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Middle Stone Age (MSA) in the Atlantic rainforests of Central Africa. The case of Río Campo region in Equatorial Guinea

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ABSTRACT

Understanding the evolutionary history of humans within the rainforest ecosystems of Central West Africa poses a significant challenge. These environments are crucial for exploring both the biological and cultural development of *Homo sapiens*. However, the lack of comprehensive archaeological and chronological sequences in African rainforests hampers efforts to situate them within a broader evolutionary framework. In this study, we present findings from our surveys conducted in northern Equatorial Guinea. Specifically, in the Río Campo (also referred to as Río Ntem) region, we investigated 30 Quaternary stratigraphic outcrops, 16 of which contained stone tools. Among these, the Campo 11 site stands out due to the complexity of its lithic assemblage, representing one of the most significant indicators of human occupation in the Pleistocene of Central West Africa. Geomorphological reconstruction of the area suggests the development of a meandering fluvial system during the Upper Pleistocene. This system was characterized by sandbars and shallow channel beds overlaying a Cretaceous basement. Optically Stimulated Luminescence (OSL) and radiocarbon (14C) dating place the occupation phases within these sedimentary units between over 44,000 and 20,000 years ago, with a lower sand unit dating back 76,000 years, marking the beginning of the Quaternary sequence. The lithic assemblages from Río Campo, particularly those from Campo 11 and Campo 4, provide compelling evidence of human presence approximately 24,000 years ago. These assemblages are characterized by tools associated with the Lupemban technocomplex, including large cutting tools, bifacial points, heavy-duty implements, Levallois cores, and occasional blade production. Their techno-typological attributes align with Middle Stone Age traditions and point to a cultural continuity rooted in the Acheulean–Sangoan–Lupemban succession, which dates back some 250,000 to 300,000 years. Nevertheless, the absence of earlier stratigraphic records limits our findings to a minimum age for human occupation in this region. The timing and extent of the earliest settlements along the Atlantic fringe remain elusive. While Lupemban industries hint at profound cultural continuity in Central African rainforests, the paucity of high-quality archaeological data prevents definitive conclusions. Further research is essential to address these gaps and fully integrate the Central West African rainforests into the broader narrative of human evolutionary history.

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1. Introduction

The origin and biocultural diversification of *Homo sapiens* remains one of the most compelling topics in paleoanthropology (Stringer, 2016; Henn et al., 2018; Scerri et al., 2018; Meneganzin et al., 2022). The integration of archaeological, palaeontological, and genomic data points to a decentralized origin of the traits defining both the cultural (McBrearty and Brooks, 2000) and anatomical "modernity" of *H. sapiens* (Hublin et al., 2017; Richter et al., 2017). This perspective has led to the development of new models for the origin and evolution of our species (Gunz et al., 2009), often referred to as "African multiregionalism" (Stringer, 2016) and later refined into metapopulation frameworks (Scerri et al., 2019). Conversely, some authors have contested these approaches, advocating for an updated version of the single-origin model for *H. sapiens* (Meneganzin et al., 2022).

A recurring challenge in evolutionary model development is the limited understanding of natural history in underexplored regions of the globe (Bergström et al., 2021), which could potentially reveal groundbreaking data (Harvati et al., 2011; Scerri et al., 2017). Central and West Africa, in particular, have garnered growing interest as critical sources of information on human evolution (Taylor, 2014, 2016; Scerri et al., 2017). This renewed focus is further driven by recent paleogenomic findings suggesting that this region represents an underappreciated locus of *H. sapiens* ancestry, harboring ancestral lineages within modern humans and potentially with archaic species (Durvasula and Sankararaman, 2020; Lipson et al., 2020). Evidence also suggests the persistence of culturally and physically relict populations in these areas (Harvati et al., 2011; Scerri et al., 2017). This study addresses these issues by analyzing recently recovered Pleistocene prehistoric evidence from the Republic of Equatorial Guinea, a largely unexplored territory on the Atlantic fringe of Central Africa.

Recent advancements in genomics have added complexity and depth to these discussions. For instance, Lipson et al. (2020) inferred a brief phase of divergence during the Middle Pleistocene, involving at least four major lineages. These lineages contributed to: 1) central African hunter-gatherers, 2) southern African hunter-gatherers, 3) a "phantom" population possibly located in Sahelian territories, and 4) an eastern African lineage that served as the ancestral pool for later populations. Southern African hunter-gatherers diverged around 300 ka and represent the deepest branch of modern human variation (Schlebusch et al., 2017). Similarly, central African hunter-gatherers diverged during the same period (or perhaps earlier) as part of a large-scale radiation (Lipson et al., 2022). Subsequently, they split into eastern (Mbuti) and western clades. In contrast, the East African lineage provided the ancestral matrix for populations involved in the Out-of-Africa dispersal (~60 ka ago). This dispersal coincided with an Inside-of-Africa migration, as evidenced by Y-chromosome phylogeography (Soares et al., 2011) and genomic studies (Lipson et al., 2022). Consequently, Central Africa emerges as both an original center of *H. sapiens* differentiation and a site of later recolonizations during the Upper Pleistocene by East African populations with distinct ancestries.

The establishment of Central Africa's archaeological sequence has a long history (Mesfin et al., 2020). Early colonial research, primarily surface collections and discoveries during mining and infrastructure projects, formed the basis of this work. Building on these foundations, Breuil (1944) developed an initial chrono-cultural framework for the region. Post-colonial research, particularly from the 1950s to the 1970s, expanded into the broader Congo Basin. Subsequent contributions from notable researchers provided significant insights (e.g., Mortelmans, 1957; de Bayle des Hermens, 1966, 1971; Lanfranchi, 1984; Allsworth-Jones, 1986; Brooks and Smith, 1987; Lanfranchi and Schwartz, 1990; Lanfranchi and Clist, 1991; Brooks et al., 1995; Cornelissen, 2002, 2003, 2015).

Despite these efforts, systematic archaeological investigations in Equatorial Guinea have been limited until recently (Clist, 1987, 1991, 1998; Mercader et al., 2002; Mercader and Martí, 2003; Terrazas and Rosas, 2016; Rosas et al., 2022; Terrazas-Mata et al., 2023). This gap underscores the scarcity of structured archaeo-paleontological information from Central Africa, even in regions with extensive research traditions (Roberts and Petraglia, 2015; Taylor, 2016; Scerri et al., 2017; Padilla-Iglesias et al., 2023). Central Africa's dense rainforest vegetation presents unique challenges for research, including limited infrastructure, political instability, and difficulties in dating records (Taylor, 2014). Furthermore, the rainforest's adverse conditions hinder organic preservation (Rosas et al., 2022). As a result, the timeline of human occupation in areas now covered by dense rainforests remains unclear. While evidence from Elarmékora (Gabon) suggests an ancient occupation with undiagnostic Earlier Stone Age cobble tools (~730–620 ka ago; Braucher et al., 2022), most data point to more recent colonization of these forests (Taylor, 2014, 2016). Notably, no evidence of Mode 2 occupations has been found in the Congo Basin interior, and such evidence is limited to its margins.

There are documented Mode 2 (ESA) to Mode 3 (MSA) transitional industries grouped under the Sangoan technocomplex, appearing in various parts of sub-Sahelian Africa (Taylor, 2022). However, no direct evidence of their presence has been identified in the interior of the Congo Basin. Sangoan technologies are often characterized as heavy-duty tool-based industries that evolved into Lupemban assemblages through the incorporation of MSA innovations, such as prepared core technologies and the lanceolate bifacial points known as Lupemban points. Lupemban assemblages, with dates as early as 230 + 35/-28 ka at Twin Rivers (Zambia) (Barham and Smart, 1996), are more widely distributed in territories adjacent to rainforest environments. In Equatorial Guinea, several MSA sites have been identified in the Centre-South Province, including Mosumu, which dates to a minimum of 30 ka based on the stratigraphic sequence's 14C dating (Mercader and Marti, 1999; Mercader et al., 2002), and Mabewele I, which dates to a minimum of 12 ka cal BP based on a single radiocarbon date (Terrazas-Mata et al., 2023). The presence of bifacial lanceolate points at both Mosumu and Mabewele I supports the connection between the MSA in Equatorial Guinea and the Lupemban technocomplex, suggesting its persistence during the Late Upper Pleistocene.

No microlithic technologies have been reported from Equatorial Guinea, either from stratified contexts or surface sites, indicating the apparent absence of LSA technocomplexes in the region. Against this background, many questions remain unresolved, including the identity of the creators of these technologies. Two primary hypotheses emerge: these assemblages could represent the work of ancestors of contemporary Central African hunter-gatherers or result from demic diffusion processes originating in East Africa. Central to these discussions is the nature of the archaeo-palaeontological record and the limitations imposed by the stratigraphic preservation in rainforest environments, which constrain the depth and reliability of our models.

This paper addresses these questions using data from multiple field campaigns conducted in the Río Campo region of Equatorial Guinea. While areas of Cameroon, Gabon, and Congo offer insights into recent prehistory, Equatorial Guinea remains severely under-researched in archaeo-paleontological terms (Mercader and Marti, 1999; Terrazas and Rosas, 2016; Rosas et al., 2022). Nonetheless, improved research conditions and renewed initiatives provide a foundation for current investigations (Rosas, 2014; Rosas et al., 2021a, b; 2022; Terrazas-Mata et al., 2023). Our findings highlight technological assemblages exhibiting hallmark features of MSA technologies, including key traits of Central African Lupemban industries. Additionally, we examine the preservation of the stratigraphic record in this region by proposing a sedimentary model characterized by systematic large-scale erosive phases. This model explains the scarcity of evidence and challenges in establishing the sequence and antiquity of human occupations.

2. Material and methods

2.1. Study area

The surveyed area is located in the Río Campo region in northern Equatorial Guinea, bordering Cameroon, at approximately 2°21′N and 9°49′E (Fig. 1). Ecologically, the entire continental territory of Equatorial Guinea lies within the Atlantic strip of Central Africa. Central Africa is broadly defined by the expansive lowland basin formed by the Congo River and its tributaries, supplemented by smaller basins such as the Ogooué River (Gabon), the Muni River, the Wele (or Wolo) River, and the Campo (or Ntem) River in Equatorial Guinea (Fig. 1). Biogeographically, the Río Campo area is situated within the African lowland rainforest belt, dominated by dense equatorial rainforests characteristic of the Guinean-Congolese domain. These include various types of hygrophilous coastal evergreen rainforests (White, 1983; Rosas, 2022).

2.2. Prospecting and sampling method

Since 2014, successive archaeo-paleontological surveys in Equatorial Guinea have identified Quaternary material outcrops through systematic observation of road and forest track clearings, slopes, and aggregate quarries. A total of 30 outcrops were characterized using GPS geolocation in the Río Campo area. These were sampled, photographed, and recorded as "Campo Point x," numbered sequentially from Campo 1 to Campo 30. For each site, stratigraphic columns were constructed, with sedimentological analyses focusing on lithology, grain size, and bed thickness. Systematic sampling prioritized sediments and charcoal fragments for subsequent laboratory analysis and lithic industry dating. Sedimentological and lithofacies studies described sedimentary processes and depositional environments, enabling paleoenvironmental reconstructions of archaeological interest sites. Evidence of Paleolithic lithic industries was identified at 16 locations.

Campo 11, situated a few kilometers from Río Campo town (2°19′06.68″ N, 9°47′05.00″ E), stood out for its extensive, high-quality material exposure and an abundance of lithic artifacts. A horizon rich in lithic remains and charcoal fragments suitable for radiocarbon dating (δ14C) was detected. Additionally, two samples from the tool-bearing horizon were selected for Optically Stimulated Luminescence (OSL) dating. The main objective of field campaigns in the Río Campo region was to evaluate the presence of archaeo-paleontological evidence related to Stone Age human occupations and determine whether such evidence occurred recurrently. Due to limited fieldwork time and challenging access, the research strategy precluded extended archaeological excavations. However, fluvial sediments containing an unusually high density of stone tools were identified at Campo 11, prompting a second, more detailed sampling campaign.

Initially, surface materials were collected through successive sweeps of the area. During the second campaign, a 2 × 2 m grid was established over an approximately 180 m^2 area (Fig. 2). Systematic and detailed sampling was conducted grid-by-grid to recover all detectable lithic elements. Many artifacts were excavated in situ from undisturbed sediments, while others were manually collected through visual inspection without sediment sieving. A small trench was excavated to expose a sedimentary section and extract undisturbed samples for OSL dating. Approximately 1000 kg of sediment were removed, yielding some charcoal fragments but no lithic artifacts, supporting the hypothesis that all anthropogenic materials originated from a well-defined, thin horizon.

2.3. Dating

Siliciclastic sediments interpreted as alluvial deposits were selected for Optically Stimulated Luminescence (OSL) dating. These sediments primarily consist of quartz, along with feldspar and clay minerals, with

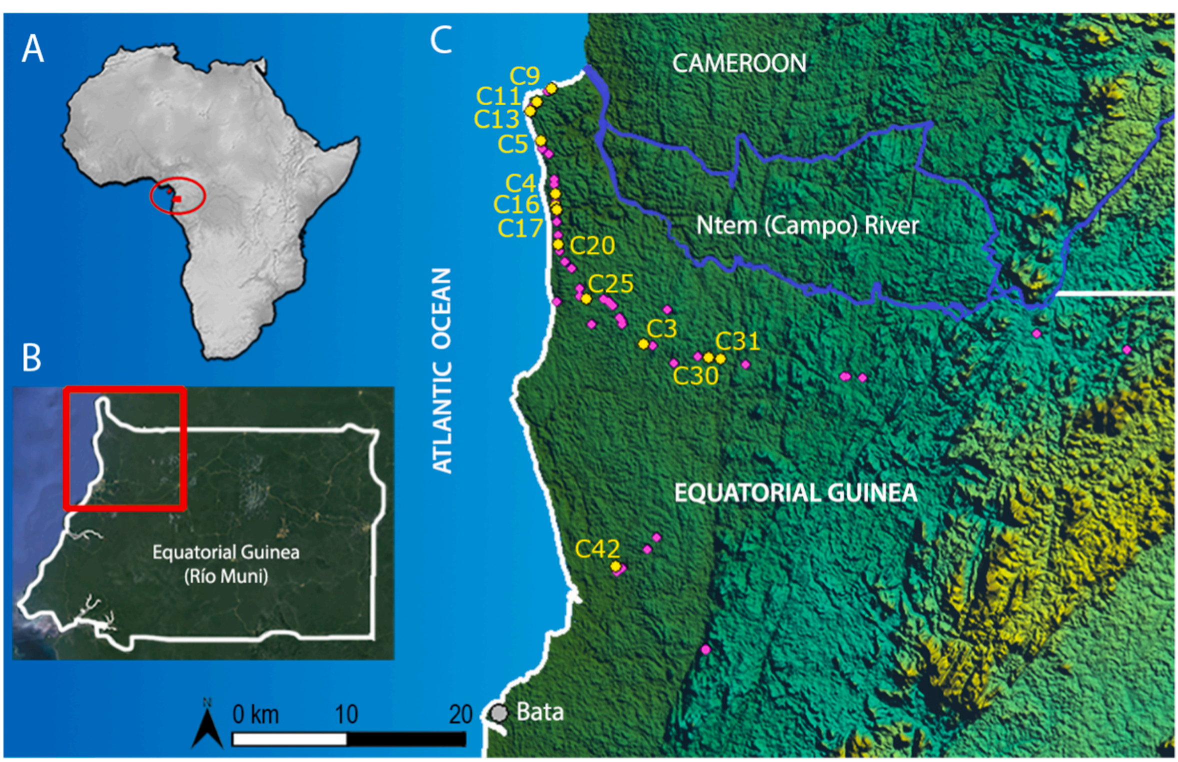

Fig. 1. Situational maps. A) Map of Africa showing the location of Equatorial Guinea, highlighted with a red ellipse, on the west-central coast of the continent. B) Continental Equatorial Guinea (Río Muni) with the surveyed area outlined in red. C) Enlarged view of the Río Campo region, detailing surveyed points (pink) and locations where lithic industries were found (yellow, labeled with point numbers). The Ntem River (formerly Campo River), which borders Cameroon, is visible to the north.

Fig. 2. General view of the Campo 11 site, showing the 2 × 2 m excavation grid.

varying grain size distributions. Sampling was conducted using sharpened PVC tubes measuring 8 cm in diameter and 40 cm in length. The sampling locations met the following criteria: (1) being situated at least 0.5 m from any stratigraphic boundary or visible changes in soil properties, and (2) having a sandy texture with a grain size ranging from fine to coarse sand.

Once a site was selected, the upper 25 cm of weathered soil was removed, and precautions were taken to avoid sunlight exposure of the sampled sediments. As the fieldwork was carried out during daylight, the area was shielded using a double-layer black tarpaulin to ensure complete opacity. The PVC tube was then hammered into the ground using a standard hammer until full insertion. Both ends of the tube were sealed with duct tape and marked with an arrow indicating the driving direction. Afterward, the tube was placed inside an opaque black canvas bag, sealed with duct tape, and labeled with the same identification code as the tube. All sampling locations were precisely mapped onto stratigraphic columns and geolocated using a handheld GPS device. The OSL analyses were conducted at the Luminescence Dating Laboratory of CENIEH (Burgos, Spain) under Report #FR-LM22185, associated with Project Reference C2022185, and carried out by Alicia Medialdea and Miren del Val. Ages were calculated using the formula). Ages are based on the relation $Age\ (ka) = De\ (Gy)/DR\ (Gyka/)$ where De is the equivalent dose in Gray and DR is the environmental dose rate in Gray per kiloyear. The principles of luminescence dating are outlined in Aitken (1998). Quartz grains (180–250 μm) were extracted under controlled lighting conditions for analysis. Luminescence measurements were performed using Risø TL/OSL DA-20 automated readers equipped with 90Sr/90Y beta sources delivering dose rates of approximately 0.10 Gy/s at the sample position. Multi-grain quartz aliquots were measured following the Single-Aliquot Regenerative-Dose (SAR) protocol (Murray and Wintle, 2000, 2003) to derive representative dose distributions. Outliers were removed using the 1.5x interquartile range rule, and the equivalent dose (De) was calculated using the Central Age Model (CAM; Galbraith et al., 1999) on the refined dataset. Environmental dose rates (DR) were determined from beta, gamma, and cosmic radiation contributions. Beta and gamma contributions were derived from radionuclide activity concentrations measured via High-Resolution Gamma Spectrometry. Conversion factors from Guérin et al. (2011) were used to calculate radiation doses based on radionuclide concentrations in the sediment matrix. Cosmic radiation contributions were estimated using a linear accumulation model accounting for burial depth, latitude, altitude, and overburden density (Prescott and Hutton, 1994). Total dose rates were adjusted for moisture and grain size attenuation, with a 5% uncertainty added to the estimated water content. The Dose Rate & Age Calculator (DRAC; Durcan et al., 2015) was used for environmental dose rate calculations. Table 1 summarizes radioelement activity concentrations, moisture content, and sampling depths used to calculate cosmic radiation contributions.

Additionally, two charcoal samples were dated using AMS radiocarbon (14C) dating by Beta Analytics, following the BetaCal4.20 (HPD method: INTCAL20). These samples were collected from Campo 11 (Beta #606478) and Campo 13 (Beta #606479).

2.4. Lithic assemblages

Surveys conducted in continental Equatorial Guinea have revealed a significant presence of stone tools scattered across various areas, including Bata, Evinayong, Monte Alen, Mosumu, and Río Muni. However, the highest concentration of findings is distinctly associated with the Río Campo basin, where 16 locations yielded a total of 418 lithic artifacts. These findings form the basis of the analyses presented here.

Table 1
Radioelements activity concentration, water content used for attenuation correction and sampling depth used to calculate the cosmic radiation contribution.

Sample	Depth (m)	Moisture (%)	40K (Bq/kg)	232Th (Bq/kg)	238U (Bq/kg)
GE-1 Campo 4	1.5	5	15.2 ± 3.2	46.1 ± 0.5	25.9 ± 0.4
GE-2 Campo 5a	4.5	5	6.6 ± 2.9	11.5 ± 0.3	8.5 ± 0.3
GE-3 Campo 5b	3.0	5	12.2 ± 3.9	25.3 ± 0.5	18.8 ± 0.5
GE-4 Campo 5c	1.0	5	18.6 ± 3.3	26.1 ± 0.4	16.7 ± 0.3
GE-5 Campo 11a	1.0	10	34.7 ± 3.0	33.8 ± 0.4	17.2 ± 0.3
GE-6 Campo 11b	1.5	15	37.3 ± 5.0	31.2 ± 0.6	15.3 ± 0.3
GE-7 Campo 13	0.5	5	34.1 ± 4.5	17.0 ± 0.5	14.0 ± 0.5
GE-8 Campo 30	1.0	5	65.5 ± 3.6	62.7 ± 0.5	19.5 ± 0.4

2.4.1. Comparative analysis of size distribution

To assess the structural integrity of the lithic assemblage from Campo 11, we conducted a comparative analysis of its size distribution against data from other assemblages formed under different processes and collection methods. This comparison provided a contextual framework for interpreting the size patterns observed at Campo 11.

For this analysis, we utilized size distribution data from archaeological assemblages in Eastern Morocco and Northeastern Spain, representing a variety of formation processes and collection strategies (Morales and Oms, 2009; Morales et al., 2013, 2022; Sala-Ramos et al., 2022) (Table 2).

2.4.2. Statistical analysis

The Kolmogorov-Smirnov (K-S) test was applied to statistically compare the cumulative distributions of artifact lengths between the Campo 11 assemblage and each of the selected comparative assemblages. This test evaluates the null hypothesis that the two samples originate from the same underlying distribution. Specifically, D-Statistic: quantifies the maximum difference between the cumulative distributions of the two samples. Lower D-values indicate greater similarity, while higher D-values reflect more substantial differences. P-Value, represents the likelihood of observing the data if the null hypothesis is true. A lower p-value suggests a significant difference between the distributions.

All statistical analyses were performed in R software (R Core Team, 2022). The Kolmogorov-Smirnov test (Massey, 1951) was executed using the base stats package, while the ggplot2 package (Wickham, 2016) was used to generate heatmap visualizations of the K-S test results. Statistical significance was determined at the $\alpha = 0.05$ level.

2.4.3. Technological approach

Lithic analyses were conducted using a technological approach (Karlin, 1991; Karlin et al., 1991; Inizan et al., 1999) to identify key technological patterns and reduction sequences within the Río Campo assemblages. A more detailed examination of the larger Campo 11 assemblage enabled the characterization of operative fields (Guilbaud, 1995), which reflect the stages of the reduction sequences.

3. Results

This section addresses three key aspects. First, we present the results of the geological setting and dating. Second, we analyze the recovered lithic assemblages. Finally, based on these findings, we evaluate the formation processes that influenced the integrity of the Campo 11 site.

3.1. Geology

The continental geology of Equatorial Guinea is divided into two main regions: a Coastal Belt, characterized by sedimentary rocks, and an inner region, dominated by igneous and metamorphic rocks of the Congo Craton. The Río Campo study area is predominantly part of the Coastal Belt, where marine carbonates (limestone and marl facies) alternate with sandstone beds. These sediments were deposited within a rift system associated with the opening of the Atlantic Ocean and are dated to the Lower to Upper Cretaceous (Aptian to Turonian, ~121 to 90 Ma) (Martínez-Torres and Riaza, 1996). Overlying the Cretaceous basement, an anastomosing fluvial system developed during the Tertiary (Cenozoic), although its preserved geological record is primarily restricted to Quaternary sediments, dating from approximately 76 to 20 ka BP (see Section 3.2: Chronometric Dating). This fluvial system, exhibiting sedimentological dynamics similar to those of other tropical rivers, shaped the current Campo (Ntem) fluvial system. Detailed studies allowed the identification of distinct geomorphological features such as channels, bars, floodplains, and estuaries, culminating in a preliminary geomorphological map of the Río Campo area (Fig. 3). Geomorphologically, this area can be divided into two distinct units: 1) Alluvial deposits: associated with channel activity, including channels, bars, and fluvial plains. 2) Organic-rich sands: fine, dark-colored sands interpreted as deposits from paleoestuaries (Fig. 3). The fluvial deposits exhibit a consistent distribution across the study sites, with minor variations. Quaternary materials are generally poorly consolidated sands rather than sandstones and rest unconformably atop Cretaceous sandstones and/or marls. In more interior regions, these deposits occasionally overlie granitic formations from the Congo Craton. Notably, ichnofossils such as Thalassinoides (Ehrenberg, 1944) and other

Table 2
Characteristics of the comparative lithic assemblages used for the size distribution analysis.

Site	Level	Type	Location	Recovery	Sieving	Culture	Description	Sample
Sahb El Ghar 1	1	Open-air	Morocco	Modern excavation techniques	Yes	MSA	Large palimpsests with varying degrees of rounding, concretion, and edge preservation indicating complex taphonomic histories	764
Sahb El Ghar 2	1	Open-air	Morocco	Modern excavation techniques	Yes	MSA	Large palimpsests with varying degrees of rounding, concretion, and edge preservation indicating complex taphonomic histories	627
La Griera	IIIa	Rock-shelter	Spain	Modern excavation techniques	Yes	MP	Repeated domestic/residential occupations	1518
Cativera	B	Rock-shelter	Spain	Modern excavation techniques	Yes	UP	Repeated domestic/residential occupations	2454
Cova Gran de Collbató	200	Cave	Spain	Modern excavation techniques	Yes	UP	Short-duration logistical occupation with low recurrence	410
El Cavet	N/A	Open-air	Spain	Unsystematic collection by amateurs	No	NEO	Site destroyed by construction activities	1955

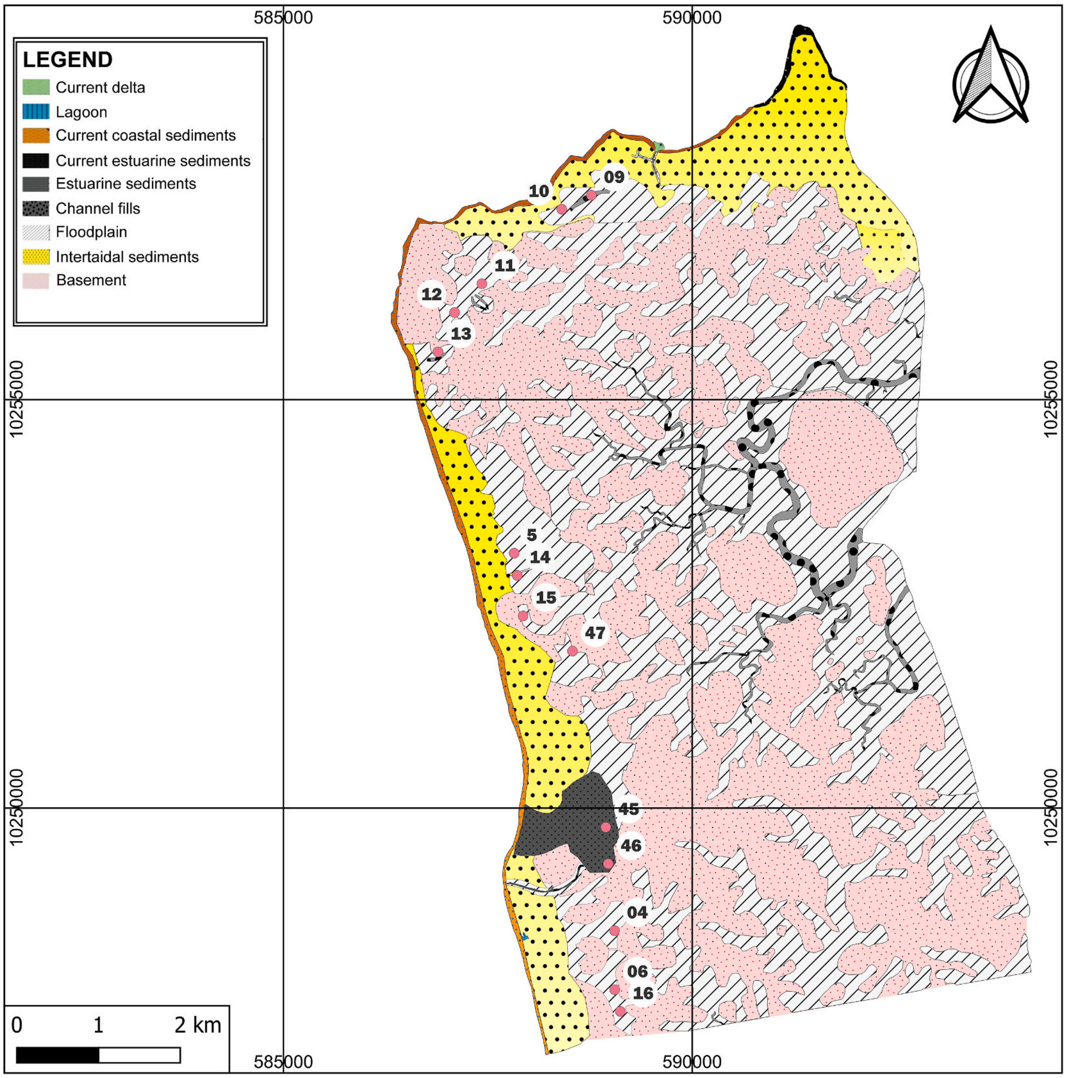

Fig. 3. Geomorphological map of the Río Campo region in northwestern Equatorial Guinea.

arthropod burrows in the Cretaceous basement indicate shallow marine depositional environments.

Tectonic uplift and subsequent subaerial exposure of the basal marine deposits have resulted in weathering, creating an alteration profile with extensive lateral continuity. Above the weathered basement, Quaternary alluvial deposits were laid down discordantly. These deposits, along with the basement, frequently display erosive surfaces indicative of multiple cycles of deposition, erosion, stasis, and redeposition. This complexity complicates the interpretation of local stratigraphy. Moreover, the intense edaphic processes characteristic of Equatorial Guinea—and tropical rainforest regions more broadly—result in continuous eluviation and illuviation. These processes lead to highly homogeneous stratigraphic profiles, where primary sedimentary structures (such as planar or cross-bedded laminations) are typically not preserved.

To establish reference points for the Río Campo region, two key localities are defined: Campo 5 locality and the Campo 11 site, corresponding to a coastal flood plain and a channel-bar system, respectively.

3.1.1. *Campo 5 locality*

Campo 5 (9°47′19″ N/2°17′25″ E) contains the longest Quaternary stratigraphic sequence studied in the Río Campo region (Fig. 4), exposed along a road slope. The outcrop is interpreted as representing a Quaternary floodplain, primarily composed of alluvial sands overlying the Cretaceous basement. The sequence begins with a Cretaceous basement, comprising marl to the north and sandstone to the south. This is overlain by a thin layer of hematitic nodules, interpreted as of diagenetic origin. Above the nodules lies a layer of fine to coarse sands with abundant subangular quartz grains of millimetric size. This sand layer is followed by a level of subrounded quartzite clasts, approximately centimeter-sized. Overlying the clasts is a 2 m-thick deposit of fine-grained sand, within which six lithic artifacts were discovered (see below). At the top of the sequence, there is occasionally a 15 cm-thick conglomerate layer, which supports the current soil.

Three samples were collected from the Campo 5 section for OSL dating (Fig. 4): one from below the clast horizon (coarse sands, lower sand deposit), one from above the clast horizon (fine sands, upper sand deposit), and one from the top of the outcrop, just below the conglomerate layer.

3.1.2. *Campo 11 site*

Campo 11 is located at a former aggregate quarry used for road paving, with the archaeological site situated in cuts formed during recent anthropic activities. During two field campaigns (2019 and 2021), a total of 289 lithic artifacts were collected, along with a few ceramic fragments from the most superficial layer. The lithic artifacts at Campo 11 are concentrated within a single stratified horizon in a spatially restricted area, accompanied by evidence of domestic activities

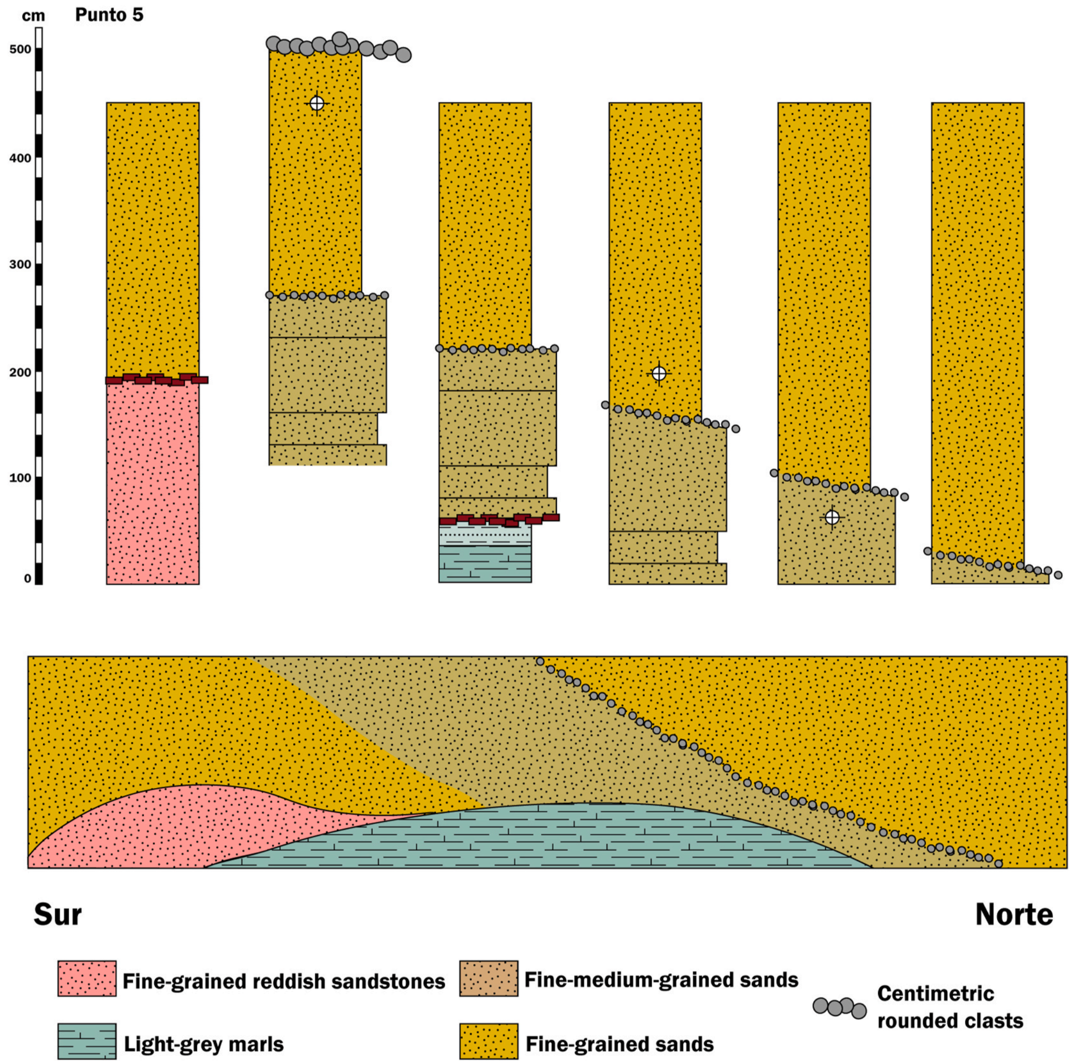

Fig. 4. Stratigraphic columns from the Campo 5 site, ordered from south to north. Below, a schematic cross-section. Bull's-eye symbols indicate the locations where samples were collected for OSL dating.

such as charcoal and burnt remains.

Campo 11 (2°19′5.7″ N/9°47′5.4″ E) was studied through the analysis of eight stratigraphic columns, 1–4 m thick, composed mainly of a basal conglomerate layer overlain by sand deposits (Fig. 5). The columns are grouped into sectors following a southwest-to-northeast direction: Sector A (Columns 1 and 2), Sector B (Columns 3, 4, and 5), Sector C (Columns 6 and 7), and Sector D (Column 8) (Fig. 5). Sector A: represents cross-sections of more distal areas of anastomosing channels. It is characterized by thinner deposits compared to central sectors and consists predominantly of conglomerates and fine sands. Sector B: the central sector exhibits greater thickness and coarser materials in both conglomerates and sands. The basal conglomerates in this area were likely deposited under higher energy conditions, as indicated by pronounced erosion of the Cretaceous basement. Sectors A and B represent cross sections of anastomosed channels. Sector C: this sector is composed of coarser sands with abundant centimeter-sized quartzite grains but lacks conglomerates, suggesting it represents a channel bar. This central zone contains the majority of lithic artifacts and a few ceramic fragments, which are restricted to the top of the profile. Sector D: situated on the northeastern edge of the site. This sector is similar to Sector A and corresponds to the opposite bank of the channel. Due to subaerial exposure and the region's climatic and geochemical conditions, material alteration is severe, making it difficult to identify sedimentary structures such as clast imbrication, cross-stratification, or parallel lamination. This alteration is a general characteristic of all sampled points in the area.

The abrupt transition between coarse clasts and the overlying sand layer suggests a rapid abandonment of channels, potentially caused by shifts in water regimes. The upper sand deposits consist primarily of quartz, phyllosilicates, and iron oxides, and lack large clasts or lithic artifacts, consistent with their interpretation as channel-fill deposits. The evidence indicates that Sector C represents a sandy channel bar that was occasionally occupied by Pleistocene populations during periods of low channel flow. This interpretation aligns with the nature of anastomosing river systems, which exhibit significant variability in flow direction and intensity, leading to moments of stasis or reduced flow that enabled human occupation of elevated features such as channel bars.

A comparison with other sites, such as Campo 4 and Campo 11, reveals that the sand deposits in these locations are thinner than those at Campo 5. This difference may be attributed to orographic factors, as the terrain at Campo 5 forms a "bathtub-like" depression that likely facilitated greater sediment accumulation.

3.2. Chronometric dating

Table 3 summarizes the dating results of eight samples collected from various locations in the Río Campo region. These samples were gathered by the authors. The table includes the field and CENIEH laboratory

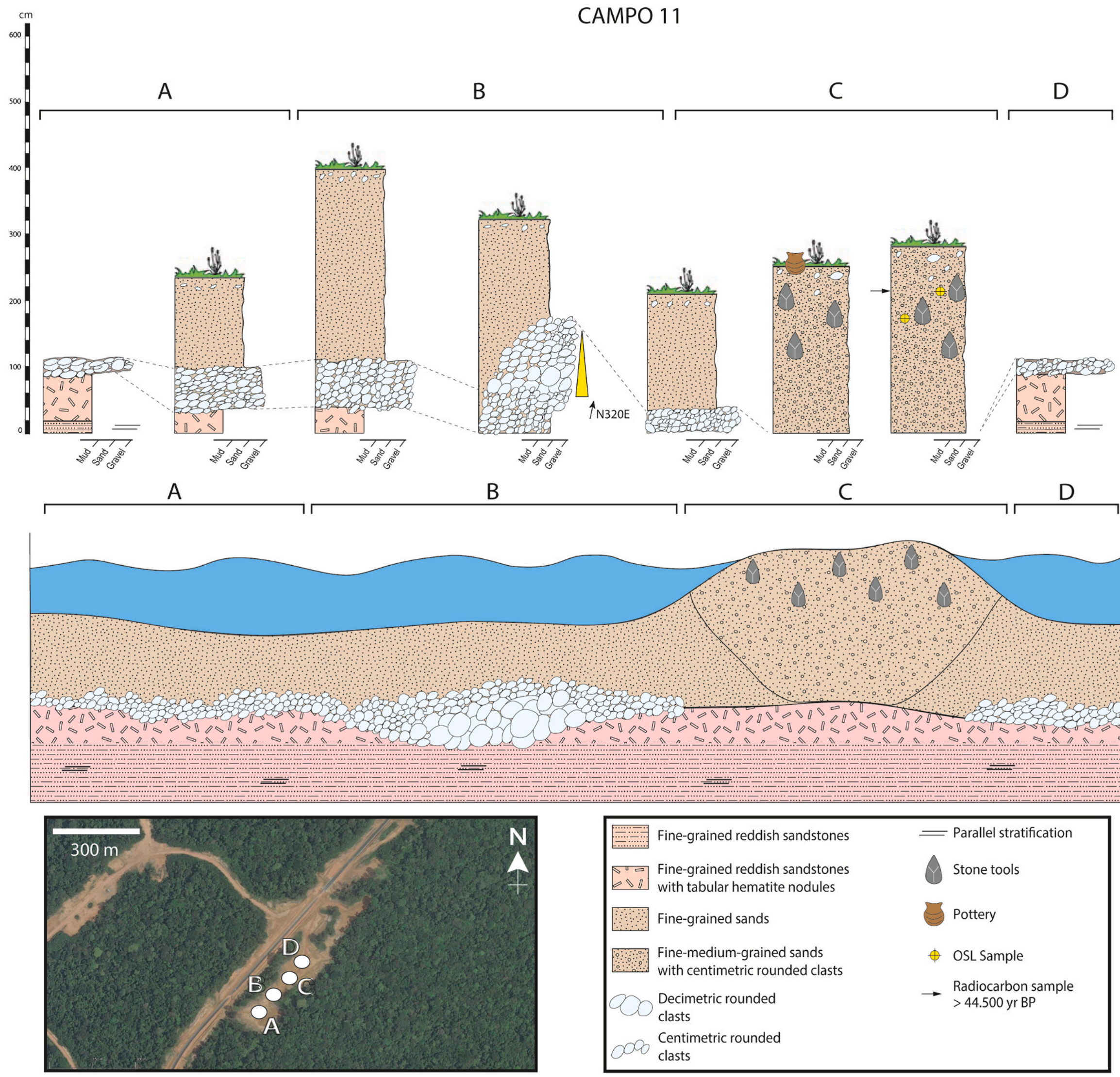

Fig. 5. Stratigraphic columns from the Campo 11 site in Equatorial Guinea, with a schematic representation of the sediment deposition environment, involving channels and bars. Includes a map showing the location of the columns along the outcrop. Bull's-eye symbols mark the positions where OSL dating samples were collected.

codes, the calculated dose rate (Gy/ka), the estimated equivalent dose (Gy), and the resulting ages. Ages are expressed in ka (kiloannum), calculated from the year 2022. All uncertainties presented in the table are quoted at 1-sigma ($k = 1$).

Sample Guinea Ecuatorial-7 lacks a luminescence signal dominated by the fast component, making it unsuitable for measuring the equivalent dose. Consequently, no final age result could be calculated for this sample. For the Campo 11 sample, the radiocarbon measurement yielded a minimum age of >43.5 ka BP, whereas the Campo 13 sample was dated to 2380 ± 30 ka BP.

The chronometric and stratigraphic data reveal key aspects of the geological history of the Río Campo region. At Campo 5, a sediment accumulation event (coarse sands) occurred around 76 ka, possibly during the transition from MIS 5 to MIS 4. Following this episode, between 76 ka and 44 ka, a cycle of erosion and stasis was identified, which led to the formation of a quartzite cobble layer (e.g., a stone line) between the first (coarse) sand package and the subsequent (fine) sand package. This cobble layer marks an interruption in sedimentation, indicating a period dominated by erosion or stasis rather than deposition. During this phase, possibly corresponding to MIS 4, low vegetation cover and high sediment exposure likely caused fine sediments to be scoured away, leaving coarser clasts to accumulate at the same level. Similar processes can be observed today in areas affected by anthropogenic deforestation, where sediment flushing creates abundant "fairy chimneys." These dynamics provide insights into the formation of quartzite cobble lines, representing periods of non-sedimentation and coarse material accumulation.

Above this clast layer, a second phase of alluvial sediment accumulation (fine sands) occurred at Campo 5 between 44 ka and 21.7 ka BP. During this time, and extending to the upper conglomerate level, sediments accumulated progressively without evidence of disturbance that might indicate erosion. This depositional event is chronologically consistent with similar processes observed at Campo 4 and Campo 11, with coherent sedimentological features across the sites. The radiocarbon date of >43.5 ka from Campo 11 aligns well with this period. It is within this timeframe that human occupations, evidenced by lithic industries, are contextualized.

Around 21 ka ago, a new erosional event occurred, potentially associated with the Last Glacial Maximum (MIS 2), as indicated by the sequence at Campo 5. During the Holocene, another sedimentary accumulation event took place approximately 6.2 ka ago. The dates obtained from Campo 30 point to a more recent accumulation than in

Table 3
Summary of the Optically Stimulated Luminescence (OSL) dating results of 8 samples collected in Guinea Ecuatorial. Ages are expressed in ka (kiloyears) counted from 2022. All uncertainties presented in this summary table are quoted at 1-sigma (k = 1).

Sample	Lab code CENIEH	Depth (m)	Dose rate (Gy/ka)	Burial dose (Gy)	Age (ka)
GE-1 Campo 4	LM22185-01	1.5	1.39 ± 0.05	33.3 ± 2.3	24.0 ± 1.9
GE-2 Campo 5a	LM22185-02	4.5	0.46 ± 0.02	67.5 ± 5.3	76.0 ± 8.5
GE-3 Campo 5b	LM22185-03	3.0	0.91 ± 0.04	87.3 ± 7.0	44.0 ± 5.0
GE-4 Campo 5c	LM22185-04	1.0	0.94 ± 0.04	20.3 ± 1.1	21.7 ± 1.4
GE-5 Campo 11a	LM22185-05	1.0	1.06 ± 0.04	21.8 ± 1.3	20.6 ± 1.4
GE-6 Campo 11b	LM22185-06	1.5	0.94 ± 0.04	21.9 ± 2.1	23.2 ± 2.4
GE-7 Campo 13	LM22185-07	0.5	0.81 ± 0.03		
GE-8 Campo 30	LM22185-08	1.0	1.70 ± 0.07	10.5 ± 0.5	6.2 ± 0.4

the coastal areas of Campo 4, 5, and 11. This is consistent with its higher elevation, where erosion dominates over deposition near the coast, making alluvial material accumulation over time less likely.

3.3. *Stone tools from Río Campo*

The lithic assemblages recovered from the Río Campo basin represent a diverse collection of stone tools, showcasing variability in sample size, composition, and structure across multiple locations. A total of 418 lithic artifacts were collected from 16 locations (Table 4).

The majority of artifacts were concentrated at Campo 11, which yielded 289 artifacts, including cores, flakes, retouched tools, and a smaller quantity of debris. In contrast, other locations, such as Campo 04, produced smaller but notable assemblages, with 68 artifacts recovered. The remaining sites provided significantly smaller samples, ranging from small clusters of artifacts—such as at Campo 20 and Campo 31—to isolated finds at locations like Campo 42 or Campo 10.

The lithic assemblages are primarily composed of chert, quartz, and quartzite. However, the raw materials are highly heterogeneous and likely represent a broader variety of lithological groups that require more detailed petrographic analysis. There is significant variability in the representation of raw materials across the different locations, with some assemblages dominated by chert, quartzite, or quartz. However, the limited sample sizes and the nature of the findings make it difficult to draw definitive conclusions about these patterns. In addition to variability in material composition, the assemblages reflect diverse collection contexts. These include: 1) stratigraphic horizons exposed due to deforestation and progressive surface erosion; 2) accumulations of materials caused by retrogradation of exposed sections due to recent human activity; 3) isolated finds with no apparent association with specific stratigraphic units or geomorphological contexts.

Table 4
Distribution of lithic remains by location and raw material type.

Location	Chert	Quartz	Quartzite	Total
Campo 03	0	1	6	7
Campo 04	20	7	41	68
Campo 05	0	0	6	6
Campo 09	0	3	0	3
Campo 10	0	0	1	1
Campo 11	211	9	69	289
Campo 13	1	6	1	8
Campo 16	2	0	0	2
Campo 17	1	0	0	1
Campo 18	0	0	1	1
Campo 20	4	0	14	18
Campo 25	0	2	0	2
Campo 30	0	0	1	1
Campo 31	4	1	4	9
Campo 39	1	0	0	1
Campo 42	0	0	1	1
Total	244	29	145	418

Although the temporal relationships between the lithic assemblages in the Río Campo basin remain largely uncertain, the sedimentary model and existing chronological references suggest a Late Upper Pleistocene age. To further assess this, technological analysis can help determine whether the assemblages represent a homogeneous techno-cultural accumulation or reflect multiple technological traditions.

Given the sedimentary and geomorphological characteristics of the Río Campo region, combined with the systematic survey and collection methods employed, we hypothesize that the recovered materials provide a representative sample of the technological and cultural variability present during the prehistoric occupation of the area. The primary aim of this analysis is to evaluate this variability. By integrating geomorphological data with chronological dating, we seek to develop a comprehensive understanding of the prehistoric occupation of the Río Campo region. Additionally, further analysis is underway to extend this understanding to the entire territory of Equatorial Guinea.

While analyzing technological variability from small or uneven samples poses challenges, the scarcity of data on this subject makes these assemblages particularly valuable. They offer critical insights into the presence, absence, or co-occurrence of specific reduction methods, tool types, and other technological, typological, or functional characteristics.

To address these challenges and provide greater temporal and cultural context, the analysis focuses on Campo 11, the largest collection from the region, which originates from a well-defined sedimentary context with available chronological references. A detailed examination of the technological attributes at Campo 11 will establish a benchmark for interpreting the more fragmented lithic assemblages from other sites.

The specific objectives of this analysis are: (i) To evaluate the taphonomic integrity of the Campo 11 lithic assemblage. (ii) To describe and characterize its techno-typological structure. (iii) To assess the chronocultural significance of its features. By defining the variability within the Campo 11 assemblage, this study provides a foundation for comparing the techno-typological information documented at other locations across the region.

3.3.1. *The Campo 11 assemblage*

The Campo 11 lithic assemblage is the largest collection recovered to date from the Río Campo area, comprising 289 artifacts (Table 5). Chert is the dominant raw material, representing 73% of the artifacts, followed by quartzite (24%) and quartz (3%).

3.3.1.1. Core reduction methods. The Campo 11 assemblage includes 12 cores (4%), demonstrating a diverse range of lithic reduction strategies. The predominant method involved exploiting hierarchized centripetal recurrent prepared cores (n = 4), the primary strategy for flake production.

Three of these prepared cores exhibit characteristics such as facial hierarchization, a perpendicular relationship between the striking platform and flaking surface, and platform preparation, classifying them as Levallois cores. The fourth core, made of coarse-grained quartzite, is an unifacial centripetal core with a less developed reduction sequence, likely due to limited fracture control.

A significant proportion of the flakes display attributes consistent with centripetal recurrent or Levallois flaking (Fig. 6). At least 15% of

Table 5
Distribution of lithic artifacts by raw material and technological category from Campo 11.

	Cores	Flakes	Fragmented flakes	Fragments	Tools on cobble	Retouched Flakes	Total
Chert	9	134	41	17	0	10	211
Quartz	1	5	2	0	1	0	9
Quartzite	2	26	17	7	5	12	69
Total	12	165	60	24	6	22	289

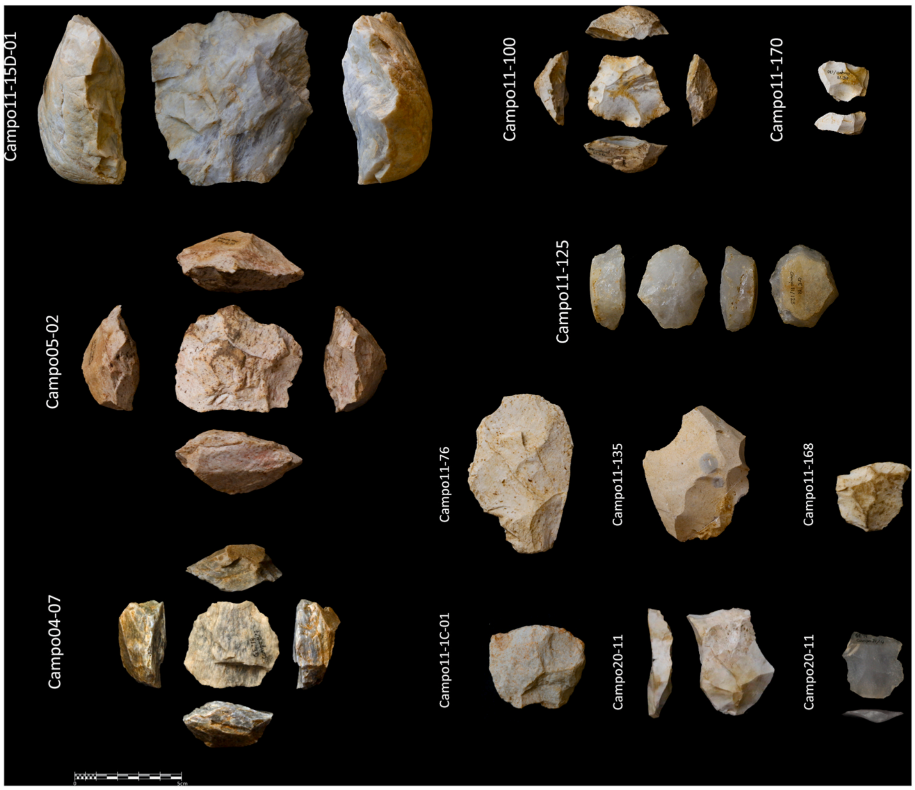

Fig. 6. Lithic remains recovered from the Río Campo region, Equatorial Guinea. Includes prepared cores and flakes from prepared cores found at Campo 11, Campo 04, and Campo 05.

complete flakes show features unequivocally linked to these reduction sequences, including: (i) dorsal scar patterns indicating systematic preparation of the core's flaking surface, (ii) a consistent perpendicular relationship between the platform and dorsal face, and (iii) prepared striking platforms. Additionally, six laterally *débordant* flakes, used to maintain core convexities, have been identified.

Beyond the prepared core strategies, two additional methods were identified, likely aimed at producing standardized blanks or flakes with specific length-to-width ratios: Unipolar longitudinal core flaking, and naviform-like core flaking (Fig. 7).

Cores with elongated or laminar scars at the discard time are present within the assemblage (n = 3) but do not exhibit characteristics associated to systematic blade production, such as maintenance and recurrence. Blade production is better documented through a small but consistent set of blades within the flake assemblage (n = 11). The produced blades are mostly wide and thick with subparallel edges and have lightly prepared or unprepared platforms, suggesting hand-held hard hammer direct percussion. This pattern suggests that blades originated mainly from opportunistic unipolar longitudinal cores rather than from well-structured and systematic laminar ones.

Naviform-like core flaking is a strategy named here based on the core morphology generated during the reduction process. Naviform-like cores are exploited through two opposed flaking platforms along the core's long axis by adjacent flaking. This approach shapes narrow and elongated cores that have been found in both initial and exhausted stages, showing that this specific strategy was maintained throughout the entire reduction sequence. In the initial stage, the flaking surface of the core is convexly shaped. No specific maintenance techniques have been observed for this strategy; as reduction advances and mass is removed, the flaking angle decreases, and the flaking surface becomes flat or even concave.

Naviform-like cores produce quadrangular or subcircular flakes with a length-to-width ratio close to 1. Therefore, naviform-like flakes are short and wide, often presenting opposed bipolar scar patterns and thick platforms. These flakes can mimic some attributes of flakes from bifacial reduction; however, they are thicker, lack platform preparation or abrasion, and clearly reproduce the scar patterns observed on the cores. The gradation from concave to convex delineations of the cores' exploitation surfaces is also reflected in the delineation of the flakes' ventral faces, being more concave as reduction advances.

Occasionally, flakes with multiple bulbs and opposed impact points have been documented (n = 6). These often coincide with edge crushing or radiating fractures, suggesting occasional bipolar or on-anvil flake production. Two possible cores with evidence of on-anvil production were identified, though in one case the features could also indicate the use of the blank as an intermediate tool.

A notable aspect of the Campo 11 assemblage is the advanced reduction stage of most cores, reflected in their small dimensions and

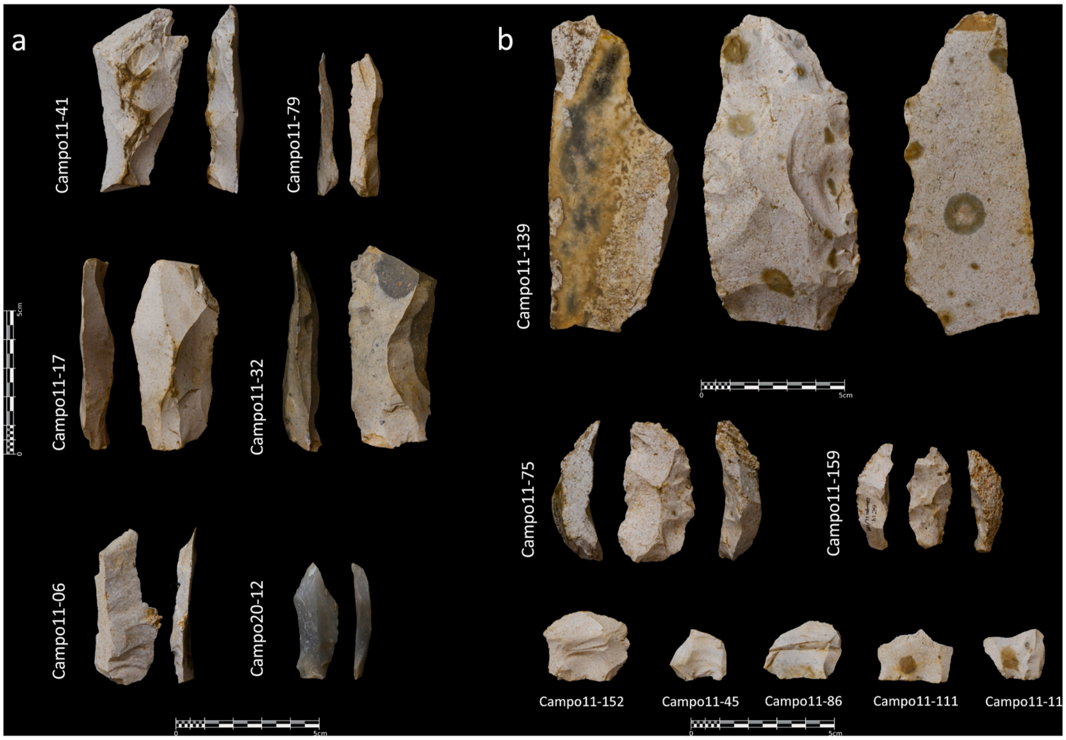

Fig. 7. Lithic remains recovered from the Río Campo region, Equatorial Guinea. Laminar products include partial crests (Campo 11–41 and Campo 11–79) and fully formed blades (Campo 11–17 and Campo 11–32). B) Naviform-like cores at early (Campo 11–139) and advanced (Campo 11–75 and Campo 11–159) reduction stages, along with flakes showing characteristic traits of this reduction method.

technological attributes. The average lengths of cores and flakes are 45.9 ± 18.9 mm and 29.1 ± 11.9 mm, respectively. This indicates a consistent reduction process through to the final stages. Retouched flakes, by contrast, have an average length of 45.9 ± 17.3 mm, suggesting a preference for shaping tools from full-production flakes. Overall, the reduction strategies demonstrate a consistent pattern of producing progressively smaller flakes until cores were fully exhausted.

3.3.1.2. Retouched tools. The Campo 11 assemblage includes 28 retouched artifacts, representing approximately 10% of the lithic collection (Table 6). Most of these tools (22 artifacts) were manufactured on flakes, while the remaining 6 were shaped from cobbles, blocks, or other natural bases (NBs). The artifacts can be categorized into three main groups: (i) retouched flakes (25%), (ii) points (28%) and (iii) heavy-duty cutting or chopping tools (47%). This classification reflects a broad range of functional and morphological variability, highlighting diverse tool-making strategies aimed at addressing various subsistence and maintenance activities.

Table 6
Retouched tools by raw material from Campo 11 assemblage.

Group	Type	Chert	Quartz	Quartzite		Total
		Flake	*NB*	*Flake*	*NB*	
HDT	Cleaver			1		1
	Handaxe		1		2	3
	Pick				1	1
	Wedge	3		2	3	8
Point	Bifacial point	2		6		8
Retouched flakes	Backed Blade	1				1
	Backed Flake	1				1
	Denticulate	2				2
	End-scraper	1				1
	Scraper			2		2
	Total	10	1	11	6	28

3.3.1.3. Retouched flakes. The retouched flake assemblage consists of seven artifacts, predominantly crafted from chert. This group includes common morphotypes such as denticulates and scrapers, along with a raclette-like backed flake and a single backed blade. Although the sample size is small, the presence of a backed blade is particularly significant, suggesting a potential focus on specific functional or hafting strategies. However, due to the limited number of artifacts and the variability within this category, further insights into their techno-functional roles remain constrained.

3.3.1.4. Points. The point assemblage comprises eight artifacts, all of which are lanceolate bifacial points, either complete or fragmented. Most points were made from fine-grained quartzite flakes, though two examples in chert were also identified. These points exhibit significant intra-group variability in size, shape, and retouch intensity, ranging from initial roughouts to heavily curated specimens displaying extensive resharpening, rejuvenation, and evidence of thermal damage (Fig. 8).

Smaller specimens show the highest degree of refinement, with fine retouch and multiple thinning phases. This level of modification suggests prolonged use-life, as these tools were frequently resharpened and reworked to maintain their functionality. Such patterns are consistent with high curation (sensu Shott, 1996; Morales, 2016), where tools were systematically maintained and adapted for various tasks, underscoring their importance in prehistoric toolkits. The presence of broken and burned points indicates that these tools were often discarded only after extended use or when they could no longer serve their purpose. This morphological diversity and evidence of multiple thinning phases support the interpretation of bifacial points as curated tools used and reworked over long periods.

3.3.1.5. Cutting and chopping tools. The largest and most functionally diverse group within the retouched assemblage comprises tools for heavy-duty use, accounting for 47% of the retouched artifacts (Table 6). This group includes both flakes and natural bases (NBs) shaped into

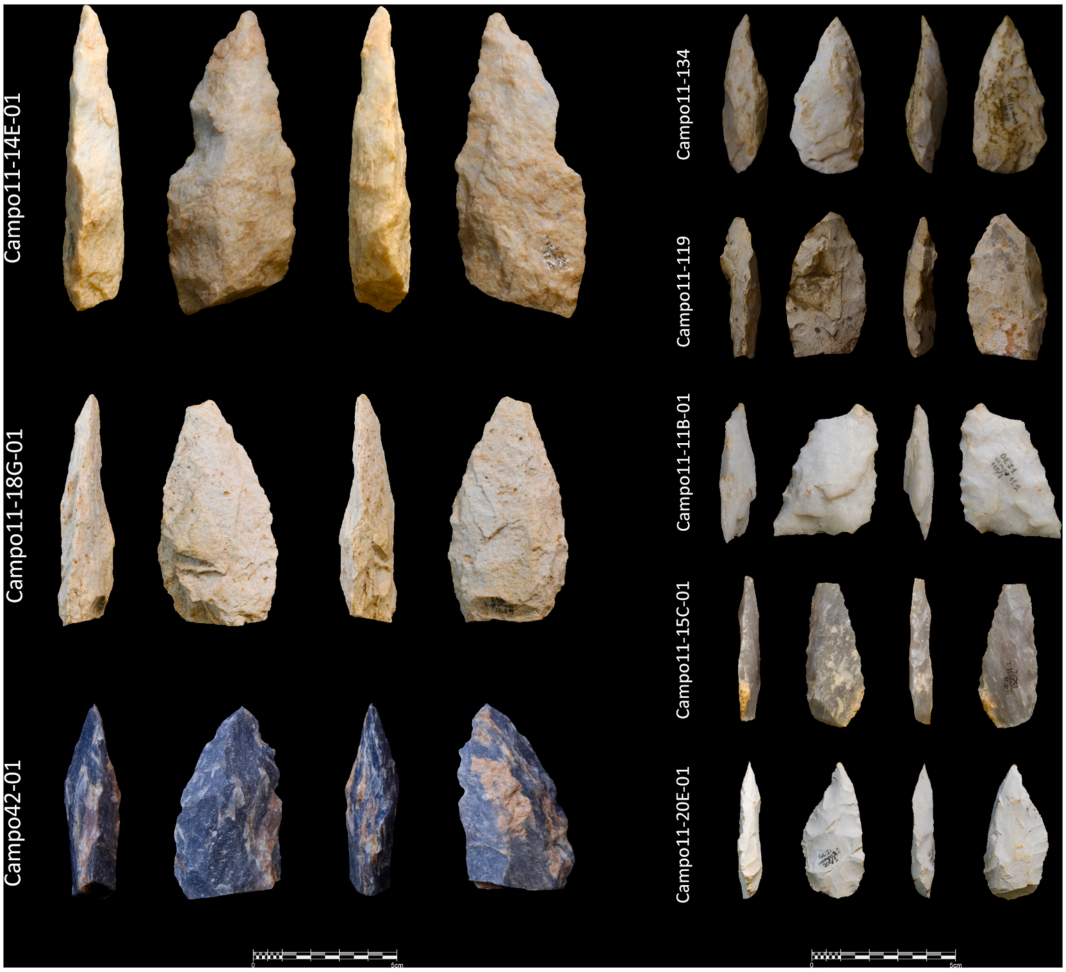

Fig. 8. Lithic remains recovered from the Río Campo region, Equatorial Guinea. Bifacial points, including specimens from the Campo 11 and Campo 42 sites.

tools that, despite their typological variety, share common functional attributes. These tools are subdivided into two main categories: large cutting tools (LCTs), including bifacial handaxes and cleavers, and wedges, as defined by de la Peña (2011, 2015).

The LCT category includes three handaxes and one cleaver (Fig. 9). The handaxes are made from quartz and quartzite cobbles, with one crafted from a large quartzite flake. The cleaver is also manufactured on a large quartzite flake. These tools exhibit clear evidence of intensive use, including crushing, chipping, step fractures, and other impact-related marks along their edges. In some cases, repeated impacts are observed on the opposite side of crushed edges, suggesting systematic use patterns. While detailed traceological analysis is pending, the wear patterns strongly suggest these tools were employed for demanding tasks such as chopping, cutting, or processing hard materials. The distribution of impact-related damage implies they were versatile implements, likely used in resource acquisition or processing.

Wedges (Fig. 10) form a less formal configuration but display a high degree of uniformity in wear patterns, resembling the damage observed on LCTs. These artifacts, predominantly made from quartzite and chert NBs, feature abrupt natural surfaces opposite heavily splintered or chipped working edges. The natural surfaces exhibit clear signs of impact, such as crushing and marginal flaking, while the opposing working edges show intense chipping and large flake scars. This wear pattern suggests that wedges were intermediate tools used in high-force tasks such as splitting, prying, or peeling hard materials.

The initial configuration of wedges likely involved intentional splintering of small quartzite or chert NBs to create functional chisel-like edges. Repeated use resulted in progressive flaking and reshaping of active edges, while the hammered surfaces developed recurrent crushing and chipping. Over time, the morphology of these tools became increasingly irregular, consistent with patterns of prolonged use. Unifacial or bifacial chipping patterns appear to have been influenced by edge angles and the direction of applied forces. While this category shows homogeneity, the wear patterns deviate from those reported in experimental reference frameworks (de la Peña, 2011), suggesting variations in specific tasks or techniques.

Further microscopic and experimental analysis is necessary to refine interpretations of these tools' functions. The variation in wear patterns may reflect differences in force application, raw material properties, or tool use stages. This highlights the need for a comprehensive use-wear study to reconstruct the operational sequences associated with these artifacts. Such analysis could provide greater insight into the specialized activities and technological strategies employed in the prehistoric Río Campo region.

3.3.2. Technological diversity across the Río Campo basin

Disparities in site formation processes, sample sizes, and collection methodologies present challenges in comparing the Río Campo lithic assemblages with the more extensive collection from Campo 11. Smaller samples may lack specific technological traits due to random sampling effects rather than their actual absence. Similarly, variations in artifact recovery methods could skew the representation of certain tool categories. To address these limitations, the comparative approach emphasizes identifying robust technological features that persist across varying sampling conditions.

Although smaller in scale, the lithic assemblage at Campo 4 (N = 68)

Fig. 9. Lithic remains recovered from the Río Campo region, Equatorial Guinea. Large bifacially shaped cutting tools from Campo 11, including handaxes and a cleaver.

exhibits a complex technological repertoire with notable similarities to that of Campo 11. Prepared core techniques dominate the reduction strategies at Campo 4, as evidenced by the presence of both *débordant* and centripetal flakes, along with a prominent preferential Levallois core. Additionally, wedges and a cleaver, either bifacially shaped or produced from splintered cobbles, align with the cutting and chopping tool classes observed at Campo 11. The recovery of two isolated blades at Campo 4, despite the absence of associated blade cores, suggests a potentially opportunistic approach to blade production, consistent with patterns at Campo 11. However, bifacial points, a defining feature of the Campo 11 assemblage, are absent at Campo 4.

The assemblage from Campo 20, though smaller (N = 18) and dominated by unretouched flakes, also demonstrates evidence of prepared core reduction strategies and cutting and chopping tools. Notably, a large wedge recovered here is comparable to those found at Campo 4 and Campo 11, suggesting a shared approach to wedge production and use.

Other smaller assemblages, including those from Campo 5, 13, 30, and 31, reinforce the prevalence of prepared core reduction strategies across the basin, with specific evidence for blade production documented at Campo 13. Additionally, bipolar-on-anvil techniques were identified at Campos 5, 24, and 31, further expanding the range of documented reduction strategies.

Isolated finds at various locations provide additional insights into the region's techno-typological variability. For instance, a quartzite lanceolate bifacial point fragment recovered at Campo 42 attests to the presence of bifacial point technology beyond Campo 11. Conversely, several sites—such as Campos 16, 17, 18, and 39—yielded only isolated flakes or fragments without distinctive technological features, limiting the scope for meaningful comparisons.

Despite the fragmentary nature of many smaller assemblages, the comprehensive collection from Campo 11 serves as a critical baseline for interpreting lithic technological strategies across the Río Campo basin (Fig. 11). Recurring patterns—such as the widespread evidence of prepared core reduction strategies, occasional blade production, and specialized tools like wedges—indicate a shared technological tradition or cultural practice during the Stone Age settlement of the region. Although the smaller assemblages are individually less informative due to their size and contextual ambiguity, their collective contribution enhances our understanding of the broader technological landscape of the Río Campo basin. These cumulative insights underscore the potential for identifying regional patterns in lithic technology during the prehistoric occupation of Equatorial Guinea.

3.4. Site formation processes and assemblage integrity at Campo 11

As one of the most significant sites within the Rio Campo basin, Campo 11 warrants a detailed examination of its depositional history and the post-depositional factors that have influenced the preservation and context of its lithic assemblage. Understanding the site's formation—through both natural and cultural processes—is critical for assessing the degree of assemblage integrity, a key factor for accurate archaeological interpretation and reliable cultural inferences. By integrating geological data with observations of the assemblage's preservation and structure, we aim to evaluate whether the assemblage reflects a coherent accumulation or has been significantly altered by natural formation processes.

Several scenarios must be considered regarding the formation and preservation of the Campo 11 assemblage: (i) the assemblage may consist partly or entirely of artifacts transported and deposited secondarily by natural processes, such as fluvial action or slope dynamics; (ii) it might represent a stone-line formation, a result of deflation processes where finer sediments are eroded, leaving concentrated stone artifacts; (iii) the site could reflect an open sedimentary context containing a palimpsest of artifacts accumulated over extensive time spans, mixing materials from different periods without clear stratigraphic separation; or (iv) Campo 11 may represent an assemblage accumulated within a constrained temporal range (e.g., a single chrono-technocultural unit), providing a more precise basis for cultural inferences. Establishing whether the assemblage reflects an undisturbed human activity context or a deposit altered by natural forces is therefore fundamental to meaningful archaeological interpretation.

3.4.1. Geological formation processes

The Campo 11 site, situated within a typical anastomosed fluvial system, features a central sandbar flanked by two active channels (Fig. 5). The lithic assemblage, recovered from the uppermost section of this sandbar, occupies a discrete stratigraphic interval. The exposed sedimentary front, visible on an inclined surface after quarrying and subsequent rain washing, extends 0.5–1 m in thickness. This suggests

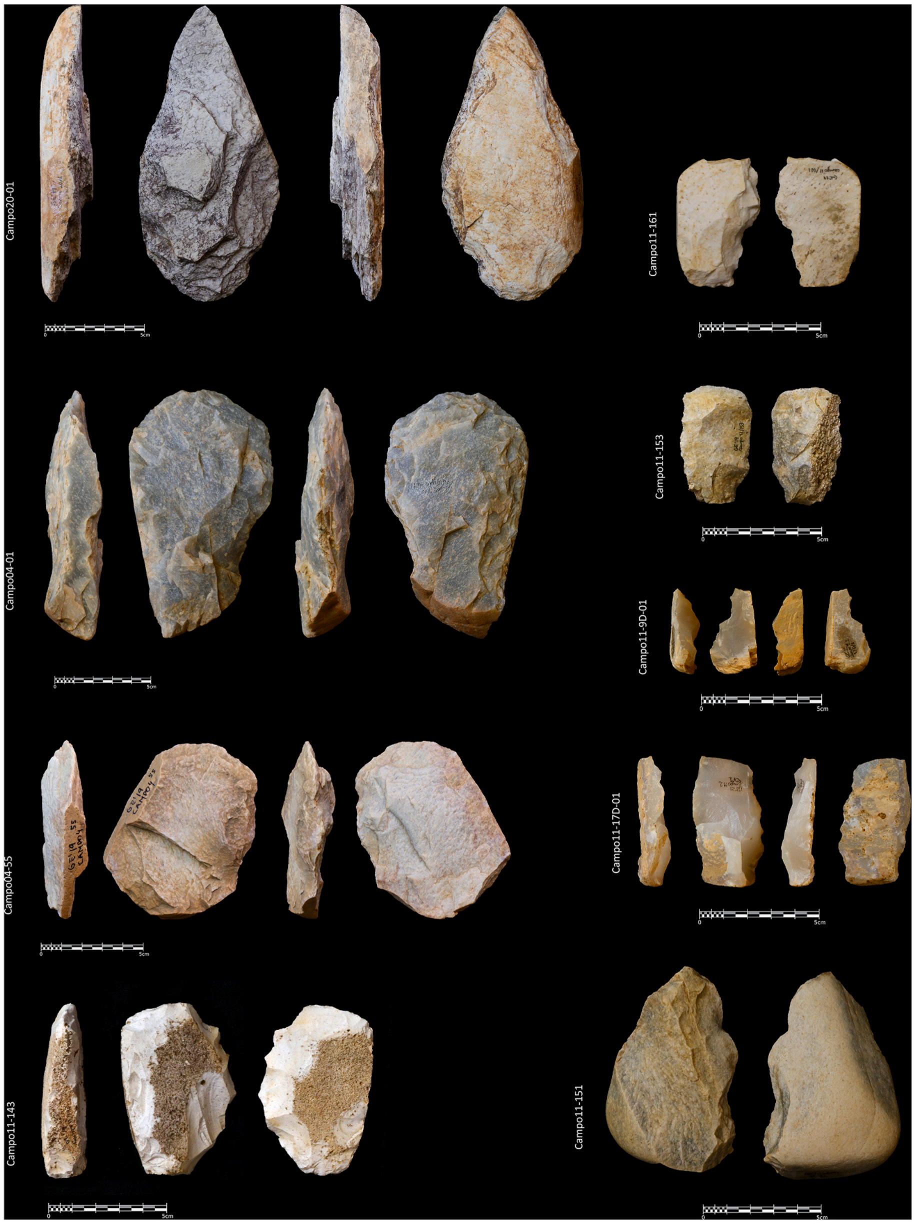

Fig. 10. Lithic remains recovered from the Río Campo region, Equatorial Guinea. Elements displaying opposing patterns of percussion marks and edge crushing/chipping, interpreted as wedges.

that the original archaeological horizon, which remains unobserved, lies beneath the currently visible dispersion interval. Several geological indicators support the hypothesis of an in situ origin for the lithic assemblage, with minimal post-depositional disturbance.

First, the confinement of lithic artifacts to a narrow stratigraphic interval implies limited post-depositional reworking. No artifacts were found in adjacent channels, which typically serve as primary zones for sediment transport and redeposition in fluvial systems. Second, fieldwork observations revealed an apparent lack of imbrication or orientation among the artifacts, indicating minimal exposure to strong fluvial currents or recent surface runoff during the Quaternary or more recent times. High-energy environments, such as active channel flows, usually produce clasts with preferred orientations due to water's directional forces (e.g., Miall, 1981). Furthermore, the sedimentary record at Campo 11 lacks evidence of depositional hiatuses or "stone lines," which are often associated with periods of erosion or stasis in similar fluvial contexts. For instance, specific forms of stone lines, like those observed at sites such as Campo 5, represent erosive surfaces where clasts, including lithic tools, accumulate due to high-energy transport. Additionally, no sub-angular pits, which would suggest mechanical abrasion during transport, were observed on the lithic artifacts.

Lastly, the consistency of OSL dating and estimated sedimentation rates at Campo 11 suggests relatively stable depositional processes within the anastomosed fluvial system. The lithic assemblage was located in the uppermost section of the sandbar, where sedimentation rates range between 30 and 70 cm/ka (Fig. 5, Table 3), indicative of a stable environment with continuous sediment accumulation. This contrasts sharply with sites like Campo 5, where OSL dates reveal a significant depositional hiatus of approximately 30 ka, evidenced by a well-defined stone line. At Campo 5, the uppermost sands deposited in the floodplain accumulated at markedly lower rates of 9.7–13.4 cm/ka (Fig. 4, Table 3).

3.4.2. *Lithic assemblage taphonomy and integrity*

Despite uncertainties stemming from limited data and the absence of systematic excavation, the characteristics of the assemblage suggest it

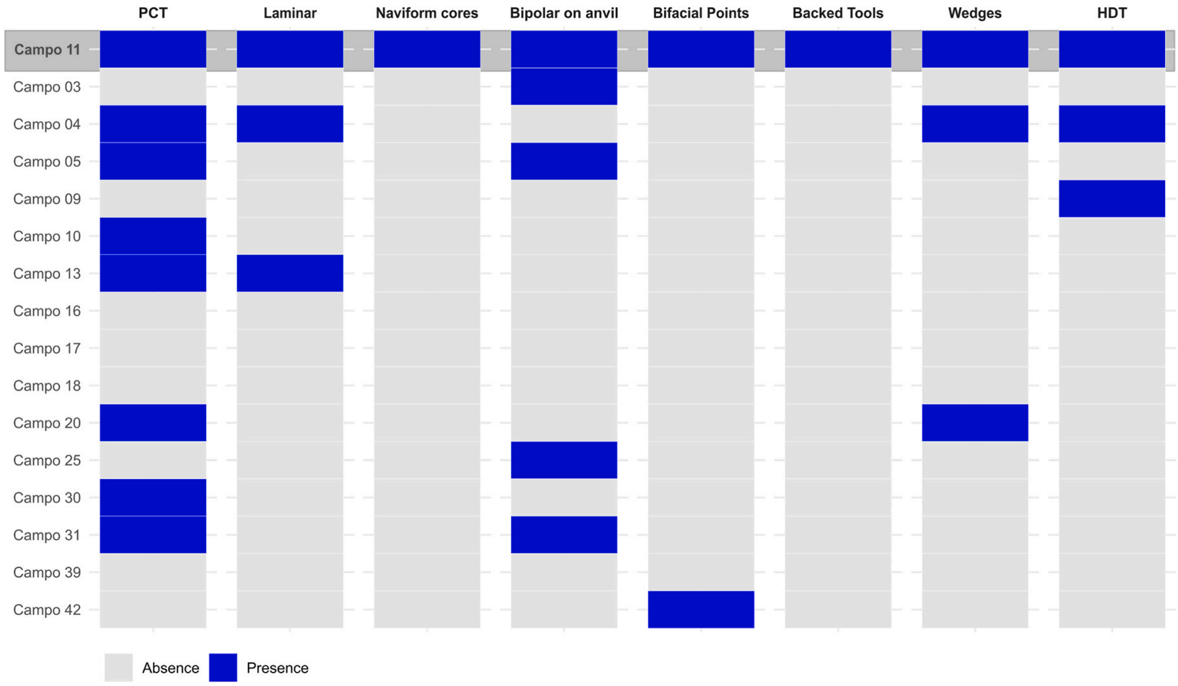

Fig. 11. Distribution of key techno-typological traits characterizing the Campo 11 assemblage across various sites in the Río Campo region, Equatorial Guinea.

represents a relatively narrow accumulation time span. Campo 11 contains artifacts spanning all structural categories of the lithic reduction sequence. The collection includes cores at various reduction stages, a significant number of flakes (both complete and fragmented), retouched flakes, tools shaped from cobble or block reduction, as well as fragments.

An analysis of post-depositional alterations reveals a low incidence of modifications, underscoring the assemblage's overall good preservation (Table 7). Light patination is the most common alteration, particularly on chert artifacts. Notably, there is no macroscopic evidence of rounding, indicating minimal transport or abrasive post-depositional processes. Other alterations—such as pseudo-retouch, significant trampling, or fire damage—are rare across all raw material types. Edge damage observed on some artifacts, particularly larger cutting tools, is characterized by localized crushing and chipping along edges. These features align with intentional use patterns rather than post-depositional modifications. Double patinas, indicative of recycling or prolonged exposure, are nearly absent. Quartz artifacts exhibit virtually no alterations, while quartzite artifacts show moderate patination but negligible other modifications. The scarcity of significant alterations suggests the assemblage has been minimally affected by post-depositional processes.

The representation of all reduction stages and the good state of preservation point to the integrity of the Campo 11 assemblage. However, the distribution of artifact sizes was also analyzed to assess potential underrepresentation of smaller artifacts, which could result from collection biases, post-depositional disturbances, or taphonomic processes affecting the completeness of the assemblage and the reliability of subsequent inferences. The main typometric characteristics of the assemblage are presented in Table 8. The distribution of artifact sizes by length and width shows no significant size biases, indicating consistent representation across different size groups (Fig. 12a). Artifacts less than 20 mm in length account for 27% of the assemblage, demonstrating a notable presence of smaller items. However, remains smaller than 10 mm are scarce, comprising only 3% of the total (Fig. 12b).

Table 8
Mean dimensions (in millimeters) and standard deviations of lithic artifacts from the Campo 11 assemblage, categorized by artifact type. Measurements include Length, Width, Thickness, Elongation (length/width), and Carination (width/thickness).

	Length	Width	Thickness	Elongation	Carination
Flakes	30.26 ±13.12	26.46 ±9.81	6.88±3.55	1.26±0.64	5.42 ±1.96
Fragmented flakes	27.65 ±10.39	25.44 ±10.36	5.98±2.92	1.22±0.52	6.07 ±2.47
Fragments	29.90 ±12.30	21.05 ±8.84	9.19±4.25	1.54±0.55	3.74 ±1.48
Cores	45.81 ±18.79	37.11 ±17.44	22.25 ±17.01	1.36±0.51	2.69 ±1.20
Retouched Flakes	56.15 ±29.84	38.83 ±21.03	14.36 ±7.35	1.53±0.56	4.28 ±1.04
Tools on Cobble	83.85 ±34.55	51.61 ±24.92	29.30 ±15.65	1.69±0.24	3.12 ±0.82

Artifacts <20 mm or <10 mm in length often fall below the threshold for individual recording during excavation and are typically recovered only through sediment processing and sorting. The underrepresentation of the smallest artifacts at Campo 11 reflects the collection methodology, which prioritized surveying larger areas rather than employing systematic excavation or fine sediment sieving.

Results from the K-S test revealed significant differences in artifact size distributions among all examined assemblages ($p < 0.001$), except between Sahb El Ghar 1.1 and Sahb El Ghar 2.1 ($p = 0.729$), which share a similar context and taphonomic history. These findings indicate that

Table 7
Summary of post-depositional alterations observed in the Campo 11 lithic assemblage, categorized by raw material type.

		Total	Patinated		Recycling (double patina)	Pseudo-retouch			Fire alteration
Chert	211	205	97.16%	1	0.47%	1	0.47%	10	4.74%
Quartz	9	0	0%	0	0%	0	0%	0	0%
Quartzite	69	21	30.43%	0	0%	1	1.45%	0	0%

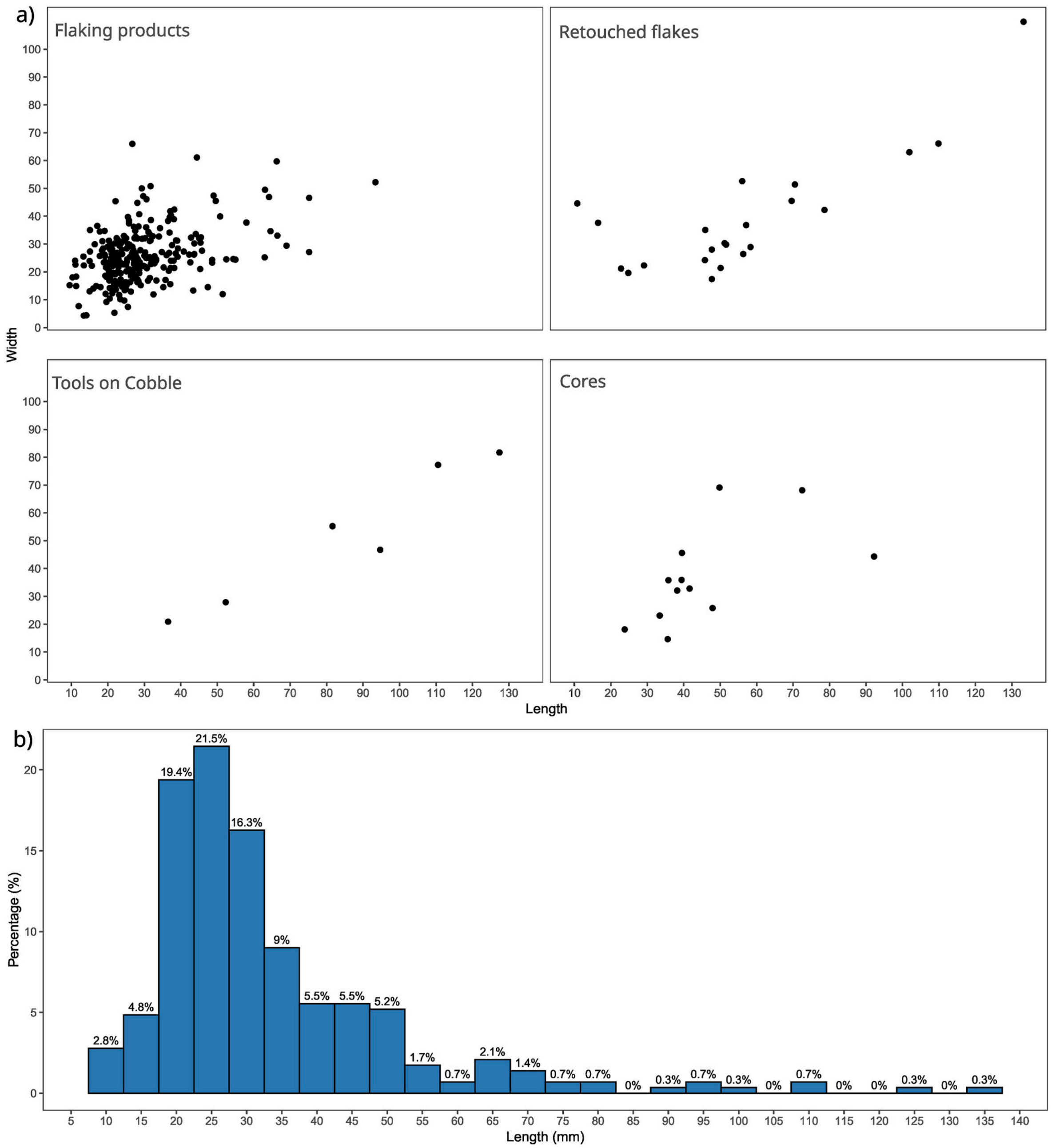

Fig. 12. Technological and dimensional characteristics of lithic artifacts from Campo 11. A) Scatterplots showing the relationships between length and width for flaking products, retouched flakes, tools on cobbles, and cores. B) Histogram showing the length distribution of the lithic assemblage.

the size distribution at Campo 11 does not align with patterns from meticulously excavated sites employing fine sieving techniques or from unsystematically collected contexts. Furthermore, it does not match patterns from either well-preserved sedimentary environments or those with complex taphonomic histories.

An evaluation of the D-statistics provides further insights into the degree of difference between assemblages (Fig. 13). While Campo 11 differs statistically from all other assemblages, the magnitude of these differences varies. Campo 11 occupies an intermediate position between meticulously excavated cave sites with fine sieving and sorting, and strongly taphonomically biased or unsystematically collected assemblages. Specifically, its size distribution is more similar to Middle Stone Age (MSA) open-air sites than to other contexts.

The contrast between Campo 11's good preservation and the variable preservation observed at the Sahb El Ghar localities suggests that the underrepresentation of artifacts smaller than 10 mm at Campo 11 is primarily due to the absence of meticulous excavation and fine sieving, rather than strong taphonomic bias.

Interestingly, the closest relationship was observed between the well-preserved short-duration logistical occupation site and the unsystematically recovered Neolithic site. This suggests that using size distributions to evaluate assemblage integrity may be challenging, as specific cultural formation processes can mimic structures resulting from natural formation processes or biased recovery methods. Thus, the absence of meticulous excavation and fine sieving at Campo 11 appears to be the main factor affecting the underrepresentation of the smallest artifacts. However, the notable presence of small artifacts (27% under 20 mm) indicates that the assemblage retains significant integrity.

Overall, the Campo 11 assemblage appears to represent a relatively homogeneous and well-preserved accumulation. The presence of elements from all stages of the reduction sequence indicates a comprehensive representation of lithic production activities. Minimal post-

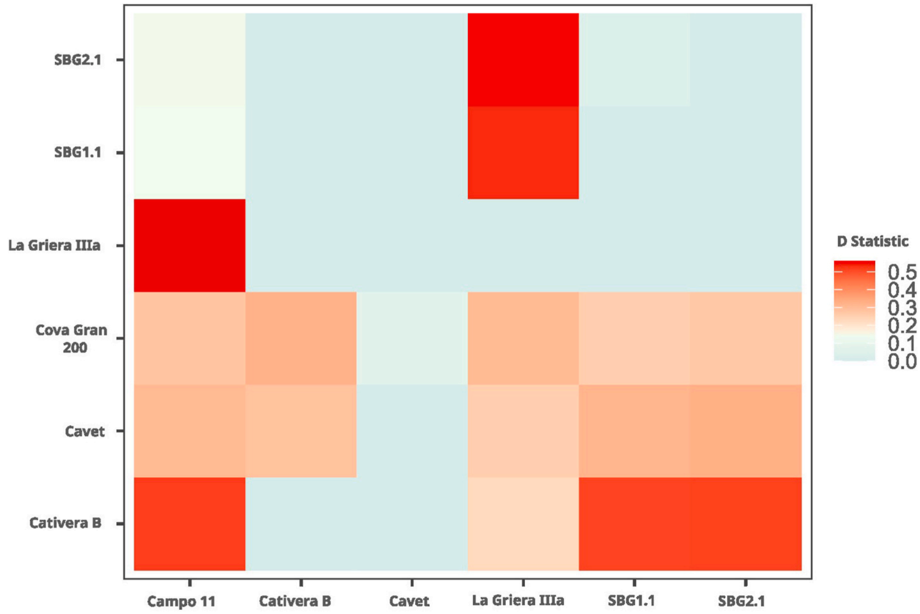

Fig. 13. Heatmap illustrating the degree of similarity in artifact size distributions across sites, based on the D-statistic from the Kolmogorov-Smirnov test. Darker colors represent greater differences between cumulative distributions of two sites, while lighter colors indicate greater similarity.

depositional alterations and the absence of coatings or macroscopic rounding suggest that the assemblage has largely escaped significant taphonomic processes. Comparative analyses indicate that the structure of the Campo 11 assemblage likely reflects the genuine temporal association of documented technological practices, rather than artifacts of collection methods or taphonomic processes. Consequently, for analytical purposes, the Campo 11 assemblage can be regarded as a relatively homogeneous accumulation, suitable as a techno-typological reference.

4. Discussion and conclusions

Developing a comprehensive model of *Homo sapiens* evolution necessitates addressing key aspects of the prehistory of underexplored regions. Among these, the Central African rainforests stand out due to their vast geographic extent and critical location (Taylor, 2014, 2016). Current understanding of Pleistocene settlement in the Congo Basin is hindered by misconceptions caused by the absence of robust stratigraphic contexts, radiometric data, and detailed lithic analyses, which in turn preclude the formulation of reliable evolutionary models. This study presents new findings from time-constrained Stone Age sites in the Río Campo region of Equatorial Guinea. These include stratigraphic data and evidence of Middle Stone Age (MSA) technologies dated between 45 and 21 ka. This tradition is widespread across the region and is particularly prominent at the Campo 11 site, characterized by assemblages that blend Acheulean morphotypes with diverse reduction methods and tool classes typical of a general MSA framework.

4.1. Geological context and chronology

Fieldwork in the Río Campo region identified 30 Quaternary outcrops, all adhering to a consistent stratigraphic pattern. A Cretaceous basement is overlain by a thin Quaternary cover (2–10 m), which can be categorized into alteration profiles and alluvial deposits. Alteration profiles (Ollier and Pain, 1996; Tardy, 1997; Beauvais, 1999) dominate the region and display three distinguishable horizons. While no lithic artifacts were recovered from these profiles in the Río Campo area, comparable horizons in the interior of Equatorial Guinea have yielded lithic remains (Mercader and Martí, 2003; Rosas et al., 2022; Terrazas-Mata et al., 2023).

The second stratigraphic category, very poorly developed alluvial deposits, rests unconformably on the Cretaceous basement. Geomorphological reconstruction (Fig. 3) suggests that during the Upper Pleistocene, the area hosted an anastomosing fluvial system with thin sand units and channel deposits overlying the basement. Chronological and geomorphological data indicate human occupation between at least 44 ka and 20.6 ka, possibly constrained to short preservation windows within a system subject to intense erosional events that reset the sedimentary record. These sediments likely correspond to the latest climatic cycle, with earlier stratigraphic evidence erased by successive erosion phases, potentially linked to cold/arid conditions (Rosas et al., 2022). The high homogeneity of the profiles together with their scarce stratigraphic development and the description of erosional events in the observed units allow us to hypothesize that the lack of archaeological data is actually due to the absence of a stratigraphic record prior to MIS5. Therefore, from a strictly archeo-paleontological point of view, it is not rigorously possible to raise the question about the nature and time of the first occupations in the rainforest, since no pre-MIS5 record has been preserved. Campo 11 provides the most complete lithic assemblage within a temporally limited accumulation and represents this chronological moment. Other sites in Equatorial Guinea show technological traits consistent with those at Campo 11. By morphology and stratigraphy, Campo 11 aligns closely with the Mabewele site in central Equatorial Guinea, as documented by Terrazas and Rosas (2016).

Within this context, lithic assemblages were found mostly in alluvial settings. The most remarkable site is Campo 11, which corresponds with a sand bar surrounded by two channels (Fig. 5). In moments of lower flow/abandonment of the channels, palaeopopulations of the Río Campo area were able to occupy the central bar between 44 ka and 21.7 ka BP, as recorded by their stone tool remains. Other sites, such as Campo 5, represent flood plains or lateral channel deposits (Fig. 4), where the lithic assemblages are found always within thin levels in the uppermost part of the stratigraphic sequences.

4.2. Site formation processes

The fluvial depositional environments of the Río Campo region often result in sediments and lithic assemblages exhibiting transport and reworking, particularly in equatorial climates with high rainfall and discharge. However, the anastomosing fluvial system at Campo 11, characterized by stable, low-energy channels, suggests minimal transport and disturbance. This is supported by several observations: 1) Stratigraphic Confinement: lithic tools are concentrated within a narrow stratigraphic interval (0.5–1 m thick), with no evidence of significant reworking across the 4 m sediment profile. In situ origin is further supported by the absence of erosive surfaces or "stone lines." 2) Preservation State: the lithic artifacts lack sub-angular pits, indicative of mechanical wear, and show no imbrication or orientation patterns, confirming low-energy deposition. 3) Sedimentation rates: the higher sedimentation rate at Campo 11 (30–70 cm/ka) compared to Campo 5 (10–13 cm/ka) aligns with its position on a central bar within the fluvial system, favoring rapid sediment accumulation in low-energy conditions.

Despite weathering processes, the lithic tools' association with fairy chimneys—features that stabilize heavier clasts—further supports their autochthonous origin. Additionally, the geomorphological stability of the sand bar likely provided a favorable environment for sustained human occupation.

In conclusion, the geological evidence indicates that the lithic assemblages at Campo 11 were deposited in situ within a stable fluvial environment. Stratigraphic confinement, sedimentary homogeneity, and the absence of fluvial transport indicators collectively support this conclusion. In contrast, higher-energy conditions at sites like Campo 5 resulted in more disturbed deposits. The unique geological conditions at Campo 11 make it a key site for understanding Pleistocene populations in the Río Campo region.

4.3. Stone tools affiliation

Our analysis shows that Campo 11, along with most sites in the Río Campo area, features Levallois reduction sequences as the dominant strategy for flake production. Levallois and other prepared core techniques coexisted with sporadic, non-standardized blade production and occasional bipolar flaking. Notably, Campo 11 demonstrates a unique reduction strategy aimed at producing short, wide flakes, which we classify as a naviform-like reduction sequence.

The retouched tool corpus is dominated by bifacial points and cutting/chopping implements, including handaxes, cleavers, and wedges. Retouched flakes are less common, primarily represented by scrapers, with occasional backed implements. Quartzite and chert were the main raw materials, with quartzite used predominantly for bifacial points, wedges, and cutting tools, while chert was preferred for flakes and smaller tools.

These technological findings, combined with systematic surveys and geomorphological models, suggest that the variability observed in Río Campo reflects the inherent characteristics of Late Pleistocene lithic techno-complexes in Equatorial Guinea's rainforest environments. A consistent technological pattern across the region indicates a shared techno-typological background, pointing to widespread occupation during this period.

The technological and typological traits of Campo 11 and the Río Campo basin align closely with defining features of the Middle Stone Age (MSA). The coexistence of diverse reduction strategies, distinct morphotypes, and tool classes reflects technological versatility, likely representing adaptations to environmental and functional demands. This diversity underscores the adaptive flexibility of Late Pleistocene groups in rainforest settings, consistent with the MSA's evolutionary trajectory.

Prepared core technologies, characteristic of the Mode 2 to Mode 3 transition, define the early MSA (Johnson and McBrearty, 2010). These coexisted with non-systematic blade production as early as the latest Mode 2 in eastern and southern Africa, where diverse blade production strategies emerged alongside prepared cores (~500 ka BP) (Wilkins and Chazan, 2012). Blade production persisted throughout the MSA's evolution in eastern (Tryon and Faith, 2013) and southern Africa (Wurz, 2013), transitioning later to microlithic industries.

The presence of backed pieces at Campo 11, though limited, is significant. Backed tools are commonly associated with hafting, often as projectile components, and are seen as markers of behavioral complexity and "modernity" (Wurz, 1999; McBrearty and Brooks, 2000; Scerri and Will, 2023; Delpiano et al., 2024). This aligns with the widespread presence of backing in MSA contexts across central, eastern, and southern Africa during the Late Pleistocene (Tryon and Faith, 2013) and some of the earliest instances near the Congo Basin periphery (Barham, 2002).

A key feature of the Río Campo assemblage is the diversity of cutting and chopping tools, spanning Mode 2 types and intermediate forms such as wedges. Despite typological variation, these tools share functional characteristics, suggesting their use as handheld or hafted axes or adzes for processing hard materials, likely woodworking (Clark, 1965). Whether this persistence of bifaces and cleavers reflects a Mode 2 legacy or an independent adaptation to forested environments warrants further study.

The technological and typological traits at Campo 11 correspond closely to Lupemban MSA assemblages of Central Africa (Breuil, 1944; Taylor, 2016). These assemblages are characterized by a mix of lithic reduction strategies, including Mode 2 bifacial techniques, Mode 3 prepared cores, and blade and backed blade production typically associated with Modes 4 and 5 industries. Tool types include lanceolate points, blade tools, and core axes, often interpreted as adaptations to tropical forest environments (Barham, 2001; Clark, 1959; Taylor, 2011). This affiliation suggests that Campo 11 is part of the Lupemban MSA tradition.

The Sangoan–Lupemban tradition, in its broadest sense, centered in Central Africa's rainforest and woodland biomes, is associated with post-Mode 2 technologies (Clark, 1965). It extends geographically from the Rift Valley system (McBrearty, 1988) to the Nile Valley (Van Peer et al., 2003), including regions with preceding Acheulean occupations, such as Zambia (Barham et al., 2015; Clark, 1969, 1974, 2001; Duller et al., 2015) and Sudan (Van Peer et al., 2005). However, Mode 2 settlements are absent in the Congo Basin interior (Taylor, 2011).

The Río Campo lithic industry aligns with the Lupemban MSA tradition. While cultural or temporal variability within assemblages cannot be entirely excluded, no diagnostic traits suggest significant deviations from MSA affiliations. The only non-MSA evidence consists of Iron Age pottery, radiometrically dated to the 3rd millennium cal. BP, matching geomorphological models and OSL dates from the basin's upper sediments.

The closest comparable archaeological evidence to the Rio Campo assemblages is the Mosumu collection (Mercader et al., 2002; Mercader and Martí, 2003). The Mosumu lithic assemblage shares several attributes with Campo 11, including the presence of prepared cores and a trend toward reduced-size bifacial points. At Mosumu, an LSA assemblage capping the sequence is described, characterized by single-platform cores and small tools but lacking the microliths or bladelet technologies typically associated with the Later Stone Age. No direct association between Mosumu's LSA and the available ^{14}C chronology of the section, ranging from 1.6 to 30 ka BP, is made. As noted by Mercader et al. (2002), these dates should be interpreted as *terminus ante quem* references for the MSA assemblage rather than direct evidence of LSA occupation.

This ambiguity raises questions regarding the apparent absence of unambiguous LSA technologies in the rainforests of Equatorial Guinea. Consistently, the Rio Campo basin and other surveyed areas (Rosas et al., 2019) reveal no evidence of bladelet production strategies, microlithic and geometric tools, or arrow points—key elements associated with LSA industries. Such features, well-documented in neighboring Western and Central African tropical regions (Lavachery et al., 1996; Mercader and Brooks, 2001; Cornelissen, 2002, 2003), are conspicuously absent from the archaeological record of Equatorial Guinea. Instead, whenever the lithic assemblages present diagnostic traits suitable for techno-cultural inference, they consistently align with the broader MSA tradition. Indeed, recent research suggests that MSA technologies may have persisted at least until the Pleistocene–Holocene transition (Cruz-y-Cruz et al., 2022; Terrazas-Mata et al., 2023).

Current knowledge of Pleistocene settlement patterns in Equatorial Guinea reflects the sparse archaeological record typical of the Congo Basin rainforests and woodlands. This record is characterized by a lack of robust stratigraphic contexts, radiometric data, and detailed lithic analyses. These gaps hinder the development of comprehensive evolutionary models and complicate the contextualization of the Río Campo assemblages within established frameworks. Furthermore, the ambiguity often seen in MSA assemblages—defined by a limited set of attributes that form an MSA "basic package" (Will and Scerri 2024)—contrasts with the emergence of distinct regional techno-typological trajectories. These trajectories align with a broader anisotropic and non-linear model of human technological evolution (McBrearty and Brooks, 2000; Scerri, 2017; Blinkhorn and Grove, 2018; Scerri and Will, 2023).

Despite these challenges, the techno-typological diversity documented in Río Campo may reflect the tropical specificity of the MSA, potentially rooted in deep-time regional evolutionary dynamics or more rapid functional adaptations. The assemblages' technological features, such as the coexistence of prepared core technologies, bifacial points, heavy-duty implements, and occasional backed pieces, suggest an adaptive flexibility and regional distinctiveness within the MSA framework.

The persistence of MSA technologies in Equatorial Guinea may be attributed to various factors, including environmental stability, population continuity, and isolation from technological innovations elsewhere. Prolonged occupation could have led to technological drift or adaptations finely tuned to the tropical forest environment. The lithic tools, adapted to processing dense forest materials like hardwoods and fibrous plants, suggest a strong functional basis for the assemblages. Cultural and demographic factors may have reinforced the continuity of these established technologies, favoring their retention over the adoption of new innovations. However, the limitations of the current dataset, including small sample sizes and low contextual resolution, require caution in interpretation. Future systematic excavations in Río Campo and other regions of Equatorial Guinea are essential to refine these hypotheses. Such efforts would improve chronological frameworks, stratigraphic control, and lithic analyses, offering deeper insights into prehistoric occupation and technological development.

4.4. Origins of the MSA's maker populations

The evolutionary history of Paleolithic populations in central West Africa is complex (Mitchell and Lane, 2013). Based on new data, we propose two potential scenarios regarding the biological origins of the populations responsible for the Río Campo assemblages. 1) Deep ancestral lineage: genomic data (Lipson et al., 2022) suggest the possibility of a deep lineage of Central African hunter-gatherers, potentially long-isolated within these rainforest environments. 2) East African migration: alternatively, the Río Campo populations may have originated from East African groups carrying MSA variants, arriving around 60 ka during an intra-African migration event associated with the broader Out-of-Africa dispersals. However, the generalized nature of the Río Campo MSA, alongside the presence of Large Cutting Tools (LCT), challenges this hypothesis. Comparative analysis of East and West African MSA industries is needed to identify potential technical similarities and assess this connection. In either scenario, a fundamental question arises: how can we interpret the presence of these LCT in chronologies much later than what would correspond to a classic sequence of technological evolution? The persistence of MSA elements in Río Campo at dates close to 24 ka ago undoubtedly indicates cultural persistence and possibly population isolation. This suggests a scenario of *H. sapiens* evolution that is more complex than a simple linear model of temporal changes.

4.5. Conclusions

The three fundamental conclusions of this work are summarized below. First, the sedimentary record of the Río Campo region, and by extension all of Equatorial Guinea (Rosas, 2014; Rosas et al., 2021a; Rosas et al., 2022; Terrazas-Mata et al., 2023; Saladié et al., 2024), and most of the areas covered by rainforest, preserve sediments fundamentally from the Upper Pleistocene. In most cases, alteration profiles developed over the last millennia. Virtually all of the previous sedimentary record has disappeared due to successive erosive cycles. Therefore, the absence of a previous archaeological record is due more to taphonomic reasons than to the absence of earlier human occupations. Reconstructing human evolutionary history in these ecosystems is a complex task based solely on archaeo-paleontological data. It is essential to resort to other markers (e.g., genomic) that leave a record of the history of these populations. Secondly, the persistence of typical ESA tool-classes, including handaxes and cleavers, leads us to hypothesize that the human makers of these industries maintained an ancestry linked to populations from the time when Mode 3 was differentiating from Mode 2, at least 320 ka ago (Clark, 1988; McBrearty and Brooks, 2000; Morgan and Renne, 2008; Tryon and Faith, 2013; Lycett and von Cramon-Taubadel, 2015). Finally, the chronological data indicate the survival of this MSA into periods close to the Last Glacial Maximum, potentially associated with a time of high aridity (Street-Perrott and Perrott, 1990; Weldeab et al., 2007; Shanahan et al., 2015). This arid period may have initiated a new erosive cycle that destroyed potential records and/or led to the disappearance of these populations from the territory. In any case, the persistence of MSA as late as 24 ka illustrates the complexity in the bio-cultural evolution of *H. sapiens* and rules out a homogeneous gradual transformation sequence across different African population groups.

These findings underline the nuanced and regionally diverse evolutionary paths of early humans, particularly within the challenging environments of Central African rainforests. Continued multidisciplinary research is critical to unraveling this complexity.

CRediT authorship contribution statement

Antonio Rosas: Conceptualization, Writing – original draft, Funding acquisition. **Antonio García-Tabernero:** Conceptualization, Writing – original draft. **Darío Fidalgo:** Investigation, Data curation. **Maximiliano Fero Meñe:** Resources, Investigation. **Cayetano Ebana Ebana:** Resources, Investigation. **Mateo Ornia:** Resources, Investigation. **Javier Fernández-Martínez:** Resources, Investigation. **Sergio Sánchez-Moral:** Resources, Investigation. **Juan Ignacio Morales:** Conceptualization, Writing – original draft, Investigation.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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