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Archeology in "stone line" sedimentary environments. A methodological approach and results based on the Early and Middle Pleistocene sites at Melka Kunture (Upper Awash, Ethiopia)

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ABSTRACT - Sites in sedimentary cobble-bed environments, which are quite common in African Pleistocene sites, are routinely reported as extensively affected by sedimentary processes. The Gombore II and Garba I sites (Melka Kunture, Ethiopia), both in a cobble-bed setting, allow a different approach. Using archive data from previous excavations and new field observations, we analyzed size ranges, orientation, sedimentary fabrics, and spatial distribution patterns at both sites as well as in a nearby present-day stream deposit, to make comparisons and assess any similarity in sedimentary setting. The results suggest that Gombore II and Garba I have been subjected to a low degree of sedimentary disturbance, without severe taphonomic effects on the archeological assemblages.

Keywords: Acheulean; Lower Pleistocene; fluvial environment; geoarcheology; lithic taphonomy; spatial analysis.

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1. INTRODUCTION

All over the Paleolithic, and markedly so during the Acheulean, the hominins settled in fluvial environments (White, 2022) which provide access to water and to a varied range of food resources (plants, root crops, animal biomass, etc) as well to lithic raw materials. Accordingly, many sites, notably the early ones, are preserved within fluvial sedimentary sequences (Leakey, 1971; Bordes et al., 1972; Bordes, 1975; Leakey et al., 1994; Isaac and Isaac, 1997; Mussi, 2002; Santonja and Villa, 2006). Different types of sedimentary facies, related to fluvial styles (*sensu* Miall, 1996), impact the preservation degree of the archeological record. Channel beds with stone lags (e.g., stone lines) are quite common. Plio-Pleistocene archeology has traditionally considered sites in these sedimentary environments as extensively disturbed and therefore of low scientific value to understanding human behavioral patterns (e.g., Schick, 1986; Schiffer, 1987).

Melka Kunture site-complex, in the Upper Awash of Ethiopia, preserves an extensive archeological record spanning over 2 million years (Ma) on almost the whole African Stone Age (Mussi et al., 2022). Geologically, the region displays a large fluvial-lacustrine succession strongly influenced by volcanic activity (Raynal et al., 2004; Pioli et al., 2023). Several sites are linked to lag channel bed environments, such as the Acheulean sites of Gombore II and Garba I (Gallotti et al., 2010; Méndez-Quintas et al., 2019; Sánchez Dehesa-Galán et al., 2022). Both sites have been extensively researched and have yielded large lithic and faunal assemblages. More recently they have been analyzed to understand the degree of taphonomic integrity and spatial distribution patterns (Méndez-Quintas et al., 2019; Sánchez Dehesa-Galán et al., 2022). As both sites were excavated in the past, part of the analysis procedures has been performed on unpublished documentation kept in the archives of the archeological mission at Melka Kunture, which includes very precise excavation plans. We detail below the specific workflows and methodological approaches that we implemented, as well as the main results of their application.

2. AREA DESCRIPTION

Melka Kunture area (MK), 50 km south of Addis Ababa (Fig. 1), is crossed by the meandering Upper Awash River, and is located within a half-graben with a dominant NE orientation according to the Rift pattern (Raynal and Kieffer, 2004; Pioli et al., 2023), The area was affected by extensive volcanic activity since Pliocene times. The basin stratigraphy consists of a succession of primary (fall and flow) volcaniclastic deposits, interbedded with reworked volcaniclastics emplaced in a floodplain environment developed in the subsiding area. Interbedded volcanic deposits provide radiometric dating which, coupled with magnetostratigraphic, allows to establish a detailed chronology of the complex archeological record (Morgan et al., 2012; Perini et al., 2021). The sequence starts at ~2 Ma and includes many Oldowan, Acheulean, Middle Stone Age, and Late Stone Age sites (Bailloud, 1965; Chavaillon and Berthelet, 2004; Mussi et al., 2022). The Acheulean sites of Gombore II and Garba I stand out for extensive excavations and detailed archive data, which were produced during the second half of the 20th century and left mostly unpublished (Chavaillon and Berthelet, 2004). Since 2013, new fieldwork has been conducted to get updated information. Both sites are located on the right side of the Awash River along two small gullies at about 300 m from each other, the Garba and Gombore ones (hence the site names), which have been cut by seasonal streams through the Lower and Middle Pleistocene deposits (Fig. 1). The erosion revealed a string of archeological deposits starting with the Oldowan close to the level of the main river. Here we focus on the upper part of the two sequences.

2.1. GOMBORE II

Gombore II was discovered by Gérard Bailloud (1965) who first surveyed Melka Kunture. Currently, it includes various sectors: Gombore II-1, Gombore II-3, Gombore II-4, Gombore II-5, Gombore Open Air Museum (OAM), and Gombore II-2 (Fig. 2). The latter one will not be discussed here as it lays at a different chronostratigraphic level and is later in age (Altamura et al., 2020b). Instead, we refer here to Gombore II "main site", extending over estimated

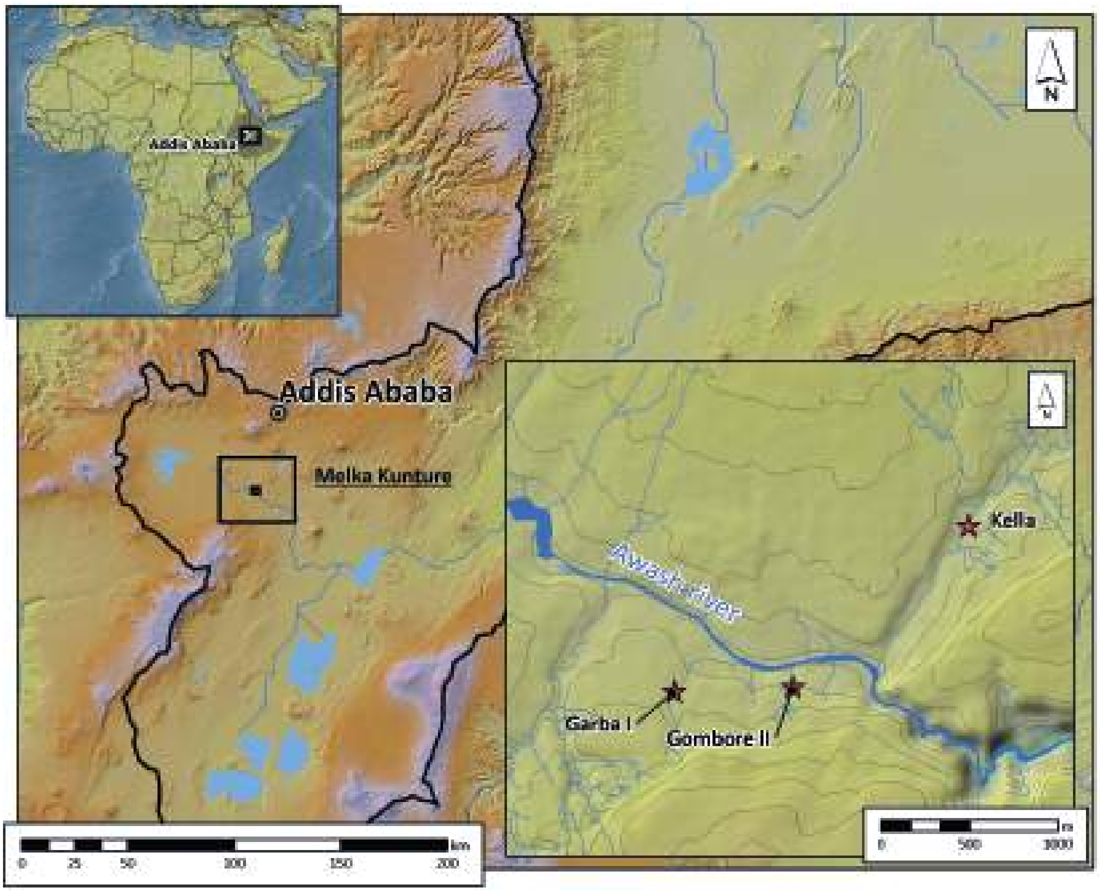

Fig. 1 - Location map of the Melka Kunture area and the sites discussed in the text.

1000 m^2 (*sensu* Chavaillon, 1972), which were variously intercepted in the excavated sectors. Jean Chavaillon opened several areas between 1970 and 1976 but focused on Gombore II-1(~39.5 m^2). Between 1993 and 1995 he then excavated the minor areas of Gombore II-3, Gombore II-4 and Gombore II-5. In 2001 Marcello Piperno started a new operation totalling ~29.5 m^2 at Gombore II OAM, that he left protected by a thatched roof and open to visitors. Overall, ~90,3 m^2 of Gombore II have been excavated through time (Méndez-Quintas et al., 2019) (Fig. 2).

The site displays an extensive accumulation of Acheulean artifacts (Figs. 2 and 3b-d) and bones of different size and variable state of integrity. In addition, Gombore II-1 yielded two hominin skull fragments initially attributed to *Homo erectus*, and more recently interpreted as representing one of the best candidates for the origin of *Homo heidelbergensis* (Profico et al., 2016). New discoveries are ichnological surfaces, with animal and human footprints, found just above and below the main Acheulean deposit (Altamura et al., 2018; Altamura et al., 2020a).

We discuss below part of the upper sequence of the Gombore gully, ~5 m thick, composed of fluvial and volcanic deposits including Gombore II (Fig. 3a) (Mussi et al., 2016; Mussi et al., 2023). It starts here with a massive silty deposit (~20 cm thick) with bivalve imprints (back swamp environment) and is covered by coarse poorly sorted sands (20-30 cm thick). The occurrence of low-angle cross-bedding structures, obsidian gravels, and silty clasts is indicative of rapid deposition by a relatively high-energy flow. Above those channels fill sediments there is a massive dacitic tuff originated by an ash fall in the water and dated 875±10 ka by Ar/Ar (Morgan et al., 2012). An erosional surface separates the tuff, from a channel-floor lag deposit (~20 cm thick) consisting of coarse volcanic pebbles within a well-sorted sandy matrix. It is the main archeological layer of Gombore II. This layer is covered by about 2 m of sand interbedded with white pumiceous silts of ash-fall deposit reworked by water. Following upwards, ~2 m of floodplain massive silty clay sediments are interbedded with sandy crevasse-splay deposits which cover poorly developed paleosoils (Fig. 3a) (Méndez-Quintas et al., 2019). Above this level starts the Gombore II-2 sequence, which is not discussed in this paper.

The chronology of the main archeological level is well constricted by the 875±10 ka volcanic deposits just below the Acheulean level discussed here, while higher up in the gully another volcanic ash, dated 709±13 ka, caps Gombore II-2 (Morgan et al., 2012). The age of the main level as initially suggested by $^{40}Ar/^{39}Ar$ ages (Morgan et al., 2012), therefore is in the range of ~780 ka, but recent paleomagnetic analysis establishes its age at 1.03 Ma, i.e., at the beginning of the Jaramillo subchron (Fig. 3a) (Perini et al., 2021).

2.2. GARBA I

Garba I is another of the first archeological sites discovered at Melka Kunture by Bailloud, who originally called it Godetti (Bailloud, 1965). As Gombore II, it is located in the upper part of a succession, the Garba gully sequence (Fig. 1). Fieldwork was carried out by J. Chavaillon from 1965 to 1971 over an excavation area of 243 m^2. Some 12.000 artifacts were reported from the main archeological level, i.e., level B (henceforward Garba IB) (Chavaillon and Berthelet, 2004) (Fig. 4).

The lithic assemblage displays clear Acheulean features, with 828 Large Cutting Tools (LCTs) (mainly handaxes and cleavers on flake) out of an analyzed series of 7227 pieces (Sánchez Dehesa-Galán et al., 2022) (Fig. 5b-d). Therefore, Garba I stands among the most important of the African Acheulean sites characterized by extensive accumulations of LCTs. Faunal remains are very scarce, in contrast with other sites of Melka Kunture (Geraads et al., 2022).

We discuss here a ~3 m-thick sequence in the upper part of the Garba gully. As at Gombore, silty to coarse sandy beds and lag deposits alternate with primary and reworked ash fallout deposits (Fig. 5a). It starts with a ~1.5 m-thick level of well-sorted medium-coarse sand, low-cross to plane parallel stratification and ripple cross-lamination (unit 1). Above, unit 2 (~1 m-thick) is formed by reworked pumice clasts and is evidence of crevasse splay deposits. Overlying unit 2, a poorly stratified floodplain deposit (unit 3) (50-100 cm-thick) contains sand lens, *lapilli,* and distal ash fallouts which had deposited in shallow water. Coarse layers intercalated within unit 3 are interpreted as crevasse splay deposits. Some artifacts and bones were discovered at the bottom of the unit. Unit 3 is capped, after an erosional unconformity, by unit 4, i.e., archeological level B in Chavaillon's terminology, which is up to 30-50 cm thick. It consists of red coarse fluvial channel deposits with cross-bedding stratification and of a lag channel deposit rich in pebbles and cobbles, indicating higher energy of the channel flow and the migration of the paleo-Awash in the floodplain. Finally, this layer is capped by unit 5 (~1.5 m thick) consisting of a silty clay overbank deposit with ash fallout, pedologically altered at the top (Fig. 5a) (Sánchez Dehesa-Galán et al., 2022).

The age of the site was at first tentatively established by correlations with the tuffs in the upper sequence of the Garba and Gombore gullies. This suggested that the archeological layer had accumulated in the first half of the Middle Pleistocene (Chavaillon and Chavaillon, 1980; Piperno, 2001; Chavaillon and Berthelet, 2004). Recently, ESR dating of quartz grains from unit 5, which overlies the main archeological level (unit 4, i.e., level B), provided a date of 538 ± 48 ka. This places the age of Garba IB, the main Acheulean level, at ~0.6 Ma in the first half of the Middle Pleistocene (Sánchez Dehesa-Galán and Mussi, 2023).

3. METHODS AND MATERIAL STUDIED

The taphonomic and spatial analyses of the Gombore II and Garba I deposits were performed through the analysis of archive data and new fieldwork observations. Archive data allow approaching new methods of excavations made

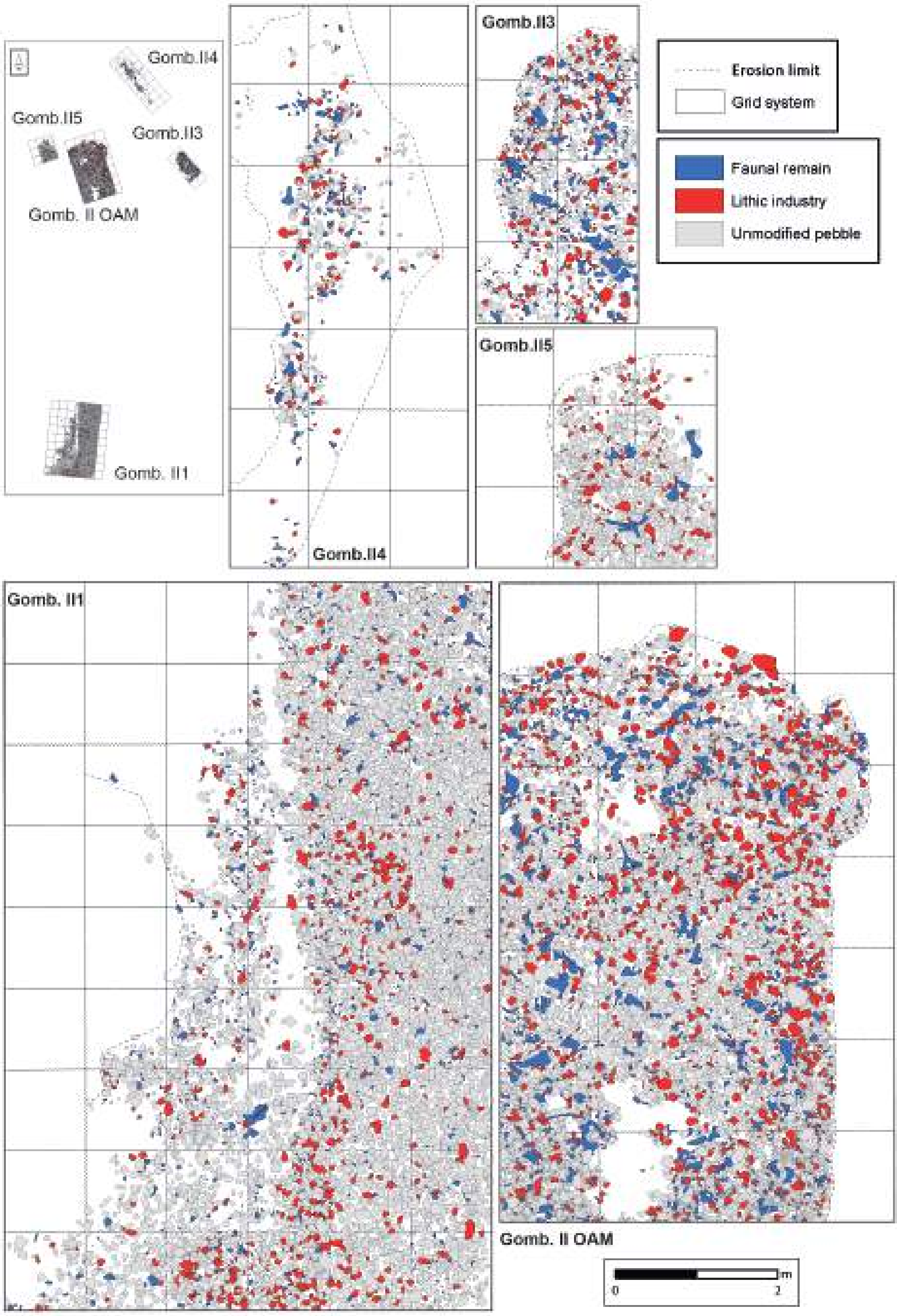

Fig. 2 - Maps of the different sectors discussed in the text at Gombore II.

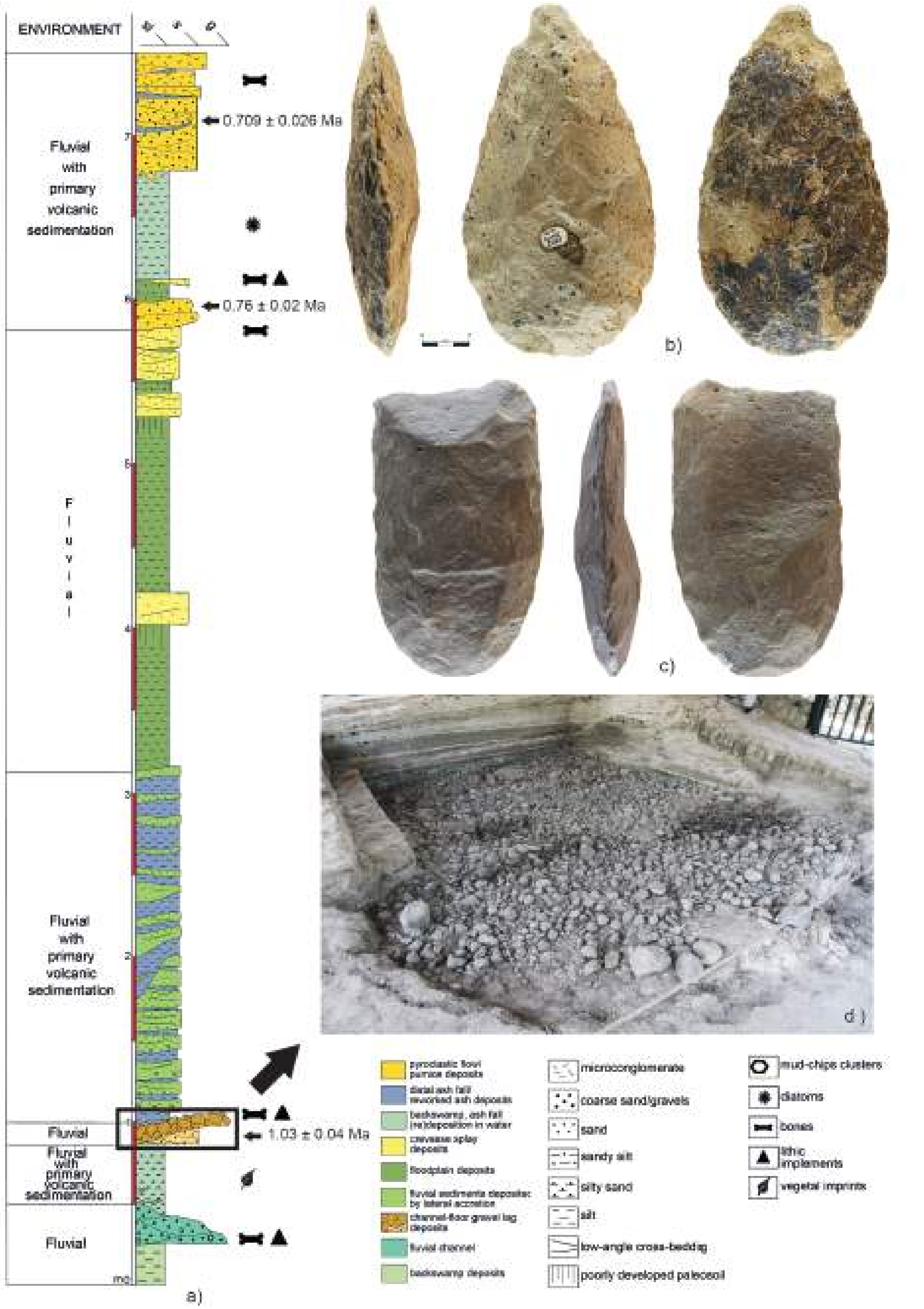

Fig. 3 - The site of Gombore II. a: sedimentary log of the site with indication of the main level (adapted from Méndez-Quintas et al., 2019); b-c: handaxe and cleaver on flake; d: photograph of the Gombore II OAM sector.

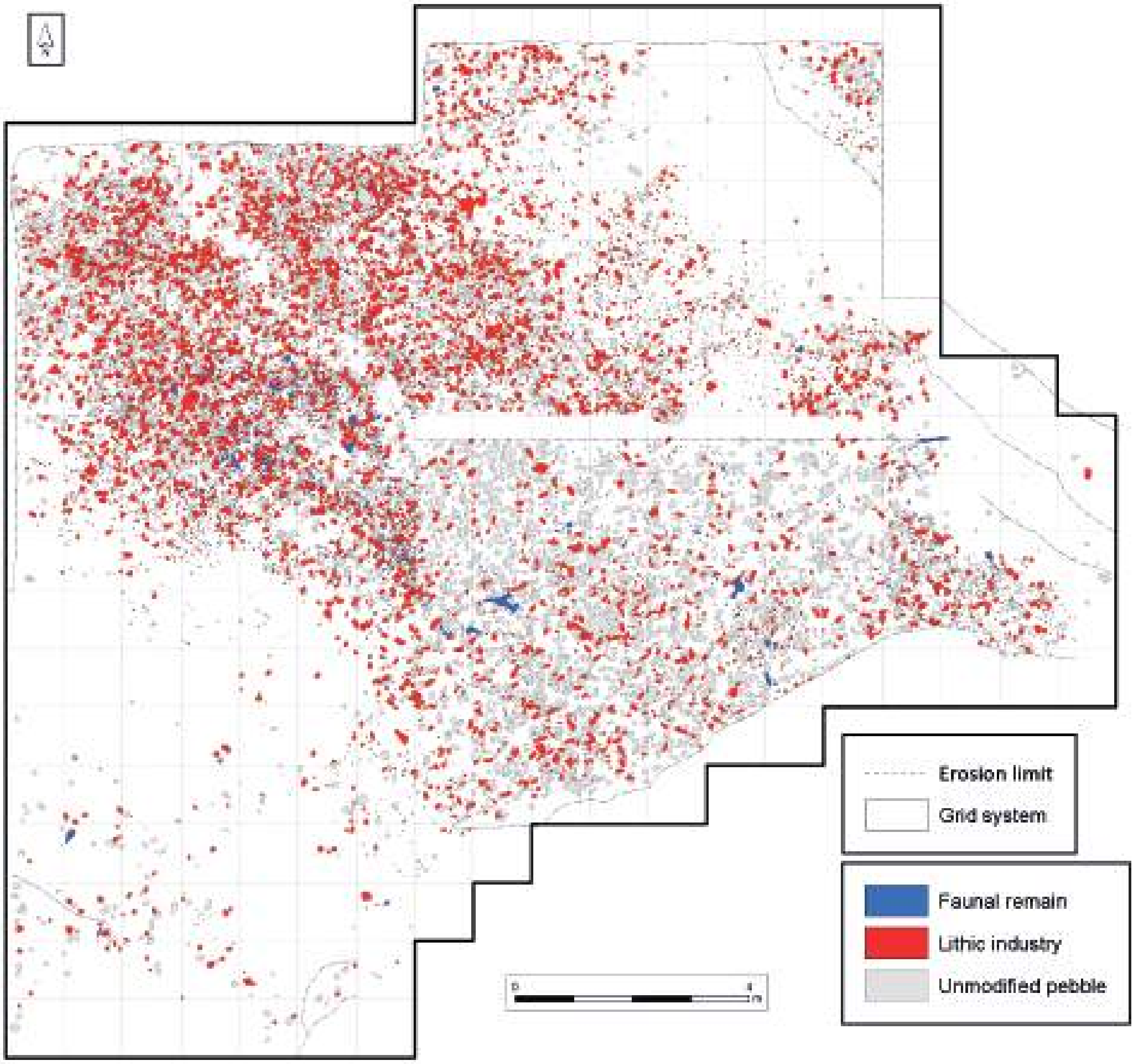

Fig. 4 - Map of the excavated area at Garba I.

well before the development of site-formation analysis. As already underlined elsewhere (e.g. cfr. Mussi et al., 2022), Chavaillon and his team recorded the excavations at Melka Kunture with unparalleled accuracy and meticulousness (Fig. 7 a,b). This makes it possible to statistically test these data many years after the original fieldwork.

This approach has been complemented by new fieldwork including stratigraphic analysis, sampling, and photogrammetric recording of both the archeological surfaces and of a present-day fluvial channel. Understanding the sedimentary features (i.e., size range, orientation, or dip) and distribution patterns in a modern sedimentary setting similar to the past ones is needed to perform statistical tests and validate the results. We recorded and analyzed a modern channel bed of the Melka Kunture region, specifically in the valley of the Kella River, an ephemeral tributary of the Awash River whose mouth opens ~600 m downstream the Gombore and Garba gullies (Figs. 1 and 6) (Méndez-Quintas et al., 2019). The detailed methodology and workflow are described below.

3.1. RECENT FIELDWORK

At Gombore II the analysis of the main archeological layer, as well as of the stratigraphic succession, has been easier because a relevant excavation surface is visible and open to inspection at Gombore II OAM. Starting in 2012, stratigraphic and archeological tests have been carried out in the upper part of the Gombore sequence. This has generated a significant amount of information on the sedimentary features of the site. Since 2017, detailed measurements and recording by photogrammetry (see below) of the exposed surface at Gombore II OAM have also been carried out, which produced key data allowing

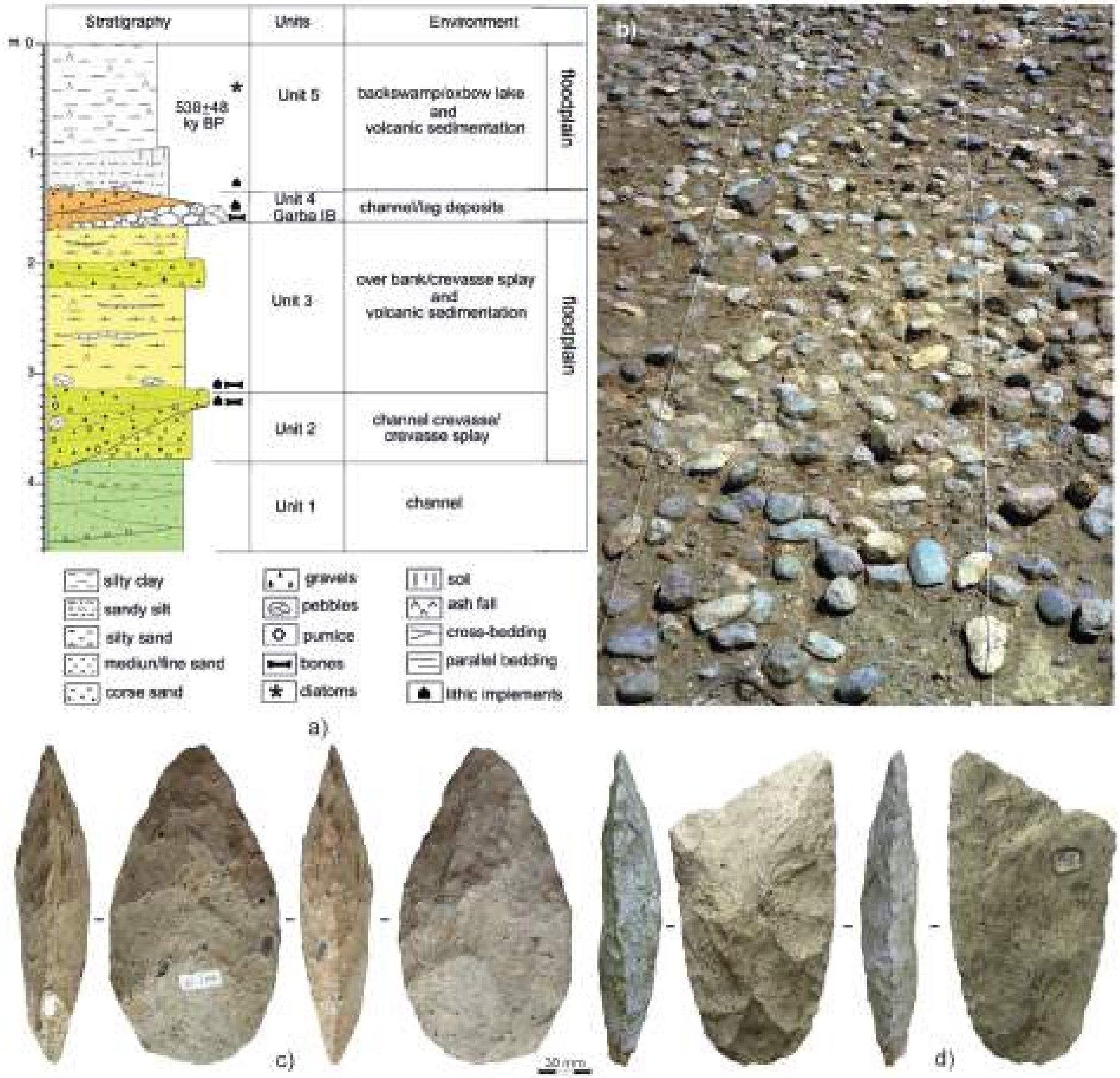

Fig. 5 - The site of Garba I: a: sedimentary log of the site (adapted from Sánchez Dehesa-Galán et al., 2022); b: detail photograph of the excavated surface with extensive accumulation of LCTs; c-d: example of handaxe and cleaver on flake.

to define the sedimentary fabrics.

At Garba I no excavation surface had been left in view, nor was the sedimentary sequence available for inspection. In 2015 and 2017 fieldwork was conducted to assemble updated information. The original excavation was relocated, and trenches and test-pits opened. A small excavation over 2 x 1.3 m was also carried out in level B to recover data on the position and density of the remains (Sánchez Dehesa-Galán et al., 2022).

3.2. DIGITIZING MAPS AND PHOTOGRAMMETRY

As said above, most data for the analysis come from the digitalization of Chavaillon´s excavation maps of Gombore II and Garba I which had been accurately drawn on graphic paper using a plumbline and a 1 x 1 m-grid. We scanned, resized, and georeferenced the maps of the different phases of excavation using GIS software (e.g., Esri ArcMap, QGis, OpenJump) (Fig. 7c). With the georeferenced maps we digitized all items (artifacts, faunal remains, and natural clasts), eventually producing polygon maps with a great accuracy (.shp shapes files). In the case of Garba I we were able to combine the data from the maps with the technological analysis of the archeological assemblage, allowing for detailed spatial analyses. At Gombore II, the result of the digitalisation of the maps generated 17520 polygons: faunal remains =2346; lithic industry =2302; and unmodified pebbles =12872 (Fig. 2). At Garba I 17506 polygons were drawn: faunal remains =1746; lithic industry =7008; and unmodified pebbles =8752 (Fig. 4). In the end, the

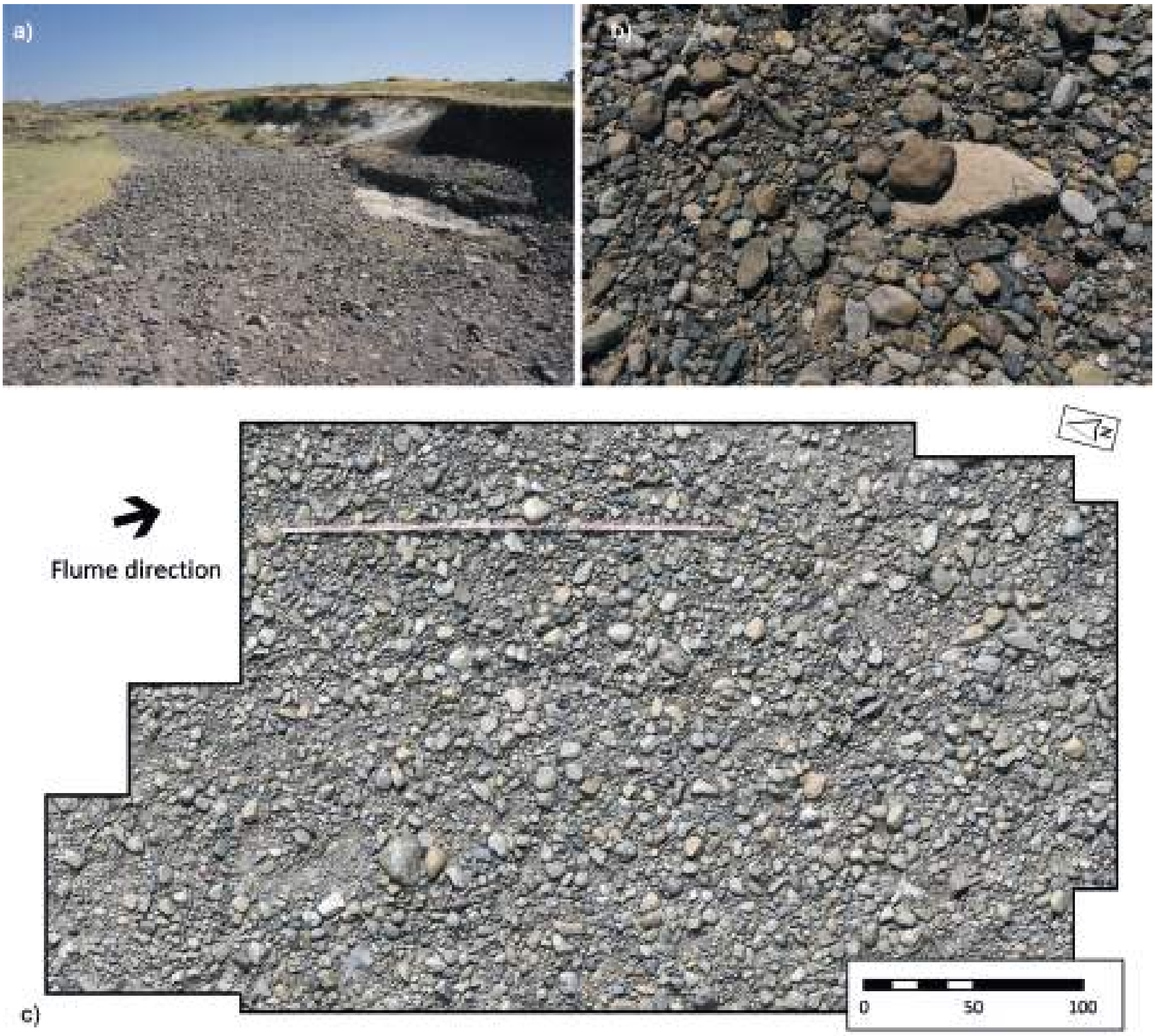

Fig. 6 - Sampled site on the Kella River River: a: General view of the area; b: Detail view of the sampled surface; c: ortho-image of the sampled area.

mapped and digitalised surfaces are 90.3 m² for Gombore II and 243 m² for Garba I.

In the case of Gombore II OAM, a photogrammetric restitution of the surface was also performed and combined with the data from the digitalised maps. The photogrammetry makes it possible to generate large-scale orthophotographs and digital elevation models (DEM) providing geometric and morphological information data (mainly dip values) (Fig. 8). For comparison purposes we selected and similarly recorded a channel bed at the mouth of the Kella River. This site provides an environment similar to that of Gombore II and Garba I during the Pleistocene, and in the same sedimentary setting. From the orthophotograph, we digitalized and examined with GIS software 11.6 m² of the channel bed with 5753 clasts (Fig. 9).

Processing with specific software GIS process (e.g., minimum bounding rectangle) the shape files, the orthophotographs and DEMs, we produced new files and raster images that combine information such as size, axial direction, and slope. The final data allow analysis and comparison of spatial patterns between past and present sites, as well as of size range, orientation, and fabric features (i.e., dip values).

3.3. LITHIC TAPHONOMY

So far there is no detailed study of the faunal remains taphonomy. Therefore, taphonomic studies have been performed on the lithic assemblages of Gombore II and especially of Garba I. In both cases, to assess the degree of integrity we used the size range of lithic artifacts (e.g., Bertran et al., 2012). This method must be used cautiously when dealing with assemblages excavated by other researchers, but in this case, we know that most items identified in Chavaillon's excavations were carefully mapped and kept. With these methodological constraints

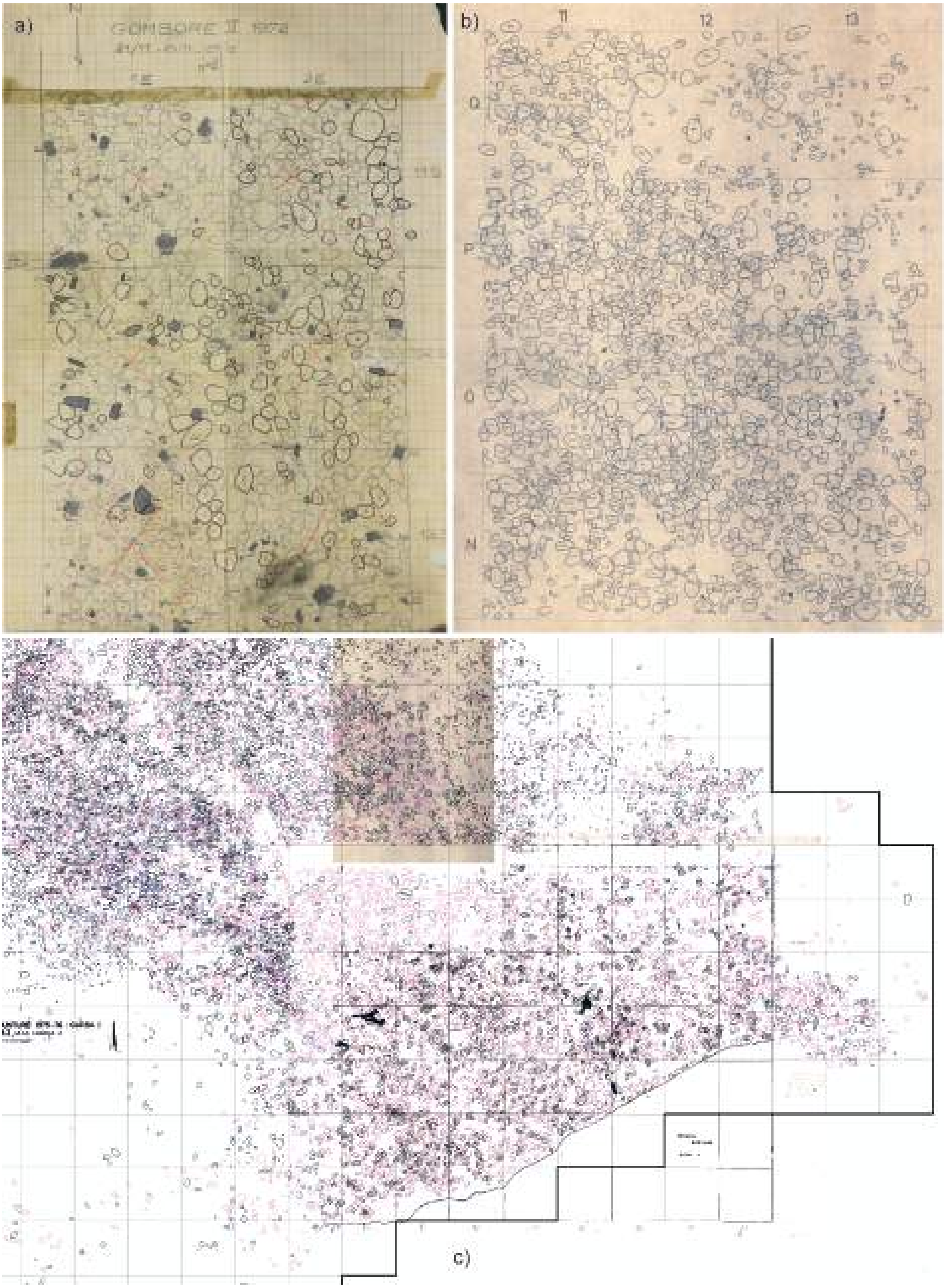

Fig. 7 - Example of the original maps of Chavaillon's excavations at Gombore II (a) and Garba I (b) kept in the archives of the Melka Kunture and Balchit project. Digitisation process of the Garba I map mosaic in a GIS software environment (c).

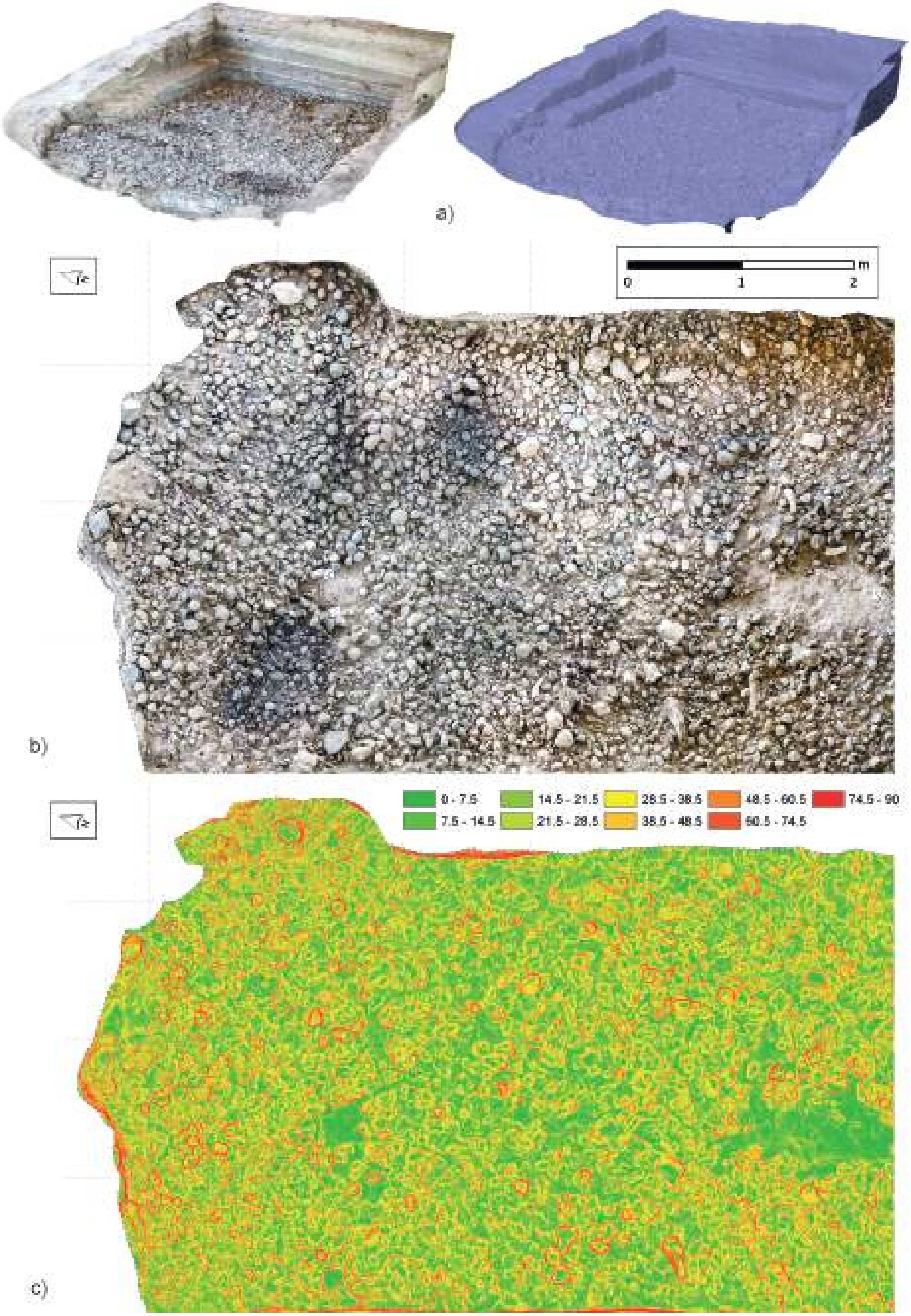

Fig. 8 - 3D photogrammetric restitution of the Gombore II OAM sector: a: oblique view of the textured and shadow model; b: ortho-imaging of the surface; c: slope map.

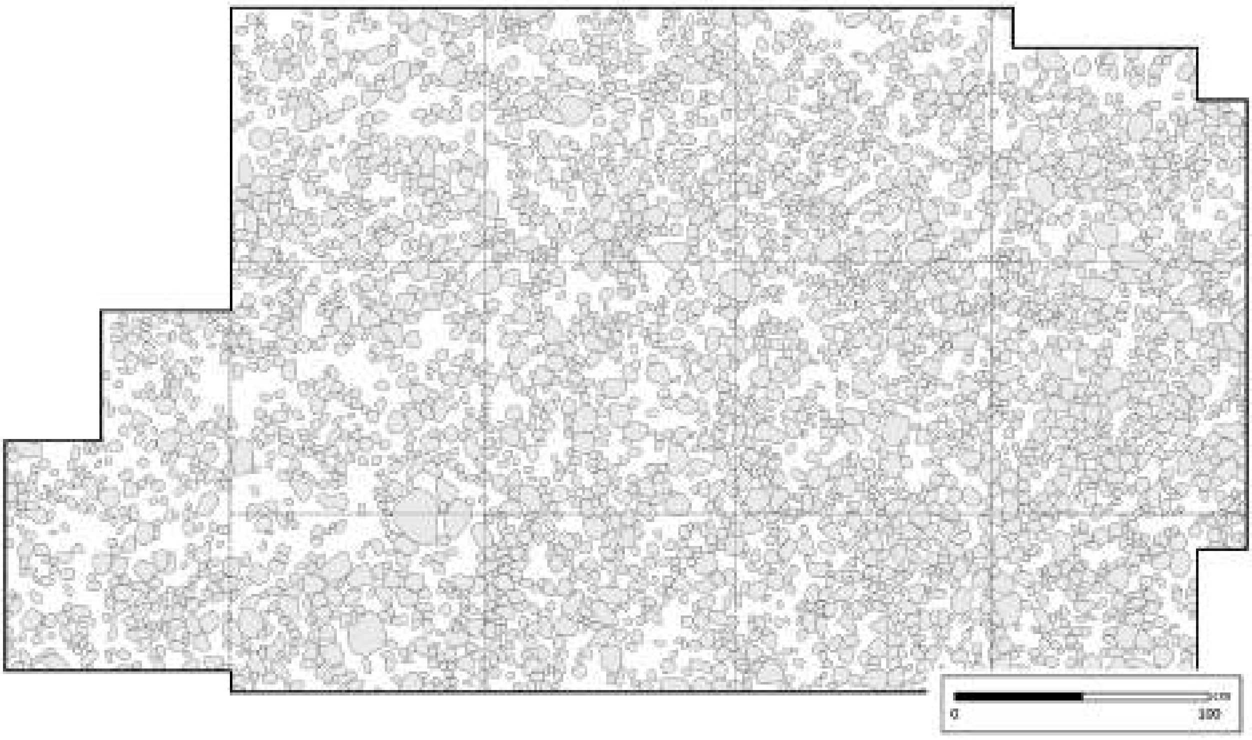

Fig. 9 - Map of the area sampled at Kella River.

in mind, we compared the size and size-range of the lithic industry and bones with those of the unmodified pebbles, both from the archeological layers and from the Kella River. We applied the following statistical tests to quantify any difference among the samples: Mann-Whitney (*U*) tests, Chi square test (X^2) or Kolmogorov-Smirnov test (*D*).

3.4. ORIENTATION AND DIP PATTERN

The orientation and fabric analysis are suitable methods to assess the sedimentary and degree of disturbance of archeological assemblages, mainly at open-air sites (e.g., Bertran and Texier, 1995; Lenoble and Bertran, 2004). Usually, the data are recorded with a compass and clinometer during fieldwork, which had not been systematically done in past excavations. As an alternative, at Garba I, Gombore II and Kella River we produced orientation values by GIS geo-processing (e.g., Minimum Endosing Box) from digitalized maps, which is a fairly common solution (Domínguez-Rodrigo et al., 2012; Cobo-Sánchez et al., 2014; Güler et al., 2021). Using the centroids of the polygons we calculate the dip value of each item from a slope map from the DEMs.

For the purpose of orientation and fabric analysis, we only take into account the items >50 mm of maximal length and with an elongation index (i.e.=length/width)>1.6 (Drake, 1974). In orientation analyses, we use the Rayleigh and Kuiper tests to differentiate between samples with a uniform (isotropic) and non-uniform (anisotropic) distribution pattern (Fisher, 1993). In fabric analysis, we calculate some fabric indexes (eigenvectors, eigenvalues, K and C ratios, Vollmer´s fabric indexes) to produce graphs (stereographic projections, Woodcock and Vollmer diagrams) (Woodcock, 1977; Benn, 1994; Benn and Ringrose, 2001).

3.5. SPATIAL ANALYSIS

The analysis of the spatial distribution pattern of archeological sites is an important source of information to measure the degree of sedimentary disturbance (e.g., Domínguez-Rodrigo et al., 2018). The performance of robust statistical tests allows for suitable comparisons between sites and different archeological items. Here we follow the pattern point analysis methodology of Baddeley et al., (2015) and use the R software library Spatstat. These tests have been performed on datasets with large window sizes. Therefore, in the case of Gombore II, we chose only sectors II1 and OAM.

The first step is to characterize the typology of the spatial point pattern, which can be defined as random (i.e., CSR -Complete Spatial Randomness-), cluster or regular. CSR and regular spatial point patterns are mostly linked to a higher degree of sedimentary disturbance, while cluster patterns suggest higher spatial integrity. This methodological approach also allows us to assess the spatial correlation (i.e., co-dependence) between archeological items (faunal remains and lithic industry) and natural elements (unmodified clasts). This, in turn, helps measure the degree of sedimentary disturbance of any archeological assemblage. In addition, at Garba I we differentiate the LCTs assemblage from the other artifacts, in order to test if there is any specific spatial pattern.

Regardless of the spatial point pattern, it must be assessed whether the analyzed samples display spatial homogeneity or non-homogeneous patterns, which request different types of tests. We performed the Chi^2 (X^2) test to test for homogeneity, which evidenced non-homogeneous patterns in all cases analyzed here. Accordingly, in the next step, we use the non-homogeneous variants of the tests. We also calculate intensity maps based on Likelihood Ratio test statistics (LRTS) with hotspot validation of significant item presence (p >0.05) and Kernel Smoothed Intensity maps. Such maps are quite informative on the spatial relationships among the different items.

To measure the type of spatial pattern of the main samples we perform statistical tests such as the Inhomogeneous Pair Correlation Function (PCF); the Hopkins-Skellam, Clark-Evans; or the non-homogeneous Kscaled, Lscaled functions. Each test provides different results allowing the establishment of the spatial distribution pattern, as well as the degree of clustering and its pattern over the analyzed spatial window. We perform supplementary tests to determine the degree of spatial co-dependence (aggregation vs. spatial segregation between elements) between the main types of analyzed items. These include the Monte Carlo test of spatial segregation and inhomogeneous Kcross function.

Tab. 1 - Basic statistics (range, mean and standard deviation) of dataset.

Assemblage	n	x-X	Mean	Sd
Kellac	5753	3-216	28.2	16.8
Gombore II unmodified clasts	12872	6-332	58.0	32.8
Garba I unmodified clasts	9744	6-500	65.2	38.0
Gombore II faunal remains	2346	8-553	59.6	44.8
Garba I faunal remains	1746	6-610	34.9	28.4
Gombore II lithic industry	2302	11-295	71.8	35.2
Garba I lithic industry	4435	11-272	63.6	45.1

4. RESULTS

4.1. LITHIC TAPHONOMY: SIZE PATTERN

The analysis of sizes and size ranges performed on the samples from Kella River, Gombore II, and Garba IB point to different patterns (i.e., sedimentary sorting) between the natural clasts and the archeological record (especially on the lithic industry). At Kella River, the average and size range distribution includes a high component of small elements, mainly pebbles and cobbles with less than 40 mm in maximal length and 28.2 mm in average size (Tabs. 1 and 2, Fig. 10). At Gombore II and Garba IB the unmodified clasts have an average maximum length of 58.0 and 65.2 mm, respectively. The distribution of size ranges is statistically different between Kella River and Gombore II (X^2=52.9; p=<0.05), and the same occurs with Garba IB (X^2=38.4; p=<0.05). In contrast, the size and size ranges of the unmodified clasts from Gombore II and Garba IB, although significantly different (U=5.783; p=<0.05) are more similar to each other than to the Kella River sample (X^2=20.3; p=0.04). Note the existence of some large cobbles at Garba IB (at least seven specimens) between 300-500 mm in maximum length, whose presence does not have any straightforward geological explanation.

The artifacts from Gombore II display a concentration of size ranges between 40-80 mm, and between 10-40 mm at Garba IB (excluding 29,835 small fragments <20 mm, which is the sieve material). In addition, the mean sizes are respectively 71.8 and 63.6 mm. The data conclusively suggest a significant difference between the maximal length average (U=15.97; p=<0.05) and size distributions (X^2=65.01; p=<0.05) of artifacts at both sites. At both Gombore II and at Garba IB the lithic industry and unmodified pebbles have significantly different averages (U=13.0; p=<0.05 and U=6.16; p=<0.05) and range size patterns (X^2=17.8; p=<0.05; X^2=31.2; p=<0.05) (Tabs. 1 and 2, Fig. 10). However, at Gombore II the comparison between the average (U=0.97; p=0.329) and size ranges (X^2=10.2; p=0.17) of the faunal remains and unmodified clasts points to patterns closer to each other. More specific

Tab. 2 - Sample size range of the analysed sample.

Size range	Kella clasts		Gombore II clasts		Garba I clasts		Gombore II bones		Garba I bones		Gombore II tools		Garba I tools	
	n	%	n	%	n	%	n	%	N	%	n	%	n	%
<10	264	4.6	41	0.3	660	6.8	1	0.0	275	15.8	0	0.0	161	3.6
10-20	1924	33.4	1164	9.0	2687	27.6	125	5.3	1067	61.1	35	1.5	1887	42.5
20-40	2454	42.7	3360	26.1	1734	17.8	776	33.1	306	17.5	413	17.9	795	17.9
40-60	781	13.6	2846	22.1	1347	13.8	619	26.4	59	3.4	523	22.7	369	8.3
60-80	246	4.3	2386	18.5	1412	14.5	345	14.7	14	0.8	496	21.5	317	7.1
80-100	70	1.2	1675	13.0	1148	11.8	210	9.0	6	0.3	397	17.2	261	5.9
100-120	10	0.2	843	6.5	756	7.8	96	4.1	19	1.1	235	10.2	645	14.5
>120 mm	4	0.1	557	4.3	660	6.8	174	7.4	275	15.8	203	8.8	161	3.6

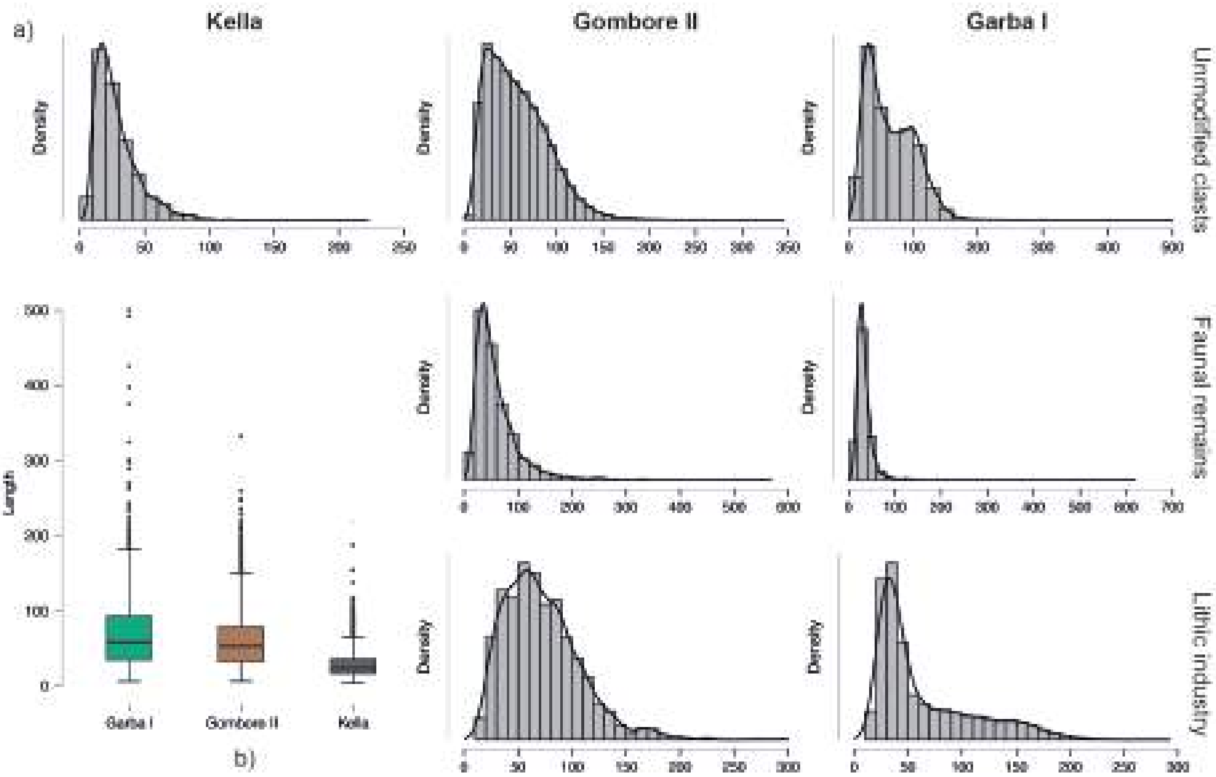

Fig. 10 - Size patterns: a: density plots for the maximum length for the analysed samples; b: detailed boxplots of the maximum length of unmodified clasts.

tests (e.g., Kolmogorov-Smirnov Test), however, allow to discriminate the two samples (D=3.02; p=<0.05). At Garba IB the size pattern of faunal remains and unmodified clasts is different (U=25.56; p=<0.05; X^2=102.2; p=<0.05). Furthermore, both sites do not display average (U=16.7; p=<0.05; U=27.78; p=<0.05) and size range (X^2=30.18; p=<0.05; X^2=117.02; p=<0.05) correspondence between faunal remains and artifacts.

The available information does not suggest any extensive metric sorting between the archeological elements (mainly on the lithic industry) and the unmodified clasts of Gombore II and Garba IB. At Garba IB the large number of micro-artifacts <20 mm (29,835 items) further points to low sedimentary disturbance of the archeological assemblage.

4.2. ORIENTATION AND DIP ANALYSIS

4.2.1. Orientation trends

The orientation pattern tests performed on the lag deposit of Kella River display a preferred orientation concordant with the direction of the present-day water flow. Rayleigh and Kuiper´s test results are conclusive with an anisotropic distribution (Tab. 3). A similar anisotropic pattern was identified on the unmodified clast assemblage of Gombore II and Garba IB (Tab. 3, Fig. 11). This is further evidence that the sedimentary process was similar at Gombore II and Garba IB and at the Kella River, which agrees with geological observations.

At Gombore II the Rayleigh and Kuiper´s test values similarly conclusively point to an isotropic distribution of the archeological assemblage, i.e., faunal remains and lithic artifacts (Tab. 3, Fig. 11). Minor differences were identified between the different sub-tasks and types of analyzed items (Tab. 3, Fig. 11), apparently linked to changes of the flow direction in a same sedimentary environment. At Gombore II the orientation patterns of unmodified clasts and archeological/faunal assemblages are different, suggesting distinct taphonomic histories/deposition events.

At Garba IB the statistical tests evidence distinct orientation patterns for lithic industry and faunal remains. The whole artifact assemblage displays an anisotropic orientation pattern while the bone assemblage is clearly isotropic (Tab. 3, Fig. 11). At first sight there is a contradiction between artifact assemblages and size pattern, suggesting a lowly disturbed assemblage. Garba IB allows for further refinement of the analysis, comparing the orientation of the extensive LCT assemblage with the other technological categories. The results unambiguously point to an anisotropic distribution pattern for the extensive flake assemblage, while the LCTs display a clear isotropic distribution pattern, without any main orientation trend (Tab. 3, Fig. 11). A large percentage of the lithic assemblage (mainly flakes) was deposited and disturbed under sedimentary conditions similar to those of the unmodified clasts, while the large LCTs assemblage was not. The other technological groups

Tab. 3 - Results of the main orientation trends analyse and Rayleigh and Kuiper's tests on the uniformity of all datasets. In in bold type the samples with a statistical anisotropic distribution.

Assemblage	n	Rayleigh Test (Z)	Rayleigh Test (p)	Kuiper's Test (Uniform. V)	Kuiper's Test (p)
Kella	566	6.098	0.002	2.056	< 0.01
Gombore II unmodified clast	1724	4.953	0.007	2.465	< 0.01
Gombore II lithic industry	796	0.041	0.959	0.974	> 0.15
Gombore II faunal remain	720	0.929	0.395	1.297	> 0.15
Garba I unmodified clast	1442	28.701	< 0.000	4.242	< 0.01
Garba I whole lithic industry	925	9.996	<0.000	2.772	< 0.01
Garba I faunal remains	153	0.052	0.949	1.1	> 0.15
Garba I flake/Flake fragment	216	5.343	0.005	2.082	< 0.01
Garba I core/core fragment	24	1.992	0.136	1.656	0.10 > p > 0.05
Garba I indeterminate	35	0.456	0.637	1.326	> 0.15
Garba I waste	27	1.769	0.171	1.698	0.10 > p > 0.05
Garba I flake tools	21	0.225	0.803	0.917	> 0.15
Garba I Widely abraded tools	31	3.249	0.037	1.982	< 0.025
Garba I LCTs	560	2.011	0.134	1.549	0.15 > p > 0.10

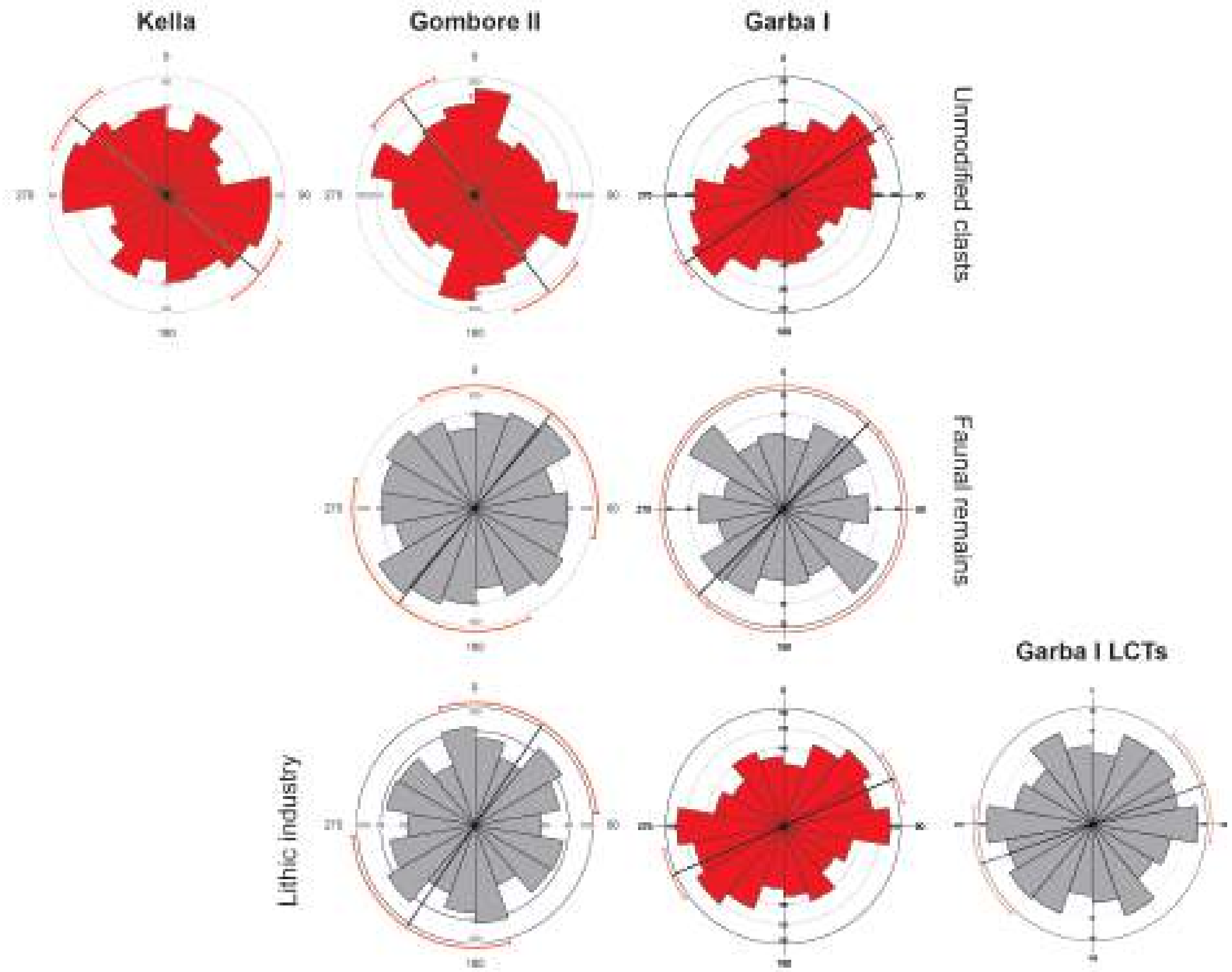

Fig. 11 - Rose diagrams with measured orientations. Diagrams filled in red display anisotropic patterns (i.e., preferential orientations).

are not representative enough (n. <50 cases) to allow any statistical analysis. (Tab. 3, Fig. 11).

4.2.2. Fabric pattern

Fabric data are available only for Kella River and Gombore II OAM but provide important input to the discussion developed here. In the present-day fluvial environment at Kella River, the fabric pattern is characterized by a high girdle degree (Tab. 4). The assemblage displays small K and C values (0.24 and 2.19, respectively), which are indicators of planar conditions with low pattern of isotropy. In addition, the Vollmer´s index values as well as F and CGI values also suggest this fabric pattern, but with some lineal trends (Tab. 4).

At Gombore II OAM the unmodified clasts display a fabric pattern similar to Kella River bed (Tab. 4). The gravels have a K index lower than in Kella River bed, but similar cluster and gridle index values (Tab. 4). The archeological remains (lithic industry and bones) display a different fabric pattern. The fabric indexes, stereographic representation, and Woodcock and Vollmer graphs consistently point to a high gridle pattern, and lower linear degree, but similar isotropic components (Fig. 12). These values suggest different sedimentary/fabric histories for archeological material and natural clasts.

4.3. SPATIAL PATTERNS

4.3.1. Main spatial pattern

The clast density at the Kella River is very high with 495.9 items/m^2. Considering only clasts >40 mm the density drops to 196.5 items/m^2, but all the same, the clasts accumulated massively on the floor of such fluvial channels (Tab. 5). All the tests (x^2, Hopkins-Skellam, Clark-Evans test...) conclusively indicate that there is no CSR pattern, but rather a regular type of point pattern (Tab. 6, Figs. 13-15). This is indicative, at least in the sampled area, of a sedimentary environment which does not produce large spatially significant accumulations of elements (i.e., clusters).

At Gombore II and Garba IB, natural clast density is different (142.5 and 43.4 items m^2, respectively) than at Kella River (Tab. 5). The values of the Kernel Smoothed Intensity and LRTS maps are close to those of Kella River (Figs. 13 and 14), reinforcing conclusions about the similarity of sedimentary dynamics. Furthermore, the natural clasts samples of Gombore II and Garba IB provide conclusive evidence of non-CSR spatial patterning. Notably, there is no extensive difference in the point's spatial pattern, which is regular, except for Garba IB where a low degree of clustering is observed (Tab. 6, Figs. 13 and 16). This further supports the conclusion that clast spatial patterning is similar at Kella River and in the archeological sites.

Artifact densities are obviously much lower than those of natural clasts, displaying ranges of 19.8-38.1 pieces/m^2 (Table 5). As in the case of the natural clasts, all analyzed artifact samples display spatial patterns different from the CSR. The tests produced values compatible with cluster distributions in all samples (Tab. 6, Figs. 13, 14 and 17). At Garba IB, the LCTs, representing a large group, were tested separately. The results are similar to the general artifact assemblage, with significant cluster patterns (Tab. 6, Figs. 13, 14, and 16).

Finally, while at Gombore II the densities of fauna and artifacts are very close to each other, at Garba IB the faunal remain densities are markedly lower (Table 5). The dispersion pattern of bones follows the trend of artifacts with widespread cluster patterns (Tab. 6, Figs. 13, 14, and 18). This is most relevant at Garba IB, where the various tests consistently display a significant degree of clustering (Tab. 6, Figs. 13, 14, and 18).

Tab. 4 - Fabric index of the Kella gravels and of Gombore II OAM clasts and archeological remains.

Assemblage		Woodcock		Eigenvectors and Eigenvalues					
	n	K	C	V1	V2	V3	S1	S2	S3
Kella clasts	566	0.24	2,19	76.9/28.5/655.2	169/3.7/426.3	265.7/61.3/73.424	0.65	0.37	0.06
Gombore II OAM clast	660	0.17	1,95	84.3/32/431.6	175.7/2.2/324.0	269.3/57.9/61.235	0.46	0.44	0.06
Gombore II OAM tools	482	0.10	1,95	107.7/18.3/162.2	16.4/4/135.5	274.5/71.3/23.1	0.49	0.43	0.06
Gombore II OAM bones	339	0.04	1.91	112/15.6/163.7	20.0/7/151.0	266.5/72.8/24.1	0.48	0.44	0.07

Assemblage		Vollmer´s index			Benn´s index			
	n	Cluster	Girdle	Uniform	IS	EL	F	CGI
Kella clasts	566	0.19	0.61	0.19	10.48	0.42	0.16	0.46
Gombore II OAM clast	660	0.13	0.64	0.22	7.25	0.05	0.14	0.06
Gombore II OAM tools	482	0.08	0.70	0.21	7.47	0.11	0.15	0.12
Gombore II OAM bones	339	0.03	0.74	0.21	6.78	0.07	0.16	0.09

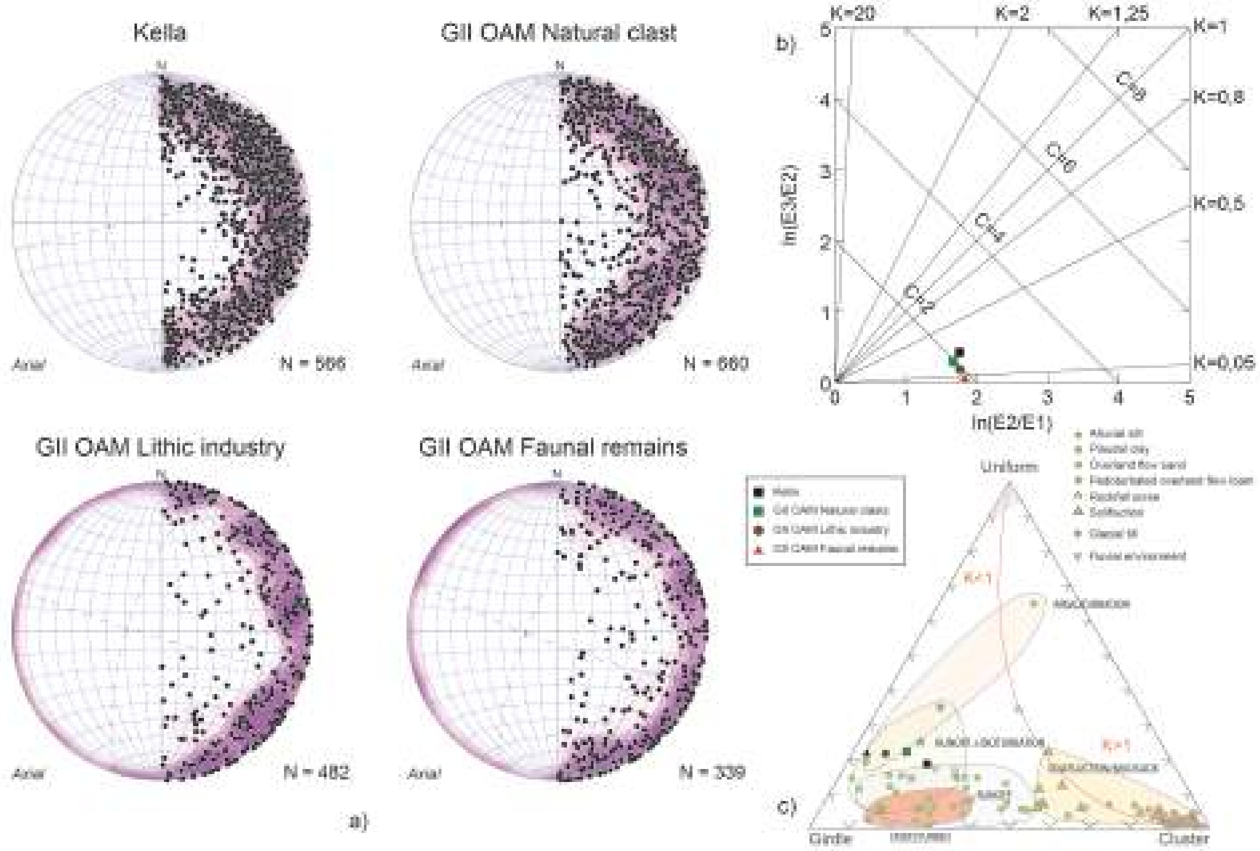

Fig. 12 - Fabric data: a: stereographic projection; b: Woodcock´s diagram; c: Vollmer´s diagram (B) (adapted from Lenoble, et al., 2008 and with additional data from Méndez-Quintas et al., 2022)

Tab. 5 - Excavated areas and items densities per m².

Assemblage	n	Density	
		m²	density/m²
Kella whole sample	5753	11.6	495.9
Kella >40 mm sample	2280	11.6	196.5
Gombore II unmodified clast	12872	90.3	142.5
Gombore II lithic industry	2302	90.3	25.5
Gombore II faunal remain	2346	90.3	25.9
Garba I unmodified clasts	9744	224.3	43.4
Garba I lithic industry	4435	224.3	19.8
Garba I faunal remain	1746	224.3	7.8
Garba I LCTs	853	224.3	3.8

4.3.2. Spatial co-dependence

At Gombore II-1 the spatial relationship pattern between the main items (natural clasts, lithic tools, and bones) is always the same: a random relationship at short distances and a progressive disaggregation from 50 cm onwards (Tab. 7 and Fig. 19). At Gombore II OAM this pattern is enhanced, and the spatial relationships are just random at all analysed distance ranges (Tab. 7 and Fig. 20).

At Garba IB, tests were performed on the spatial co-dependence of natural clasts and artifacts. There is a random relationship at short distances (<100 cm) and a clear tendency to disaggregate from 150 cm onwards (Tab. 7 and Fig. 21). The same pattern is shared between natural clasts-faunal remains, artifacts-faunal remains, LCTs-natural clasts, LCTs-other artifacts, and LCTs-faunal remains none display a relevant degree of co-dependence at a short distance, while disaggregation is significant from 150 cm onwards (Tab. 7 and Fig. 22).

These data support the lack of any spatial relationship (i.e., co-dependence) at a short distance between the whole analyzed items. Accordingly, the archeological record did not undergo the same sedimentary disturbance as the natural clasts, which falsifies any hypothesis of a depositional relationship between natural clasts and tools/faunal remains. Furthermore, these data rule out any relationship between the accumulation of faunal and lithic assemblages (either complete assemblage or only LCTs). This suggests that the sites were not related to the processing of animal resources, mainly at Garba IB (Sánchez Dehesa-Galán et al., 2022).

5. DISCUSSION

The methodology developed to measure the degree of taphonomic integrity of the archeological record at Gombore II and Garba IB followed various approaches.

Tab. 6 - Results of the point pattern type tests.

Assemblage	X^2		Hopkins-Skellam test		Clark-Evans test	
Kella whole sample	p<0.05	No CSR	A = 1.6921, p-value < 2.2e-16	Regular	R = 1.3063, p-value = 0.002	Regular
Kella >40 mm sample	p<0.05	No CSR	A = 1.9049, p-value < 2.2e-16	Regular	R = 1.3542, p-value = 0.002	Regular
Gombore II1 natural clasts	p<0.05	No CSR	A = 0.87278, p-value = 4.199e-12	Cluster	R = 1.2266, p-value = 0.002	Regular
Gombore II OAM natural clasts	p<0.05	No CSR	A = 0.72203, p-value < 2.2e-16	Cluster	R = 1.1258, p-value = 0.002	Regular
Garba I natural clasts	p = 0	No CSR	A = 0.3134, p-value < 2.2e-16	Cluster	R = 0.9844, p-value = 0.002	Cluster
Gombore II1 lithic industry	p<0.05	No CSR	A = 0.57126, p-value < 2.2e-16	Cluster	R = 0.95594, p-value = 0.006	Cluster
Gombore II OAM lithic industry	p<0.05	No CSR	A = 0.89803, p-value = 0.01131	Cluster	R = 1.0472, p-value = 0.024	Regular
Garba I lithic industry	p = 0	No CSR	A = 0.18631, p-value < 2.2e-16	Cluster	R = 0.86838, p-value = 0.002	Cluster
Garba I LCTs	p<0.05	No CSR	A = 0.25324, p-value < 2.2e-16	Cluster	R = 0.92046, p-value = 0.002	Cluster
Gombore II1 faunal remain	p<0.05	No CSR	A = 0.40698, p-value < 2.2e-16	Cluster	R = 0.86051, p-value = 0.002	Cluster
Gombore II OAM faunal remain	p<0.05	No CSR	A = 0.6806, p-value = 3.785e-16	Cluster	R = 0.94948, p-value = 0.002	Cluster
Garba I faunal remain	p = 0	No CSR	A = 0.080516, p-value < 2.2e-16	Cluster	R = 0.60904, p-value = 0.002	Cluster

One of the main issues was that the available data are mostly if not exclusively from older excavations. However, Jean Chavaillon produced remarkably complete and detailed documentation during his research at Melka Kunture, including precise and detailed maps of the excavated surfaces. These data, combined with current field observations, allow using a modern methodology to test special patterning in relation to disturbance and taphonomy.

The size pattern analyses exclude any extensive sedimentary selection patterns, especially in the case of lithic artifacts at Garba IB. Sedimentary sorting is a major problem for stone tools assemblages in high-energy sedimentary environments (Schick, 1986; Schick, 1987; Bertran et al., 2012). Experimental studies suggest that size sorting occurs rapidly, removing the smaller artifacts (Schick, 1986; Schick, 1987; Hiscock, 2002; Bertran et al., 2012).

Another factor of disturbance is displacement and spatial reorganization of the archeological record by river flows. The items, especially lithic artifacts, are oriented following the direction of the flow, or transversally to it (Isaac, 1967; Schick, 1986; Mcpherron, 2005; Domínguez-Rodrigo et al., 2012; Walter and Trauth, 2013; Domínguez-Rodrigo et al., 2014; García-Moreno et al., 2016). The measurements developed here point to a markedly different behaviour of natural clasts and archeological elements. In the case of the present-day sedimentary environment of the Kella River, the clasts display a clear preferential orientation, which follows the flow direction of the watercourse. At Gombore II and Garba IB sites, the natural clasts similarly display a preferential orientation. In contrast, most artifacts and faunal remains do not display any preferential orientation. In the case of Garba IB, the whole artifact assemblage indeed displays preferential orientations, indicative of some degree of sedimentary disturbance. However, the LCTs do not follow the pattern of the rest of the industry, which displays a clearly isotropic distribution. This suggests that the LCTs and the other artifacts have been deposited under different sedimentary conditions, i.e. they may respond to different episodes during various human visits. Most of the lithic industry is reorganized following a pattern similar to that of the natural clasts, while the LCTs assemblage has not undergone a significant process of sedimentary re-organization, with implications on the function of the Garba IB site discussed below.

We have been able to test and elaborate sedimentary fabric patterns only for Gombore II OAM, comparing them to the Kella River data. While there are shared features in the case of unmodified clasts, lithic tools, and faunal remains show different fabrication patterns when compared to natural clasts. These and other data, such as size ranges, orientations, etc. show that the archeological record mostly deposited under sedimentary conditions different from the natural clasts, ruling out intensive disturbance. Even when proven, as in the case of Garba IB lithic industry, the disturbance was not severe.

The spatial pattern analysis is a research topic extensively discussed in the literature to understand the spatial organization of activities and the functionality of Lower Paleolithic sites (e.g., Alperson-Afil et al., 2009; Sánchez-Romero et al., 2016; Domínguez-Rodrigo et al., 2017; Panera et al., 2019; Díez-Martín et al., 2021; García-Moreno et al., 2021; Moclán et al., 2023). The aim of the tests performed here was not to understand site function(s), but rather to measure the degree of spatial integrity (Domínguez-Rodrigo et al., 2018). Overall, while the assemblages of natural clasts generally display regular distributions, the assemblages of artifacts and faunal remains tend towards cluster-like spatial patterns. This further split apart the deposition of natural clasts and of the archeological record. The same happens with the degree of spatial co-dependence, which measures spatial relationships. The statistical analysis shows no co-dependence at short distances of natural clasts and

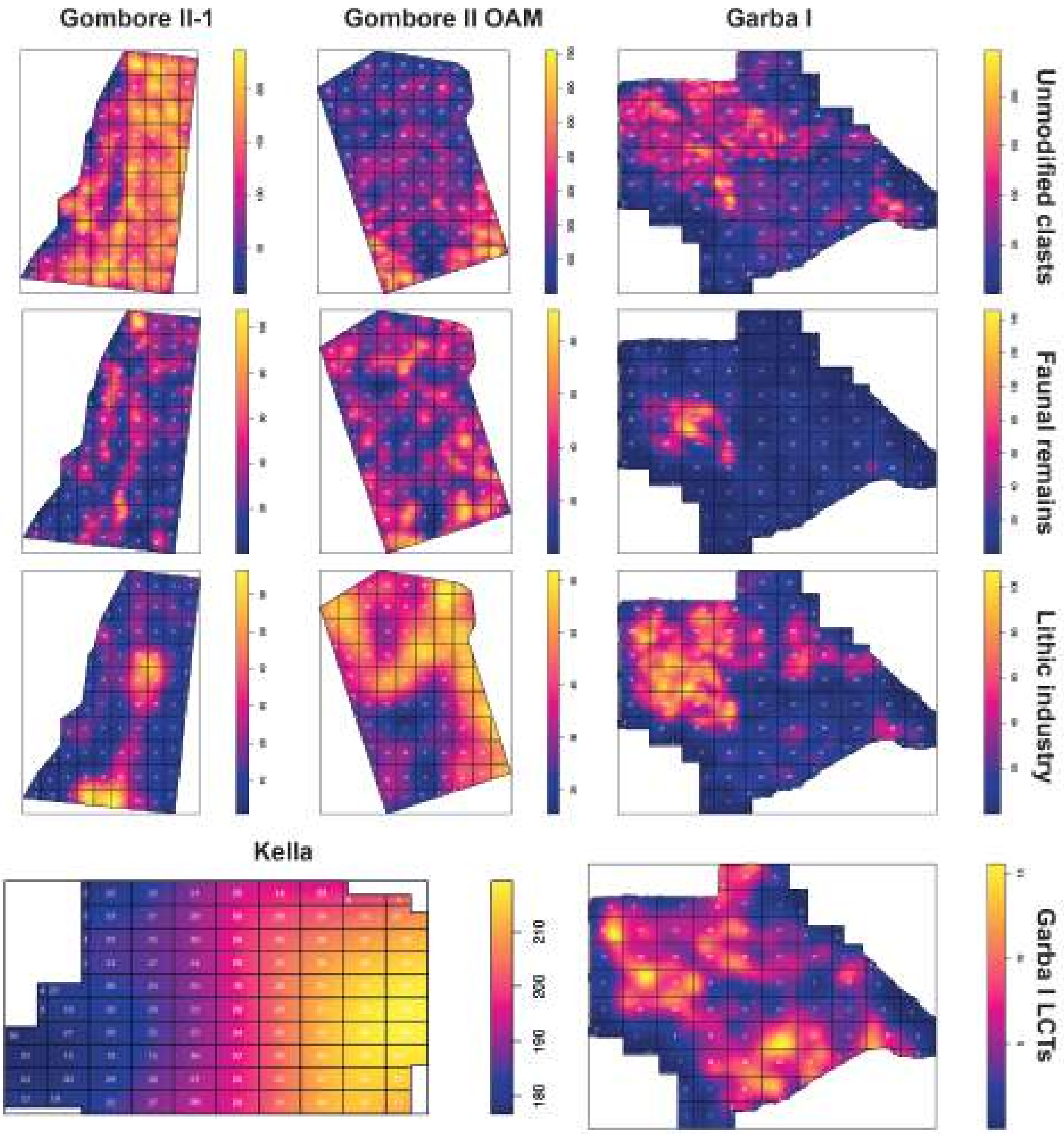

Fig. 13 - Kernel Smoothed Intensity maps for the most representative window size datasets.

archeological elements. These same tests do not establish a clear spatial co-dependence relationship between artifacts and faunal remains. This spatial dissociation helps in understanding site function, especially in the case of Garba IB. This site is characterized by an extensive accumulation of lithic industry and particularly by LCTs. In contrast, the faunal remains are few and mostly cluster in part of the excavated area. As noted above, there is no significant spatial co-dependence between bone and stone artifacts, suggesting that their accumulation is unrelated. This leads to the hypothesis that such sites (with extensive accumulations of LCTs) are not focused on large animal biomass processing (Méndez-Quintas et al., 2018; Santonja et al., 2018; Sánchez Dehesa-Galán et al., 2022).

At Gombore II, similarly, there is no strong spatial co-dependence between artifacts and faunal remains, so maybe the deposition of both is not closely related in time/function (Méndez-Quintas et al., 2019). However, although all the tests rule out any extensive sedimentary disturbance, there are no fully autochthonous scenarios either. In several cases (e.g., preferential tools orientations at Gombore II or Garba IB), the tests point to some degree of disturbance which, however, does not seem to have been sufficiently intense to completely transform the spatial distribution and features.

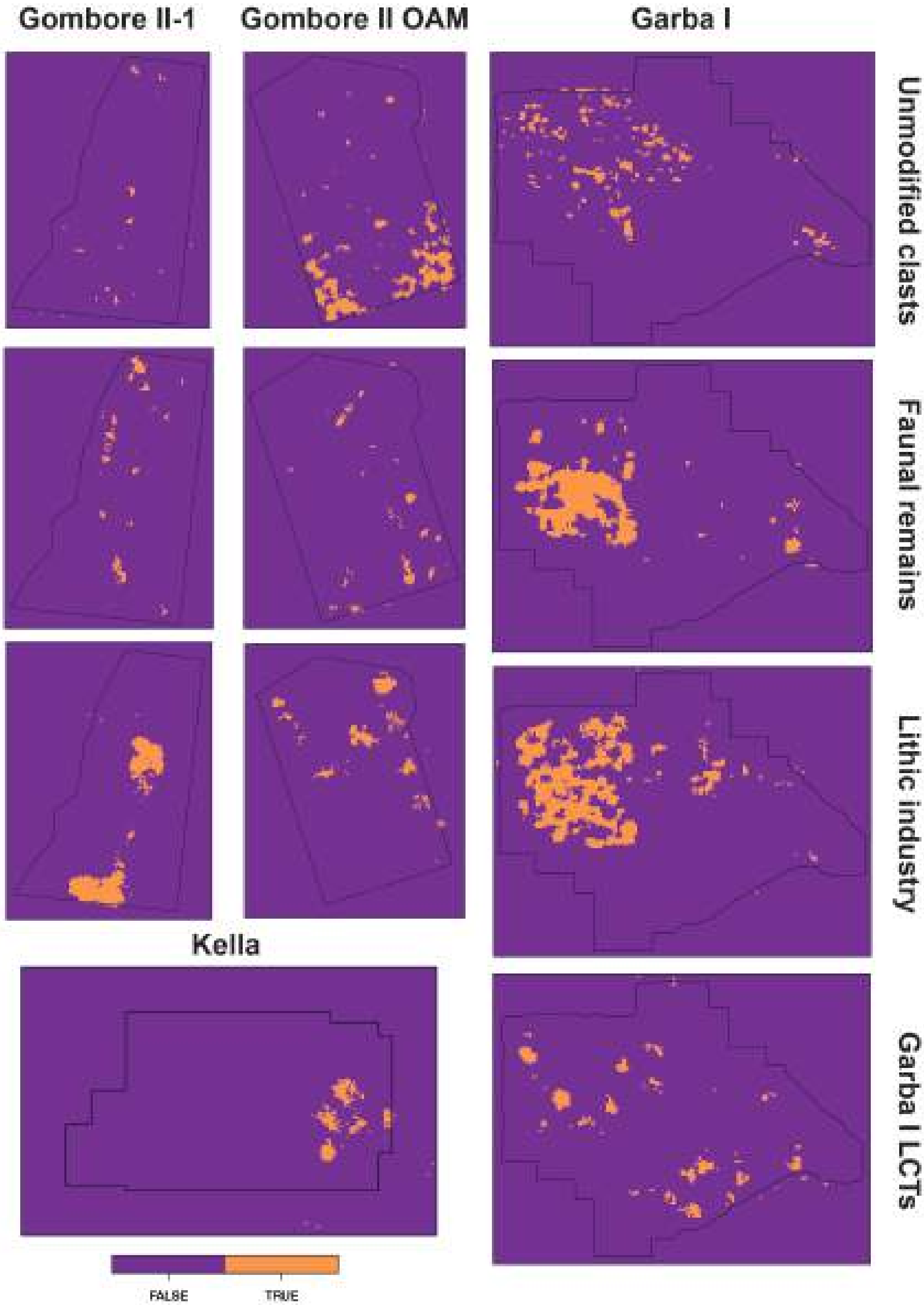

Fig. 14 - Likelihood Ratio test statistics maps -with hotspot validation of significant item presence (p >0.05)- for the most representative window size datasets.

6. CONCLUSIONS

The study of the taphonomic integrity and spatial relationships at Gombore II and Garba IB provides new data which helps in understanding sites associated with river channels and lag deposits. Our workflow combines the analysis of archive data with field observations and compared them with current analogous sedimentary

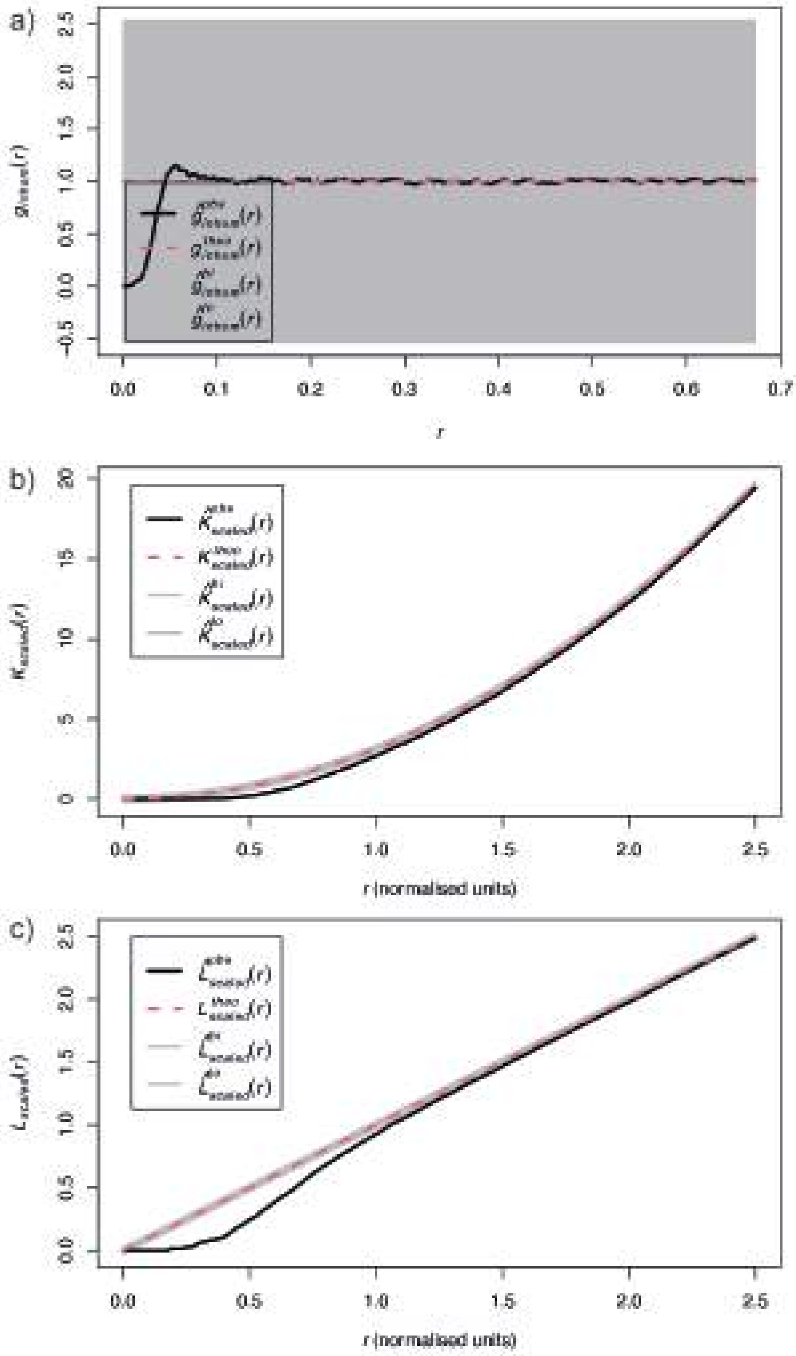

Fig. 15 - Results of Inhomogeneous Pair Correlation Function (PCF) and non-homogeneous Kscaled and Lscaled functions for Kella River dataset.

scenarios.

The results of the tests, which include the analysis of size patterns, orientations, fabrics, and spatial distribution, overall rule out that the archeological assemblages underwent sedimentary processes of the same magnitude as those affecting the natural clast accumulation at the base of the sites. The data suggest that the deposition of the natural clasts and the archeological record occurred at different times. We conclude that the archeological assemblages retain a higher degree of taphonomic integrity than might be expected, with generally autochthonous positions. However, they have been subjected to some disturbance, most probably happening when the remains were buried during a new sedimentary phase. This may have resulted in the loss of part of the record and in the spatial reorganization of some archeological elements.

We also underline the importance of producing and keeping archeological archives. Past hand-made plotting, if accurate, allows statistical tests and the development of new methodologies and approaches, as in the case of Melka Kunture. Photographs are similarly important and allow identifying features, such as mammal or other

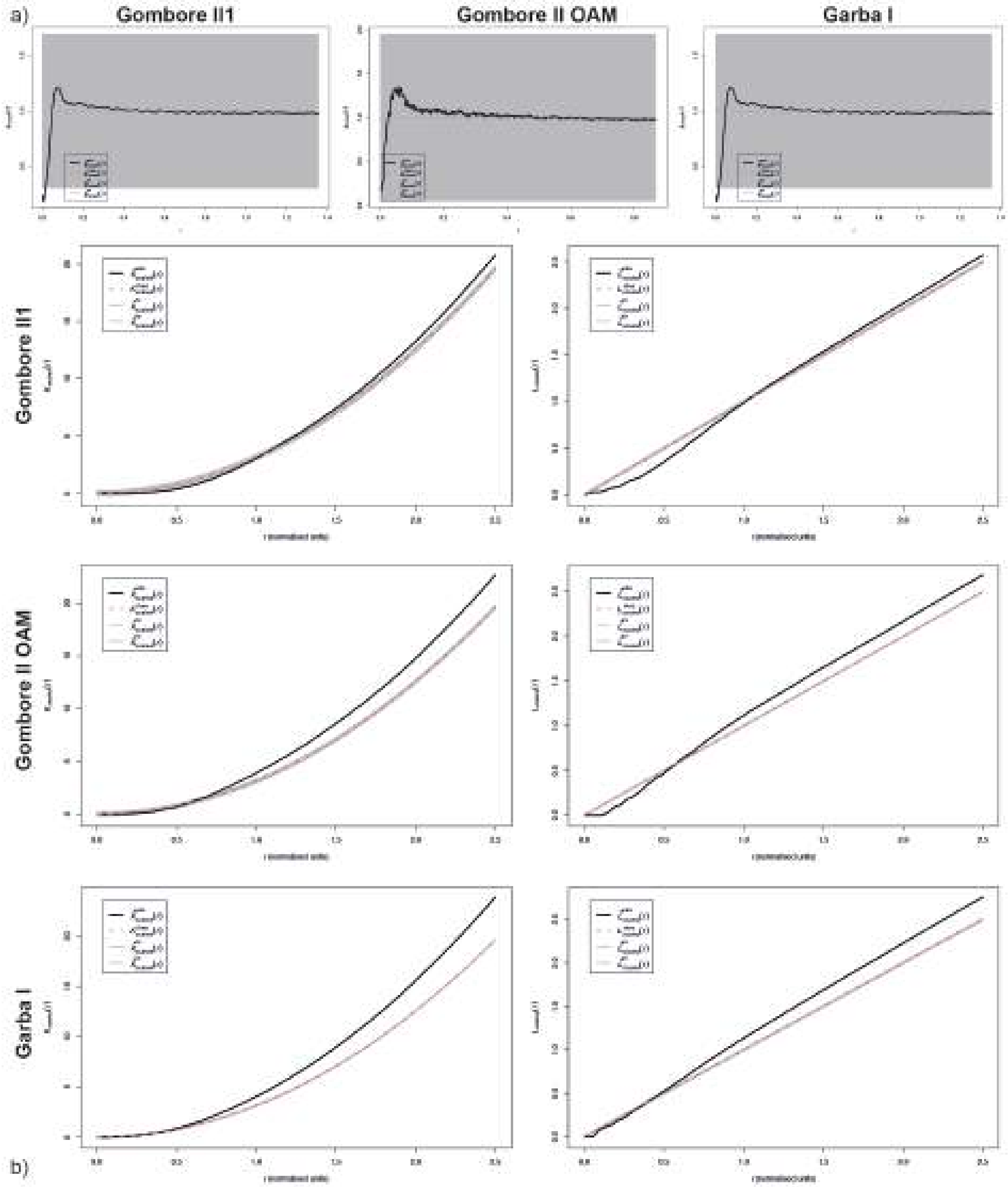

Fig. 16 - Results of PCF (a) and non-homogeneous Kscaled and Lscaled functions (b) for natural clasts dataset.

tracks, not looked for or identified at the time of past excavations (Altamura et al., 2020a). The importance of complete and well-kept archives - with all documentation of previous archeological excavations - has been repeatedly underlined by the World Heritage Thematic Programme "Human Evolution, Adaptations, Dispersal and Social Developments", established in 2010 by the 34th Committee of UNESCO.

Melka Kunture is currently on the Tentative List of UNESCO's World Heritage List (Melka Kunture and Balchit - UNESCO World Heritage Centre). The archeological archives are an asset in the candidature of Melka Kunture.

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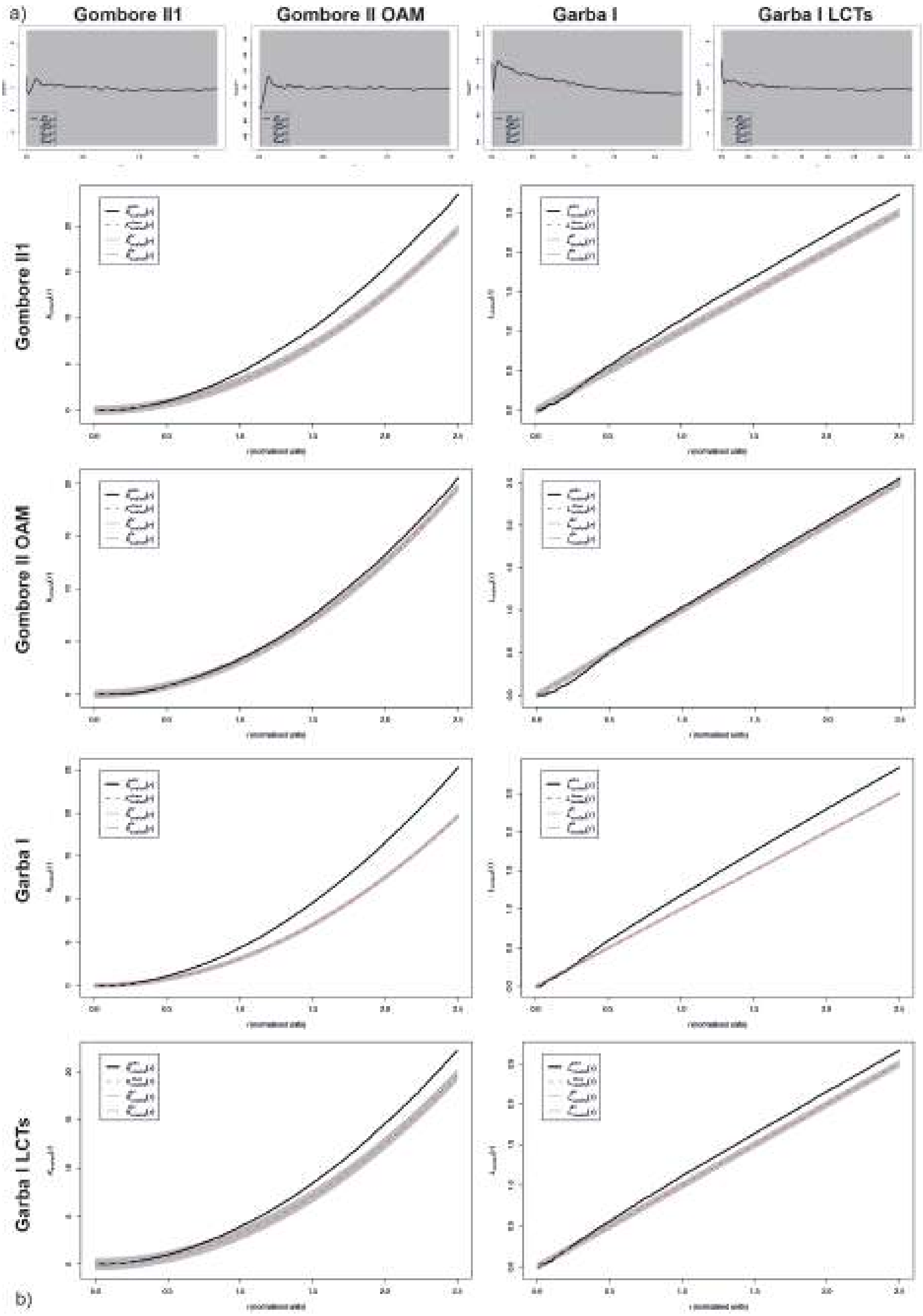

Fig. 17 - Results of PCF (a) and non-homogeneous Kscaled and Lscaled functions (b) for lithic industry dataset.

Tab. 7 - Results of the spatial co-dependence test and inhomogeneous version of Kcross functions (Fig. 19-22).

Sector	Dataset	Monte Carlo test of spatial segregation	Interpretation
Gombore II1	Clasts_tools	T = 44.277, p-value = 0.05	Spatial segregation from 0.5 m
Gombore II1	Clasts_Bones	T = 61.809, p-value = 0.05	Spatial segregation from 0.5 m
Gombore II1	Tools_bones	T = 66.77, p-value = 0.05	Spatial segregation from 0.5 m
Gombore II OAM	Clasts_tools	T = 70.86, p-value = 0.05	Spatial segregation from 0.5 m
Gombore II OAM	Clasts_Bones	T = 36.414, p-value = 0.05	Spatial segregation from 0.5 m
Gombore II OAM	Tools_bones	T = 28.901, p-value = 0.05	Spatial segregation from 0.5 m
Garba I	Clasts_tools	T = 377.16, p-value = 0.05	Spatial segregation from 1-1.5 m
Garba I	Clasts_Bones	T = 437, p-value = 0.05	Spatial segregation from 1-1.5 m
Garba I	Tools_bones	T = 382.42, p-value = 0.05	Spatial segregation from 1-1.5 m
Garba I	LCTs_tools	T = 175.52, p-value = 0.05	Spatial segregation from 1.5 m
Garba I	LCTs_bones	T = 235.97, p-value = 0.05	Spatial segregation from 1.5 m
Garba I	LCTs_clasts	T = 27.608, p-value = 0.05	Spatial segregation from 1.5 m

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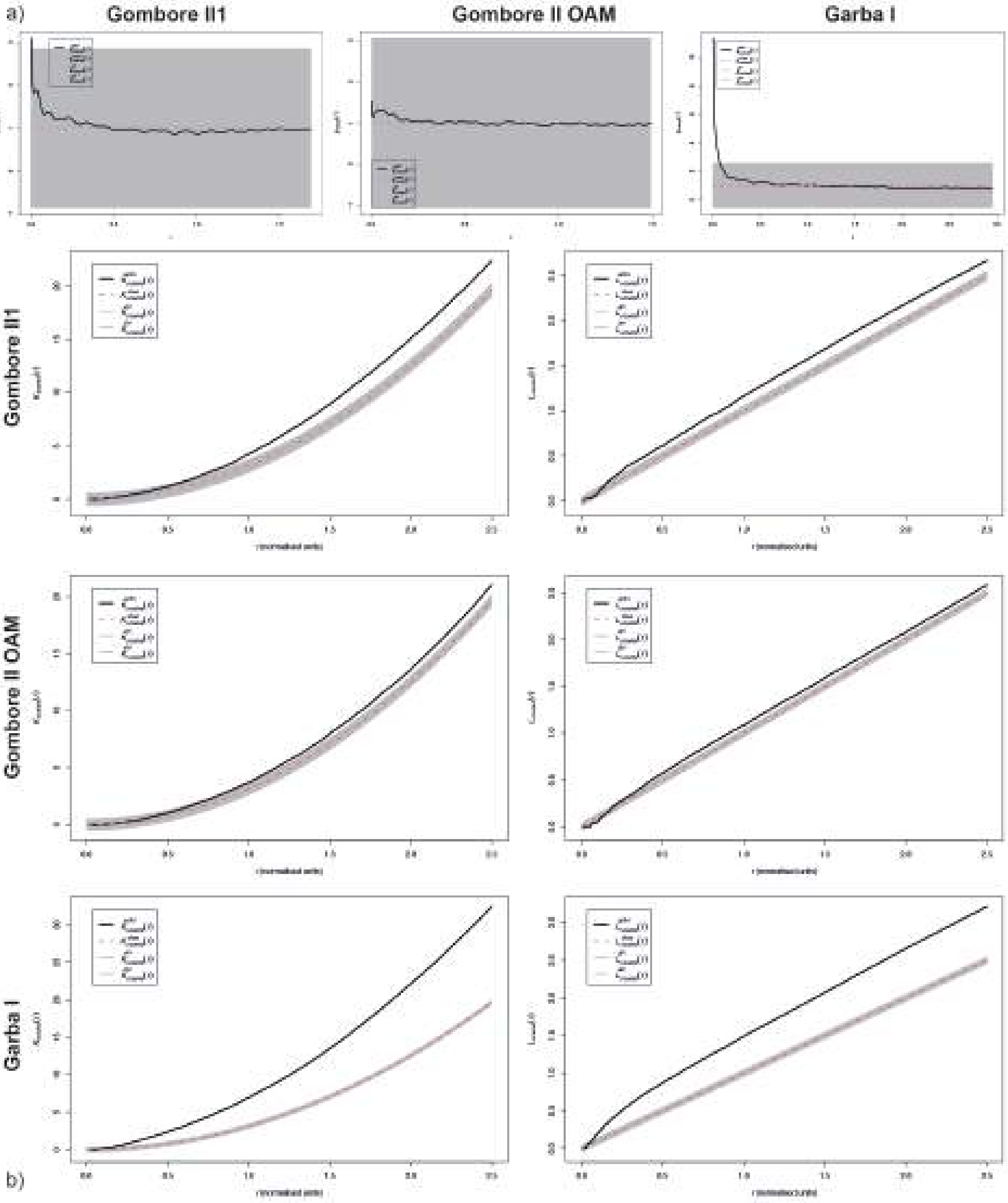

Fig. 18 - Results of PCF (a) and non-homogeneous Kscaled and Lscaled functions (b) for the faunal remains dataset.

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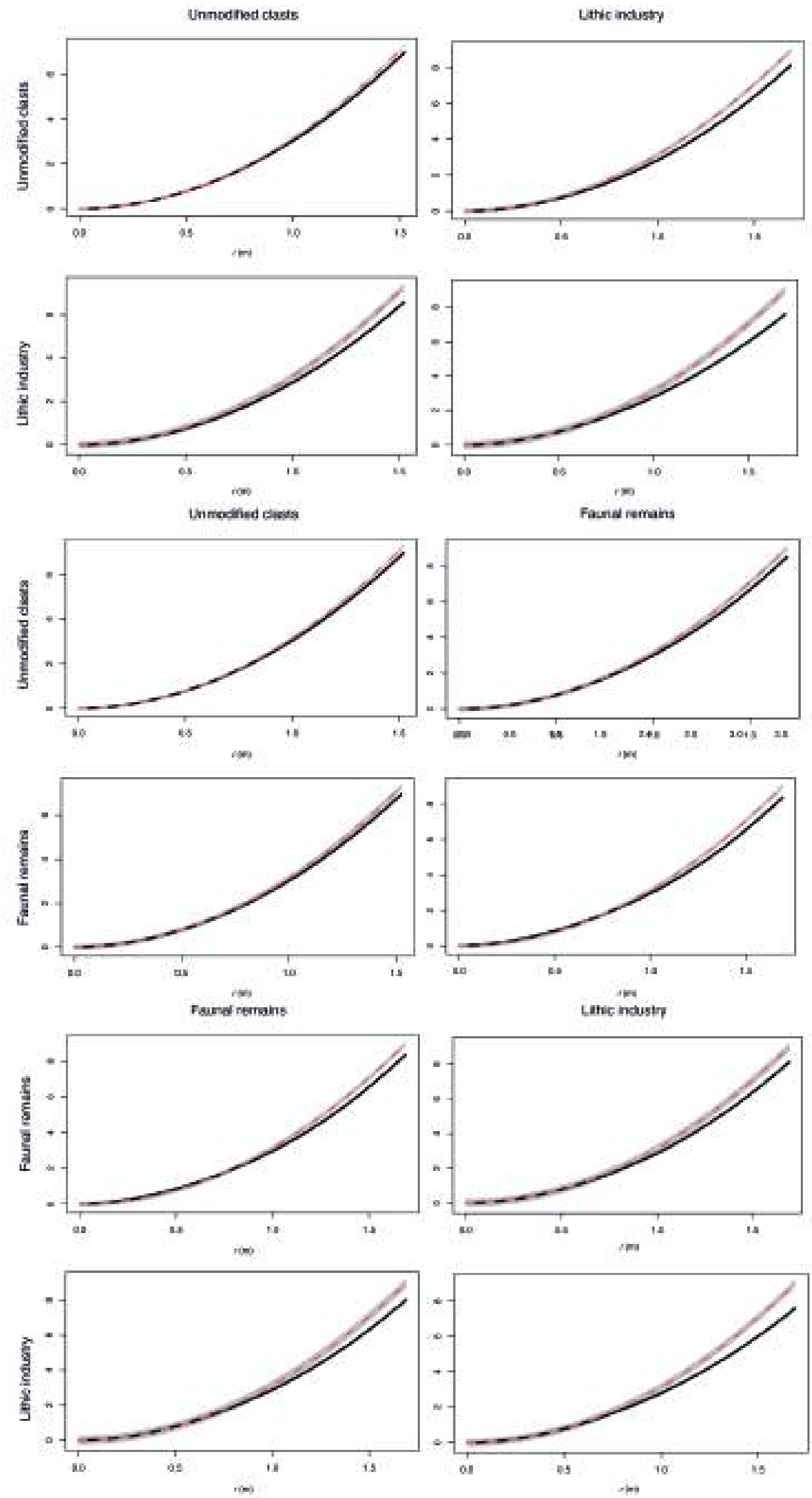

Fig. 19 - Results obtained by the inhomogeneous version of Kcross functions from Gombore II1.

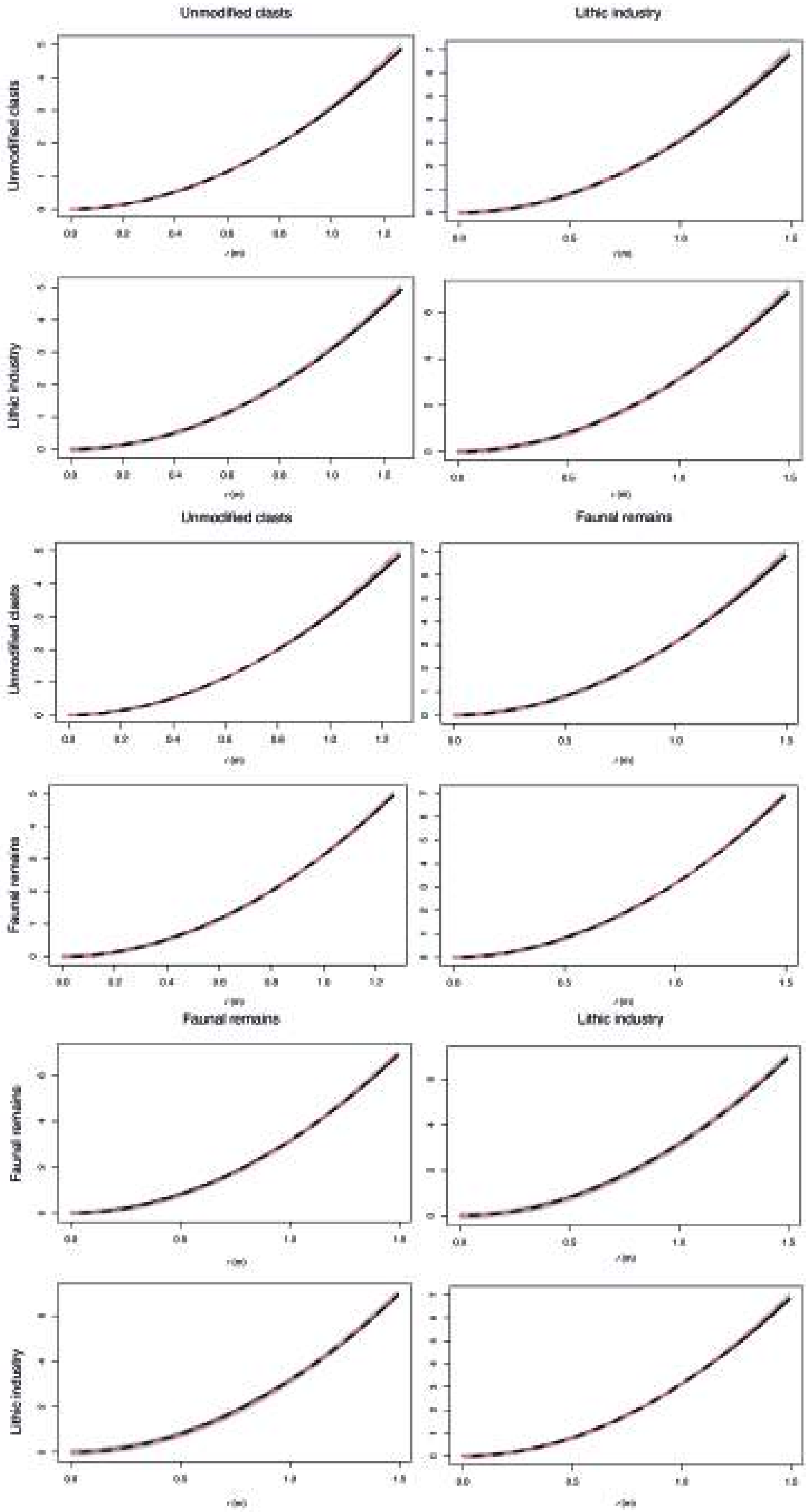

Fig. 20 - Results obtained by the inhomogeneous version of Kcross functions from Gombore II OAM.

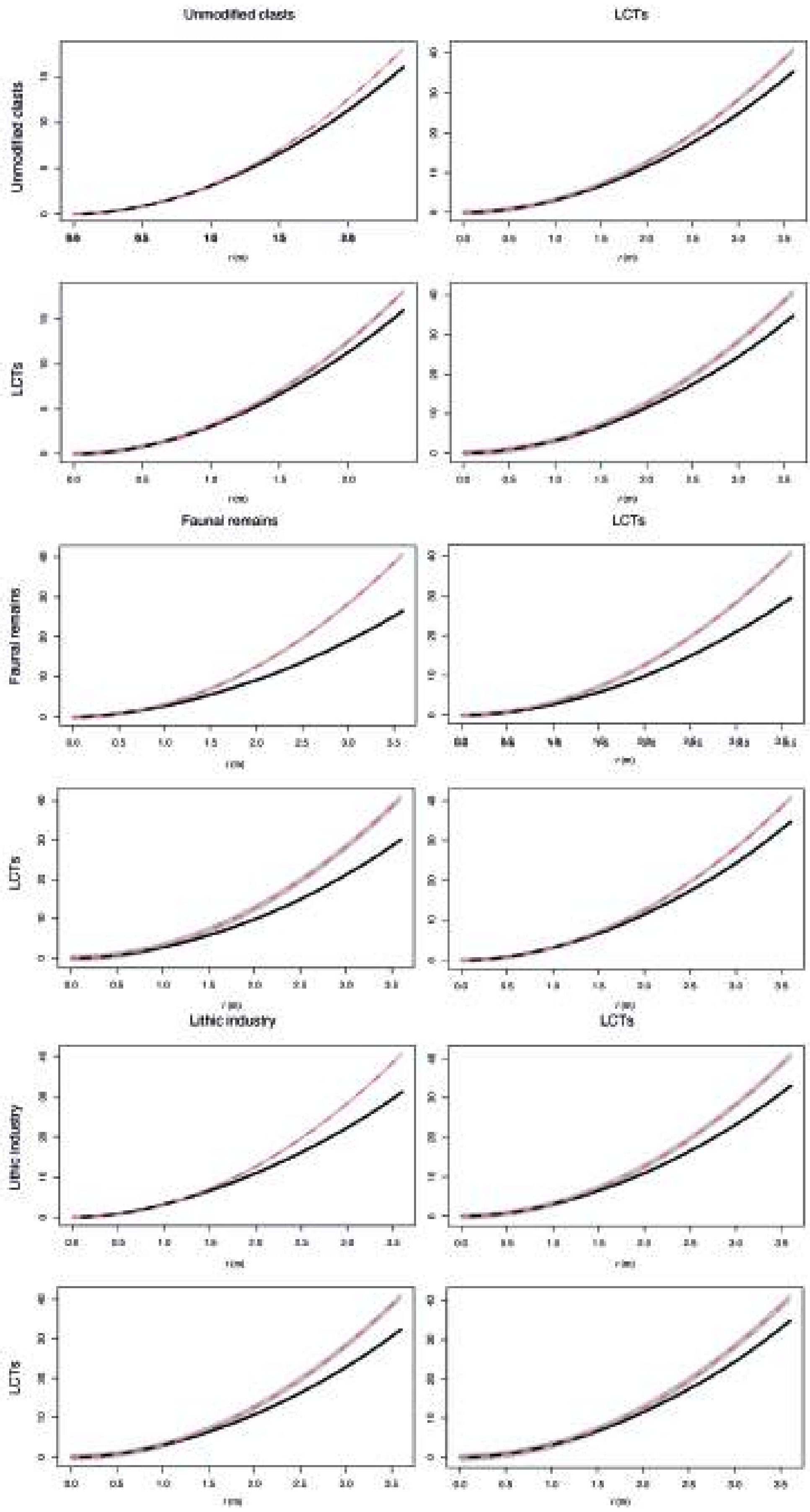

Fig. 21 - Results obtained by the inhomogeneous version of Kcross functions from Garba IB.

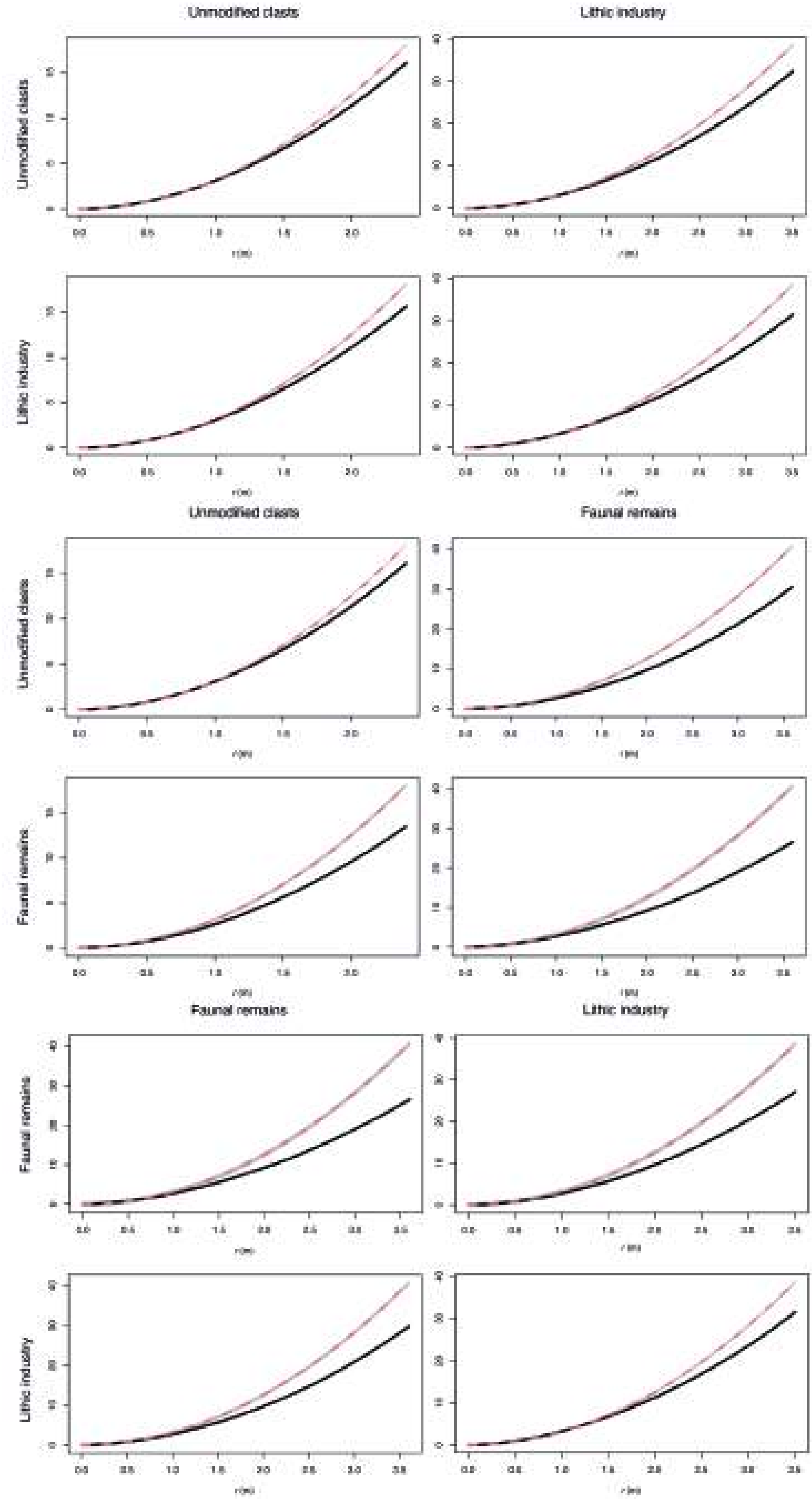

Fig. 22 - Results obtained by the inhomogeneous version of Kcross functions from LCT assemblage at Garba IB.

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