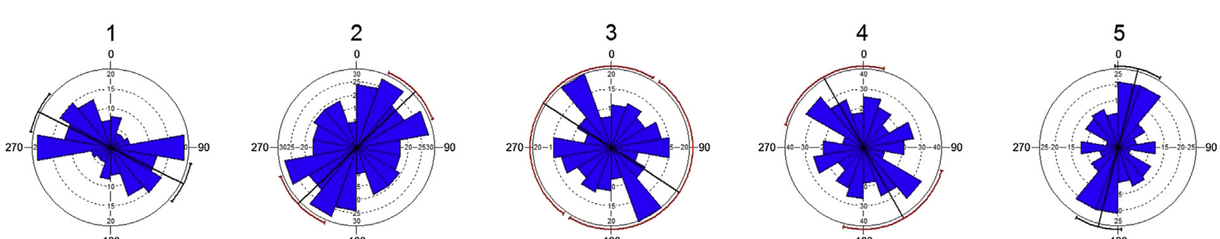

Fig. 4. Rose diagrams showing the orientation patterns of the bone materials in units 1–5. Sampling unit 3 shows uniform bone orientation.

indicate that sampling units 1, 2, 4, and 5, display non-uniformity in their orientation patterns and therefore are anisotropic, whereas the result for sampling unit 3 presents a uniform distribution. Sampling units 2 and 4 show a less clear azimuth orientation (only Rao's Spacing test and Kuiper's test show values below 0.05) than do samples 1 and 5 (in which all results coincide). Although there are some divergent results when comparing Rayleigh's test and Rao's test, which indicate the possibility of some unimodal patterns existing in the samples, Kuiper's test clearly shows that multimodal anisotropy exists in most sampling units. This means that the null hypothesis of isotropy can be rejected for four of the samples with the exception of sample 3. These results are supplemented with rose diagrams (Fig. 4). The mean vectors of each sampling unit show a different direction, probably because each sampling unit occupies a different area in which the local topography produces a surface inclination which determines the direction of the receding water.

Table 3
Statistical tests applied to sampling units 1–5 and their significance. Values with $p < 0.05$ indicate anisotropy.

	Rayleigh's test		Rao's Spacing test		Watson's test		Kuiper's test	
	Z	p	U	p	U^2	P	V	p
1	6.717	0.001	166.138	<0.01	0.378	0.005	2.455	<0.01
2	2.924	0.054	143.607	<0.05	0.186	$0.1 > p > 0.05$	1.842	<0.05
3	0.206	0.814	165.17	<0.01	0.068	>0.5	1.325	>0.15
4	0.809	0.445	170.05	<0.01	0.153	$0.1 > p > 0.05$	1.907	<0.025
5	5.571	0.004	161.273	<0.01	0.338	<0.005	2.063	<0.01

The same statistical tests were applied for each unit again separately to the following categories of bones: axial (ribs and vertebrae), long bones, scapulae and pelves. The p-values for the bootstrapped sample were <0.5, indicating that the three sets of bones that were analyzed contribute to the anisotropy of the assemblage. Long bones show the clearest orientation pattern, followed by scapulae and pelves and axial elements (Table 4) (Fig. 5). Scapulae tend to orientate with the widest side pointing towards the lake. Due to their flat and heterogeneous shape, ribs and vertebrae are less likely to orient under low energy processes than bones with a tubular shape, although they tend to be transported preferentially under stronger currents (Domínguez-Rodrigo et al., 2013; Domínguez-Rodrigo and García-Pérez, 2013).

Table 4
Statistical tests applied to the bootstrapped data for different bone types (ribs and vertebrae, long bones, and scapulae and pelves) and their significance values. Long bones (tubular shape) are more prone to orient than axial elements (flat shape). Anisotropy can also be observed in heterogeneously formed bones such as scapulae and pelves.

	Sampling unit 1			Sampling unit 2			Sampling unit 3		Sampling unit 4			Sampling unit 5		
	Ribs & vertebrae	Long bones	Scapulae & pelves	Ribs & vertebrae	Long bones	Scapulae & pelves	Ribs & vertebrae	Long bones	Ribs & vertebrae	Long bones	Scapulae & pelves	Ribs & vertebrae	Long bones	Scapulae & pelves
Rayleigh's test (Z)	13.686	151.271	226.609	15.345	12.683	47.38	0.598	4.914	4.521	22.749	53.5	33.354	12.524	16.169
Rayleigh's test (p)	1.1E-06	<1E-12	<1E-12	2.2E-07	3.1E-06	<1E-12	0.55	0.007	0.011	1.32E-10	<1E-12	<1E-12	3.64E-06	9.5E-08
Rao's Spacing test (U)	326.88	352.8	354.96	297.36	337.68	352.08	327.87	343.44	298.8	344.16	352.8	319.68	349.92	353.52
Rao's Spacing test (p)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Watson's test (U^2)	0.948	8.6	14.025	1.136	1.171	4.223	0.299	1.052	0.762	2.195	4.536	2.01	2.047	2.321
Watson's test (p)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Kuiper's test (V)	4.42	10.968	15.018	4.36	4.821	8.971	2.364	5.141	3.754	6.683	8.485	5.326	6.578	6.613
Kuiper's test (p)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

4. Discussion

The accumulation of bones belonging to all anatomical parts, especially the abundance of axial elements (ribs and vertebrae), as well as other cancellous bones (pelves and scapulae), indicate that bone deposition near the shore of Lake Masek took place under very low energy conditions. Articulated elements and carcasses further support this interpretation. The virtual underrepresentation of compact bones (carpals, tarsals, phalanges) as well as of bones from very young individuals (despite their documented mass drowning) shows that post-depositional processes, such as water winnowing or carnivore ravaging or a combination of both contributed to disturb in various degrees the original deposition of wildebeest carcasses. Carnivore ravaging must have played a central role in bone preservation and distribution, since vultures, lions and hyenas have been witnessed to have actively modified the carcasses deposited near the lake (Capaldo and Peters, 1995). Vultures seem to have been the main consumers of flesh and hyenas were actively exploiting flesh and marrow to a degree in which it was not necessary to break all grease-bearing bones. This is reflected in the high deletion of long bones, which are represented at ~20% of what would be expected according to MNI derived from the skulls (Capaldo and Peters, 1995). Complete metapodials are the most represented long bones, and tibiae (the highest marrow-yielding long bones) are the least represented long elements. Despite the intense scavenging that took place on the Masek drownings, Capaldo and Peters (1995) document that the representation of easily transportable bones (Voorhies' group I) and lag assemblages (Voorhies'group III), is very similar, suggesting a minor role in the removal of bones by water-related physical processes.

Despite the documented low-energy conditions, anisotropy was documented in four out of the five sampling units. This attests to the autochthonous nature of anisotropy in these assemblages. It is difficult to attribute such multimodal orientation patterns to specific processes. The lake transgressive–regressive cycles could be the cause, although the presence of marked runoff, rill and small channels, formed by rain water, may also be responsible for bone orientation. These smaller rills are documented in all sampling units except in unit 5, which showed anisotropy. It is unknown whether the isotropic sampling unit 3 at any point showed anisotropy, which was modified by subsequent processes affecting bone orientation, or if isotropy is its original condition, given the documented anisotropy of the other sampling units.

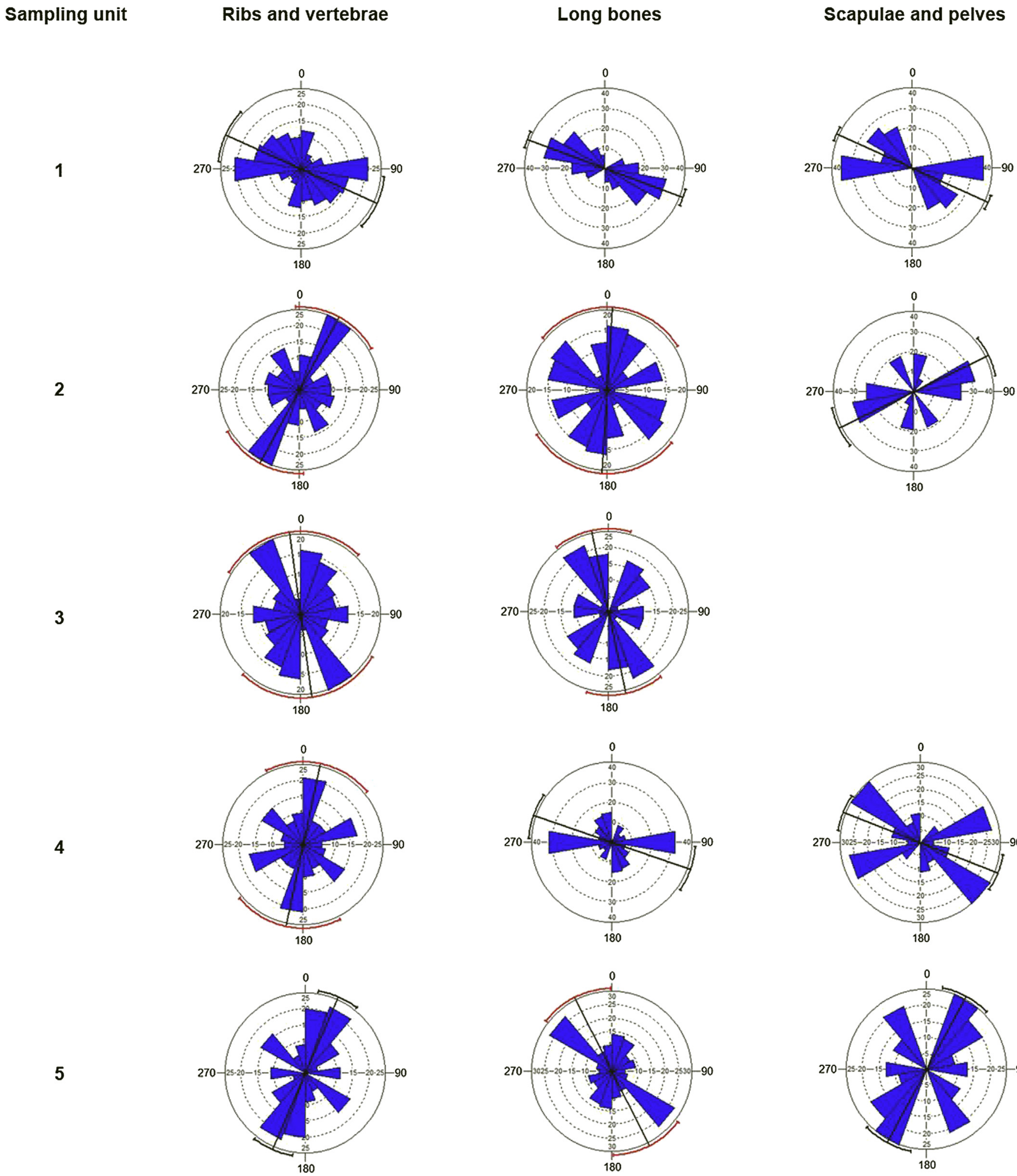

Fig. 5. Rose diagrams showing the orientation patterns of the three bone groups for each sampling unit.

Two meaningful results were obtained in this work. One of them is that even under low-energy conditions, moving water from rains and its resulting watersheet create conspicuous channels and topographic features on the lacustrine floodplain, attesting to their erosive nature. If inferences of allochthonous assemblages on paleo-lacustrine floodplains, such as those of Olduvai Gorge, are made, they can only be supported in the presence of such erosive features associated with anisotropic assemblages. Geomorphological analysis of the landscape surrounding FLK Zinj (represented by the paleosurface where the site was formed) does not provide compelling evidence that fluvial channels existed in the immediate vicinity of the site. Although Blumenschine et al.'s (2012)

Fig. 6. Left, circulating water in small channels and rills; one of the erosive processes operating in the floodplain creating topographic features and potentially contributing to bone orientation patterns. Right, bone cluster in the Masek floodplain around erosive features (sedimentary steps) created by the tilting direction of the plain towards the lake shoreline.

paleogeographic reconstruction showed purported evidence of such channels, this was only supported by providing artificially decompressed topographies, which recent work on sediment compaction and compression in the same strata prove unnecessary and, therefore, biasing (Uribelarrea et al., 2013). Trenches excavated by TOPPP (The Olduvai Paleoanthropology and Paleoecology Project) in the vicinity of Blumenschine et al.'s trenches found no evidence of these channels on the FLK Zinj paleosurface (Uribelarrea et al., 2013), but show that small channels, similar to those created by shallow rills, occur in the overlying and underlying sedimentary sequence, but are not pene-contemporaneous to the site in its vicinity. Most contacts between the FLK Zinj paleosurface and the overlying tuff IC are straight and laminar, without showing discontinuities or erosive contacts. Only at several dozens of meters away from FLK Zinj do some small channel structures occur, linked to the area south of the site being topographically lower because of erosion caused by the combined action of lake transgression and rills created by rainwater during lake regression, as is commonly documented in modern African lakes (Uribelarrea et al., 2013) (Fig. 6). This is the main erosive process documented on the FLK Zinj paleolandscape north and south of the FLK site. The alternative fluvial scenario proposed by Blumenschine et al. (2012) lacked many of the fluvial-associated structures and features (e.g., heterogeneous lithology, lamination, detritic deposits) commonly observed in fluvial deposits (Uribelarrea et al., 2013) although a small fluvial channel existed axially perpendicular to that suggested by Blumenschine et al. (2012), where some of these structural and lithological evidences can be documented (Uribelarrea et al., 2013). It is not clear if the small channel documented by Leakey (1971) at the site is a channel or a footprint or a structure resulting from clay deformation. However, under the assumption that it might be a small channel, devoid of any detritic fluvial sedimentation, its dimensions are substantially smaller than most channels formed by rain water on lacustrine mudflats (see Uribelarrea et al., 2013). The purported orientation trend of fossilized plant remains documented by Blumenschine et al. (2012), seems poorly supported, considering that plants could easily be oriented by wind or by slow-energy water currents, such as those produced by rain. Information is lacking on the orientation trends of stone tools and fossils scattered around the landscape surrounding all Olduvai Bed I sites. This information would be relevant for the discussion of the effects of water in the arrangement of fossils in the FLK Zinj paleolandscape.

The second major contribution of this study is that it shows how autochthonous bone assemblages deposited on lake floodplains can adopt anisotropic fabrics under the influence of low-energy hydraulic processes of diverse nature. Although orientation of different bone groups was divergent, this was mostly because water energy must have been too low to orient the complete assemblage. Recent fluvial experiments show that when the current force is moderate to high, most heterogeneously-shaped bones tend to orientate similarly (Domínguez-Rodrigo and García-Pérez, 2013). The low-energy processes at Lake Masek preferentially modified the orientation of tubular-shaped bones (i.e., long bones) which are more prone to move from the effect of water than flat bones, which stabilize more easily on the clayish or sandy substrate under low-energy conditions (Domínguez-Rodrigo and García-Pérez, 2013). Flat bones require a higher energy to react like tubular bones. Under such conditions, they are more easily transported than complete long bones (Domínguez-Rodrigo et al., 2013; Domínguez-Rodrigo and García-Pérez, 2013).

5. Conclusions

A study of bone orientation on five selective sampling units among the densest concentration of the Masek wildebeest bonebed shows that in most of them anisotropy is documented. This cautions against interpretations made on the autochthonous or allochthonous nature of paleontological assemblages (e.g., Benito-Calvo and de la Torre, 2011) based exclusively on the absence of isotropy. Such inferences require the use of a varied and experimentally-based set of taphonomic techniques and criteria, which can effectively detect unmodified or moderately modified autochthonous assemblages, substantially modified lag assemblages and allochthonous assemblages.

Domínguez-Rodrigo and Pickering (2010) argue that taphonomic research in the 21st century should be multivariate and take advantage of modern technology to deal with the abundant information of a wide array of variables. Discriminant analyses have heuristically improved through these multivariate approaches, which have rendered the use of isolated variables obsolete. Orientation patterns can respond to a large number of causes.

Probabilistic estimates of these causes can be statistically made provided hypotheses are inter-related and firmly linked to multivariate criteria (see description of a realistic scientific approach in Domínguez-Rodrigo, 2012). Anisotropy has to be compatible with other taphonomic criteria, such as specimen size distribution, specimen shape and structure distribution, specimen modification (i.e., abrasion and polishing), inter-relation of element distribution and even spatial analysis (i.e., shape of clusters, scatters and girdles) before heuristic interpretations of allochthony can be made. The present work of anisotropy in the Lake Masek wildebeest assemblage complements previous interpretations of classical assemblages (FLK Zinj, FLK NN, FLK N) in the vicinity of the Olduvai Bed I paleolake as locally deposited. The effect of water on these assemblages was diachronically diverse, as on-going work in some of these sites will document in the near future.

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