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Pleistocene Archaeology - African Isotope Database (PleIStO Arch-AID): A Resource for Biogeochemical Research

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Data Note

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Title: Pleistocene Archaeology - African Isotope Database (*PleIStO Arch-AID*): A Resource for Biogeochemical Research

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Abstract

The Pleistocene Archaeology - African Isotope Dataset (*PleIStO Arch-AID*) is a comprehensive, open-access repository that collates published stable and radiogenic biogeochemical isotopic measurements from Africa during the Pleistocene. Here, we introduce this dataset, which comprises 21,649 stable and radiogenic isotopic measurements ($\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$). These measurements were obtained from Pleistocene-aged (2.58 – 0.011 Ma) hominin and faunal specimen samples, alongside Mio-Pliocene aged, and modern comparative samples reported in supplementary indices (10,794 total samples). By centralizing and standardizing published isotopic measurements in an open-access format, *PleIStO Arch-AID* will enhance the accessibility and usability of such data for large-scale analysis. Over the past fifty years, extensive isotopic research has been conducted across Africa, reflecting the continent's diverse geography, climate, geology, and the evolutionary history of hominins. This repository provides an essential resource for researchers investigating these dynamics on a localized and/or continental scale. This dataset also addresses potential gaps in isotopic data for Pleistocene Africa, facilitating future research endeavors to identify environmental influences that shaped the evolution of human behavior during this critical period. The open-access *PleIStO Arch-AID* datasets can be accessed through the Pandora Initiative data platform.

Background & Summary

Spanning over 30 million km^2, the African continent is characterized by exceptional environmental heterogeneity, encompassing ecosystems from hyper-arid deserts to humid equatorial rainforests. During the Pleistocene (2.58 Ma – 11.7 ka), following the intensification of Northern Hemisphere glaciation[1], the continent experienced variable climatic oscillations, drastic environmental changes, and a shift toward more open habitats that restructured vertebrate communities relative to the more closed, mixed vegetation of the Miocene and Pliocene[2–6]. This

also marked the spatiotemporal expansion of our genus *Homo*, and provided the environmental context for our lineage's distinctive behavioral, technological, and anatomical evolution[7–11].

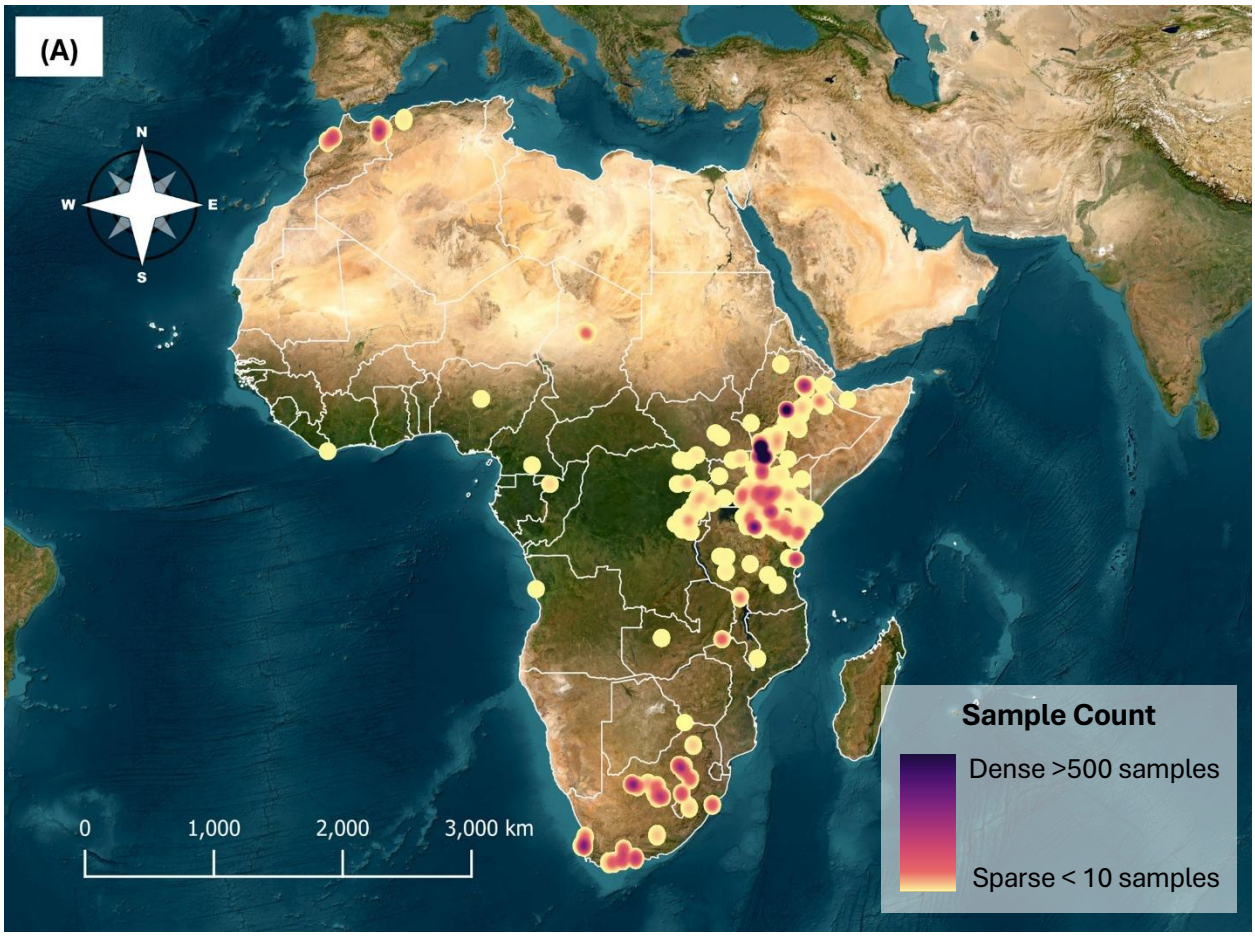
Over the last five decades, researchers have employed stable carbon ($\delta^{13}C$), and oxygen ($\delta^{18}O$), isotopic analyses to explore these past phenomena analyzing faunal and hominin diet, and reconstructing paleoenvironments from collagen[12,13] and calcified tissues[14–16], principally tooth enamel[17–42]. Additionally, some of the oldest hominin and faunal specimens to which these analyses have been applied come from Mio-Pliocene Africa[6,43–52]. In more recent years, there has been increased use of strontium ($^{87}Sr/^{86}Sr$) isotopes for mobility and provenience studies[53–58], in addition to more non-traditional isotopic systems, including calcium (Ca) and zinc (Zn) for trophic level analyses[59–61]. Despite advancements in isotopic analysis and techniques (for comprehensive review, see Loftus et al.[62]), significant challenges remain that have hindered data synthesis, standardization, and accessibility. These limitations stem from both scientific and socio-historical factors.

First, a lack of standardization has led to inconsistencies in how isotopic data are reported in publications[63]. Some early studies report isotopic values as species-based averages, often omitting chronological or contextual data. Discrepancies in reporting also arise from how feeding class is designated to genus or species, as research teams working in environmentally different regions have needed to apply varying categories, hindering synthesis across studies. Second, because preservation is a limiting factor, the likelihood of recovering identifiable hominin remains for isotopic analysis is considerably lower than for faunal remains (**Figures 1 and 2**).

Sampling biases exist within Africa due to both differential preservation of materials and uneven research investments across regions. For example, there is a dominant focus on archaeology and palaeoanthropology in the country of South Africa and Eastern Africa, particularly Ethiopia, Kenya, and Tanzania (**Figures 1 and 2**). These patterns are echoed by modern geo-political boundaries and the lasting impacts from colonization, but they do not necessarily reflect the realities of the evolutionary past. Furthermore, disparities in funding, infrastructure, and access to laboratories and facilities persist between regions, countries, and across the continent[64].

Finally, in the past, academic journal articles have been usually hidden behind paywalls that remained inaccessible to researchers and students alike who have lacked certain institutional affiliations. This inaccessibility has, unfortunately, impacted many scholars and institutions

working in African countries. Fortunately, there has been a global effort to increase accessibility over the last decade.



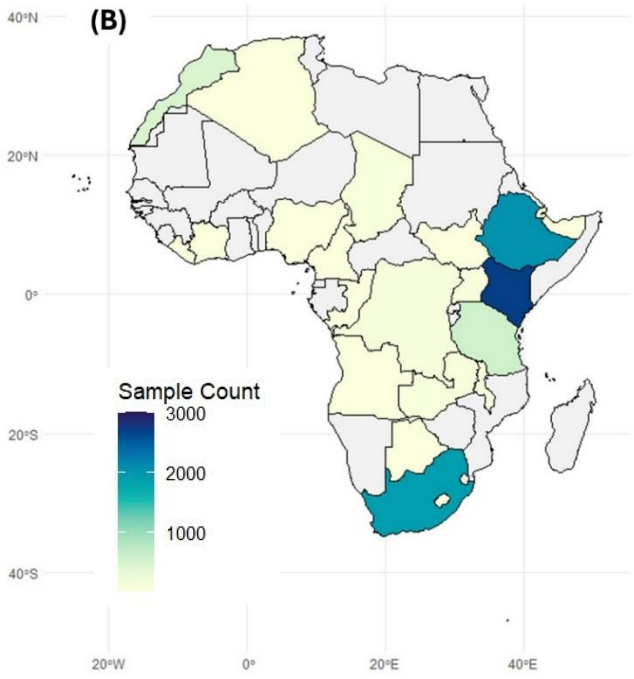


Figure 1: Geographic distribution of isotopic data included in the *PleIStO Arch-AID* repository. (**A**) Heatmap of isotopic data based on GPS coordinates 10,794 sample points; and choropleth map (**B**) displaying number of samples per country.

To address these issues of standardization and accessibility, we present the *Pleistocene Archaeology African Isotope Database* (*PleIStO Arch-AID*) data community, part of the IsoMemo network of independent datasets housed on the Pandora Platform. This structured yet flexible repository, collates published stable and radiogenic isotopic values (21,649 measurements) from faunal and hominin datasets (n = 10,794 samples) from the African Pleistocene and supplementary datasets.

The *PleIStO Arch-AID* repository includes isotopic measurements from archaeological fauna (77.7%), hominins (3.4%), and modern fauna (18.9%), which are often reported in the supplementary indices to provide modern comparative proxies. Reported measurements include $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ ratios. While there has been an increase in $^{87}Sr/^{86}Sr$ isotopic analysis for mobility and provenience studies, they are limited in their application of Pleistocene archaeological material in Africa. Therefore, most of the recorded data comprise $\delta^{13}C$ and $\delta^{18}O$ stable isotope measurements from tooth enamel, however, samples reported also include dentine, bone bioapatite, ivory, and hair keratin. Future updates to the database will include the addition of emerging novel isotopes like Ca and Zn. The robust metadata, discussed in detail below, emphasizes collecting existing contextual data, including provenance and chronology, as well as facilitating new environmental and climatological diachronic analyses.

The repository follows best practices for open science[65] and FAIR data principles[66], providing free open access regardless of institutional affiliation. This is particularly important as journal subscriptions are generally expensive, which can prevent researchers and students from accessing data published about their own country's cultural heritage and environmental ecology. These datasets will also facilitate future research by providing a synthesis to identify potential gaps and prospects for various isotopic analyses.

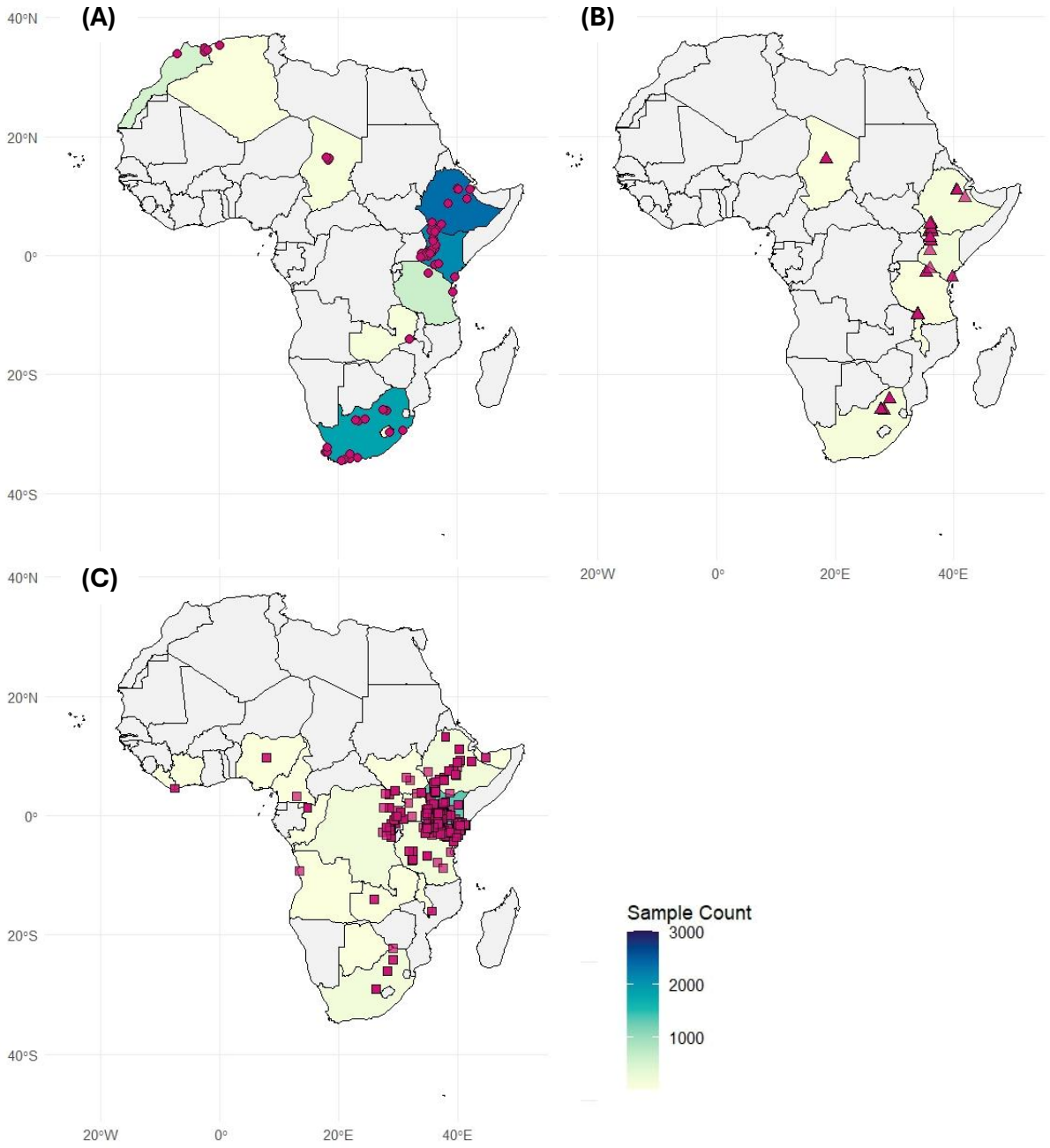


Figure 2: Spatial distribution of (**A**) archaeological and paleontological faunal, (**B**) hominin, and (**C**) modern faunal sampled specimens across the African continent currently compiled with the *PleIStO Arch-AID* datasets. Sample density is relative to the total quantity of samples recorded in both the Faunal and Hominin datasets.

Methods

Data were compiled from published, peer-reviewed sources including academic journal articles, book chapters, and dissertations. Sources were collected by conducting routine searches on academic search engines and websites, including Google Scholar, ResearchGate, and PubMed, as well as open-access repositories and publisher platforms such as ScienceDirect, Springer, and JSTOR. Searches included key words and phrases, including, but not limited to, "Africa," "Pleistocene," and "isotopes." Papers were also located by reviewing references of articles that report isotopic data. When articles were unavailable online, the corresponding authors were contacted to request access. Additionally, corresponding authors were contacted to review data entries included in the repository to ensure the original data are accurately represented.

While the primary aim of this database is to gather data from Pleistocene-aged specimens, all isotopic data reported in the original publications and supplementary indices are included in the datasets. This approach is used to avoid introducing biases in data representation or truncating datasets. Therefore, the compilation also includes data from Miocene and Pliocene specimens, as well as Holocene and modern samples.

The data recorded in the *PleIStO Arch-AID* database are reported as presented in the original publication, unless updated by the original author through personal correspondence, and are cited accordingly. The initial datasets that are now available on the Pandora Platform include only collated faunal and hominin isotopic data. Datasets comprising plant and sedimentological isotopic values will be published within the repository at a later date.

The standardized metadata structure of *PleIStO Arch-AID* is a critical component of the database, providing an essential, comprehensive description of all categorical variables and forming the foundation for interpreting and using these datasets. It includes over 150 data fields, organized into thematic categories encompassing locational description, archaeological and geological site context, taxonomic identification, site chronology, isotopic measurements, data quality control parameters, and detailed references to original publications (**Figure 3**). The datasets employ a consistent naming convention to facilitate integration with statistical software like Python and R. All column names are expressed in lowercase characters, with underscores (_) used in place of spaces (e.g., *site_locality*). The structure of the datasets expands on best practices for reporting isotopic data[63] and follows a similar organization to other databases within the IsoMemo

network[67–72]. This standardized format ensures consistency across entries and facilitates robust comparative analyses of Pleistocene African isotopic datasets.

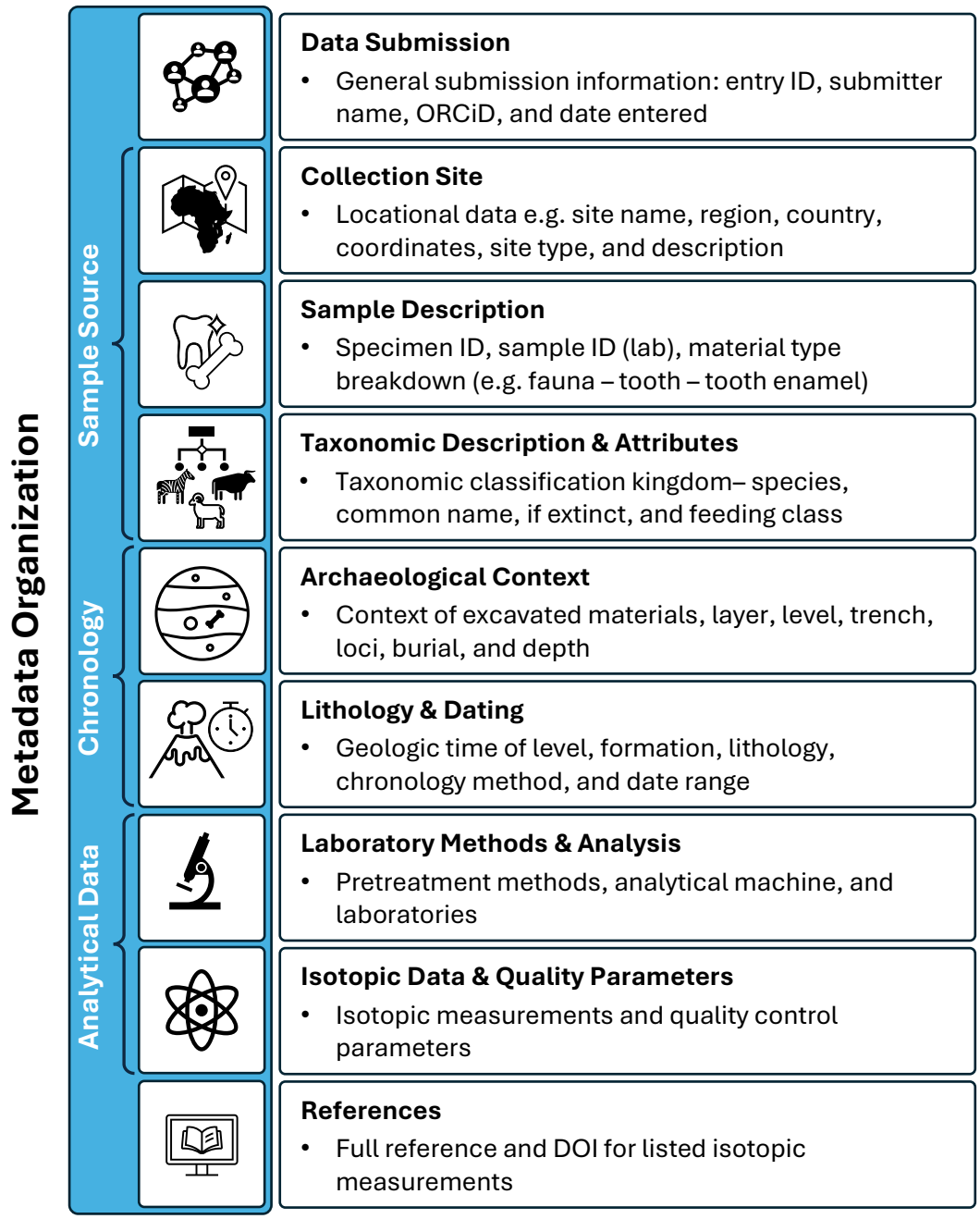


Figure 3: Data structure and general themes of the metadata categories recorded in the *PleIStO Arch-AID* datasets.

Metadata Fields

The following subsections outline the thematic categories and the associated data fields included in the *PleIStO Arch-AID* datasets as outlined in the metadata description (**Figure 3**). In the following descriptions, data fields are emphasized in bold font for clarity, and examples are italicized.

Data Submission

The data submission section includes basic entry identification information including the date, initials, and ORCiD of the researcher who entered the data. This section also provides the **entry_id** and the **unique_id** for each line of data. The **entry_id** pertains to the number of a specific line of data and the category, e.g. *FAU00001* indicates it is the first row of faunal data entered. The **unique_id** is a randomly generated string of twelve alphanumeric characters that serves as a persistent identifier for each sample. It links records to the **Dating Events** reference dataset and provides a stable key for integrating additional tables or external databases in the future. Because the identifier is randomly generated rather than derived from the provenience or sample name, it minimizes the risk of duplication and ensures long-term consistency across datasets.

Collection Site

Site locational information is recorded with as much detail as possible. The **site_name** and abbreviated **context_ID** (e.g., *Elandsfontein* and *EFT*, respectively), are recorded with the locality, region, and country. The **site_locality** identifies the nearest town, village, or city to the site location. If the recorded samples were collected from a national park, conservation area, or game reserve, this information is identified as the locality. Additional site description categories include **site_type** (i.e. open-air, cave, rock shelter, etc.) and whether the site is near the modern marine coastline (**site_coastal**), and if so, the distance in kilometers between the site and coast (**km_to_coast**).

When available, reported locational data from original publications are used to identify specific site locations. If exact **latitude** and **longitude** coordinates are not available, coordinates are estimated using Google Earth. All coordinates are reported in decimal format via World Geodetic System 1984 (WGS84). Many datasets reporting modern samples from national parks or game reserves often provide the name of the location but not geographic coordinates, likely

because the collection areas are extensive or the exact location is unknown. In these instances, we provide general coordinates for the park or reserve and indicate that these do not represent exact coordinates. Exact and estimated coordinates are identified with a "*true*" or "*false*" in the **exact_coordinates** column, respectively.

Sample ID and Description

The *PleIStO Arch-AID* datasets distinguish between **specimen_ID** and **sample_ID**. The **specimen_ID** refers to the identification number associated with the analyzed material as reported in the original publication. The **sample_ID** refers either to the referenced laboratory sample number assigned to a specimen or to a subset taken from a specimen for analysis (e.g., a drilled segment from sequentially sampled enamel). The specimen ID is preferentially reported here, as sample IDs are not consistently included or differentiated in the original source. In many publications, what we define as specimen ID is reported simply as "sample" or "sample id." However, we separate these categories to account for cases where multiple samples derive from a single specimen.

The metadata file encompasses nested descriptive fields, such as the analyzed material type, which is organized categorically as follows: **material_type1** (e.g., *fauna*), **material_type2** (e.g., *tooth*), **material_type3** (e.g., *tooth enamel*). Recording data in nested fields allows for highly detailed sample descriptions and variability of data use for analytical purposes. This is particularly important for materials such as tusks, which are identified as ivory or dentine or both, and often included as part of enamel studies.

Taxonomic Description

Other nested descriptive fields include taxonomic descriptions (**taxon_kingdom**, **taxon_class**, **taxon_order**, **taxon_family**, **taxon_tribe**, **taxon_genus**, **taxon_species**, and **common_name)**. Each sample is recorded at the highest taxonomic level possible, with identification provided to at least the family level. This approach makes explicit which specimens are identified to genus or species and which are limited to lower taxonomic assignments, allowing researchers to choose the resolution most appropriate for their analyses.

The taxonomic description also includes whether the taxon is **extinct** and notes on the reliability of the identification. For example, many publications will note that a specimen was

identified as "c.f. *Equus*" or "*Equus* c.f. *grevyi.*" In the second case, the specimen would be recorded as **taxon_genus** (*Equus*), **taxon_species** (*Equus grevyi*), and **taxon_notes** (*Equus* c.f. *grevyi*). This provides transparency about the level of reliability of taxonomic identifications recorded in the datasets and maintains the original publication's interpretation of the specimen's identification. Some taxonomic identifications have been updated in later publications; in this case, we provided the most up-to-date descriptions with citation in the **taxon_notes** column.

Species & Individual Attributes

This section contains specimen-level attributes, including sex, life stage, age, and the bone or tooth element analyzed. When available, both **tooth_element** (e.g. *M3*) and **tooth_location** (e.g. *upper right*) are noted to ensure consistency and allow researchers to select data appropriate to their analytical goals.

A key component of the species and individual attributes section is the feeding class designation. This information is central to isotopic analyses that reconstruct diet and environmental context. The dataset distinguishes between **environment** (e.g. *terrestrial, marine,* etc.), **trophic_level** (e.g. *primary consumer, secondary consumer,* etc.), **feeding_class** (e.g. *grazer, browser, carnivore* etc.), and **cerling_d13C_fc** (e.g. C4 *grazer, C3 browser,* etc.). Earlier publications have often applied behavior-based criteria for assigning feeding class, whereas Cerling et al.[21] proposed stable carbon isotope value-based boundaries for browsers (–12‰< to ≤–8‰), mixed feeders (–8‰< to ≤–1‰), and grazers (–1‰< to ≤2‰). These feeding class categories are expanded beyond the traditional triage of grazer, browser, and mixed-feeder to include hyper-grazer (>2‰), hyper-browser (–14‰< to ≤–12‰), and closed canopy browser (≤ –14‰). To accommodate this variation, the dataset records **feeding_class** as reported in the original publication, and additionally provides **cerling_d13C_fc,** which standardizes classification using the measured $\delta^{13}C$ values.

This value-based feeding class distinction is highly valuable in savannah or similar biomes characterized by C_3 shrubs and trees, and C_4 grasses like that of Eastern Africa. However, is not applicable at high altitudes, or regions dominated by C_3 grasses like winter-rainfall, Mediterranean climates of Northern and Southern African[73,74]. We include this additional feeding class category as it can provide valuable insight into shifts in past environments and dietary behaviors regarding the expansion of C_4 grasslands[20,21,43,50,75,76].

Archaeological and Geological Context

Archaeological context (**arch_context**) describes the specific context from which the sampled specimen was excavated, indicating a cultural layer or burial context when available. This also includes material provenience (**material_prov**), which is often a code unique to the research project that specifies the burial, level, trench, square, etc. Geological context refers to the sedimentary layers from which materials were originally recovered and represents the general characteristics of the rock (**lithology**) at the time of site occupation. This section assigns chrono-stratigraphic information (**ics_period**, **ics_epoch**, and **ics_stage**) to excavated materials as defined by the International Commission on Stratigraphy (ICS)[77] to standardize reporting across publications. In the case of modern materials, context is indicated as Holocene.

Chronology

Temporal data for individual samples in this database are largely dependent on stratigraphic or archaeological context. Date limits are provided in two formats: millions of years ago, mega annum (Ma) (**date_min_ma** and **date_max_ma**), as well as the upper and lower bounds of alternatively reported date intervals (*BC, AD, ka, cal BP,* etc.) As most of the Pleistocene dates included in this database are reported in Ma (**Figure 4**), these columns allow all entries to be synchronized to a single format regardless of the published notation. Dating and temporal boundaries were primarily acquired from additional sources, which are cited in the column identified **chrono_notes**. When possible, those original sources are cited within the datasets to provide full transparency of data and allow for easy updates if necessary.

Laboratory Methods & Analysis

This section includes description of the **pretreatment_technique**, the labs where samples were treated and analyzed, as well as the **instrument** used for analysis. The **lab_notes** column records notes from the original publication including cited methodological papers, whether pretreatment was conducted, or additional comments regarding the analysis. Some studies include seriated enamel samples or multiple distinct samples from a single specimen (e.g., a bulk enamel sample from and M2 and M3 in the same mandible). In this case, the number of distinct samples from a single specimen are reported in the **analytical_n** column. When multiple measurements were

combined to produce an average (e.g., multiple seriations on a single tooth), then the number of combined values is reported in the **average_n** column.

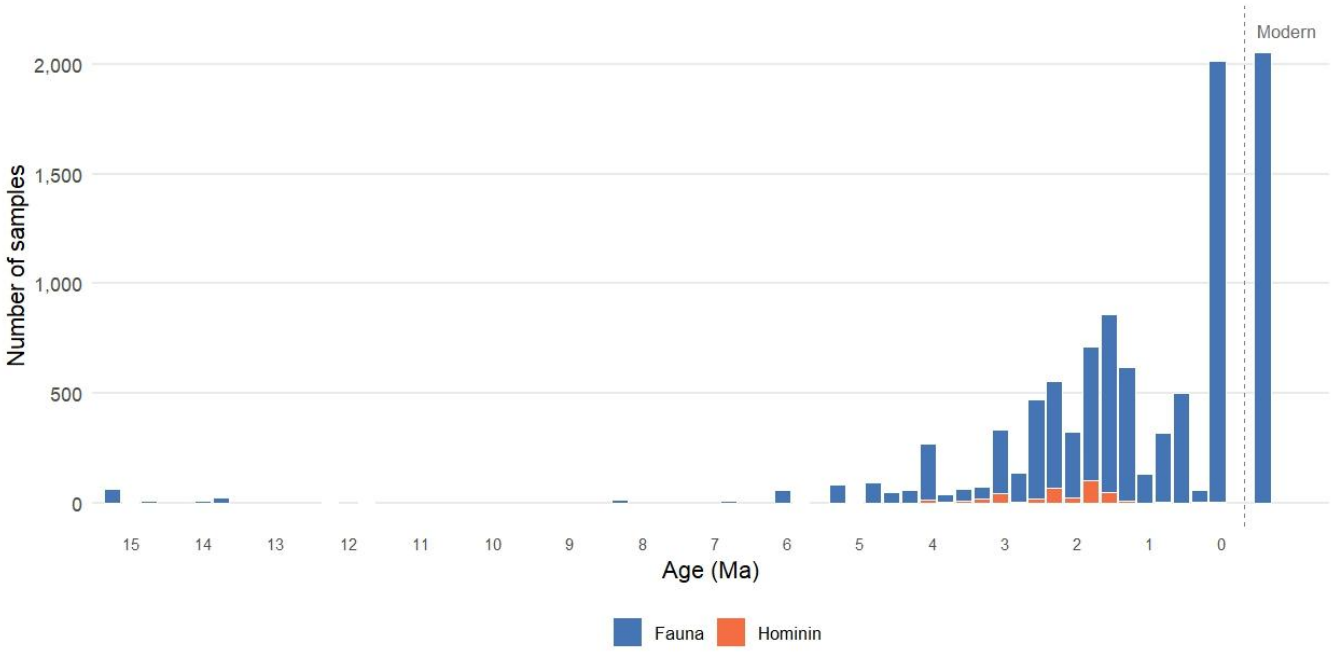


Figure 4: Distribution of average age of samples included in the faunal and hominin datasets. Modern faunal specimens are identified on the right and account for 18.9% of the collated data.

Isotopic Data

Isotopic measurements recorded in the hominin and faunal datasets include $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$. As mentioned previously, the *PleIStO Arch-AID* database differentiates between **specimen_ID** and **sample_ID**. Some publications report multiple isotopic measurements for a single sampled specimen, i.e., serial sampling. In many instances, serial sampling is carried out to interpret seasonality, dietary change, or migration during an organism's life[33,54,78–80]. Therefore, we include two columns **Sr_87_86** and **Sr_87_86_seriation**, to differentiate between $^{87}Sr/^{86}Sr$ ratio from bulk and non-seriated samples, and a single $^{87}Sr/^{86}Sr$ ratio within a sequence. Distinct seriation columns are also provided for $\delta^{13}C$ (**d13C_seriation**) and $\delta^{18}O$ (**d18O_seriation**) values as well.

Following best practices[63,81], measurements recorded in the datasets report $\delta^{13}C$ values relative to Vienna Pee Dee Belemnite (VPDB) standard notation for collagen and keratin samples (**d13C_org_VPDB**) and inorganic bone bioapatite and tooth enamel samples

(**d13C_inorg_VPDB**). Additionally, $\delta^{18}O$ values are reported in either Vienna Standard Mean Ocean Water (VSMOW) notation for carbonate (**d18O_carb_VSMOW** and **d18O_carb_SMOW**) and phosphate (**d18O_phos_VSMOW**) or VPDB standard for carbonates (**d18O_carb_VPDB**)[82,83]. All $\delta^{13}C$ and $\delta^{18}O$ included in the datasets are expressed in per mil (‰) standard notation.

Some articles report $\delta^{13}C_{1750}$ values, or an equivalent notation, to indicate measurements from modern samples where the isotopic values have been adjusted to account for the burning of fossil fuels since the onset of the industrial revolution, otherwise known as the Suess effect. Modern atmospheric CO_2 is thought to be depleted in ^{13}C by ~2.3‰[84], and therefore, values must be corrected to account for this discrepancy. However, some studies[21,48,49,85,86] included in the *PleIStO Arch-AID* datasets have used ~1.5‰[87] as a standard as the values have been rapidly changing over the course of the last five decades. When available, the **d13C_1750_VPDB** values are provided in addition to $\delta^{13}C$ VPDB values.

References

The final section of the *PleIStO Arch-AID* datasets provides information on the original publication where the data was retrieved. This includes the **in_text_citation**, **publication_year**, **complete_reference**, and the **doi** hyperlink to the online publication. Finally, this section contains a **comments** column for additional information regarding the original data, citations for updated publications, and notes regarding additional articles that have included the data as supplemental information.

Dating Events

Due to the broad temporal range encompassed by the Pleistocene, direct dating of sampled faunal and hominin materials is rare. Therefore, the **Dating Events** dataset assembles direct dating methods used for samples recorded in the faunal and hominin isotopic datasets. Similar to the isotopic data sets, each entry receives a **dating_id** (e.g., *DTE00001*). The **unique_id** corresponds to the original persistent identifier entry from the isotopic datasets, which will allow the isotopic tables to be joined to the **Dating Events** tables.

Information reported in the absolute dating section includes the method, laboratory identification code, protocol, material description, and uncalibrated dates. The following section

provides data regarding the various corrections and calibration required for radiocarbon dating, uranium series, electro spin resonance (ESR), optically stimulated luminescence (OSL), and thermoluminescence (TL).

The relative dating section includes information on how samples were dated. Samples in these datasets were mostly bracketed stratigraphically e.g., between two Ar/Ar dated volcanic tuff layers. When necessary, additional sources are referenced to identify the dating methodology.

Data are only included in the **Dating Events** dataset, if also reported in the original article that reports the isotope data. Such reporting is rare for absolute dating, as most publications in this database cite the original dating studies rather than conducting new analyses.

Data Records

To date, *PleIStO Arch-AID* contains 21,649 measurements from 10,794 individual data entries from published sources. The complete faunal and hominin datasets are available in .xlsx ('pleistoarch_fauna_v.1.xlsx') and .csv ('pleistoarch_fauna_v.1.csv') format through the *PleIStO Arch-AID* community within the Pandora Initiative data platform.

Technical Validation

Reported isotopic data were cross referenced for duplicate sampling. When isotopic values cited in the Supplementary Information (SI) of a compilation study originated from an earlier publication, data from the original article were sourced and referenced accordingly. If those data fell outside the temporal scope of this database, they were designated as comparative samples in the SI of a Pleistocene-based study to clarify their inclusion. However, no data outside the African continent was included in these datasets.

A major issue for synthesis of isotopic research is the consistent reporting of preservation criteria and quality control parameters. As previously mentioned, the *PleIStO Arch-AID* isotopic datasets include a preservation criteria and quality control parameters section (**Figure 3**), which includes reporting on collagen yield, %C, %N, and atomic C:N ratios from analysis of collagen samples. Currently, the datasets do not include any bone collagen data, as bone collagen from the Pleistocene is less likely to preserve and is generally more susceptible to post-depositional diagenetic processes than tooth enamel[88,89]. Therefore, measured $\delta^{13}C$ and $\delta^{18}O$ values of tooth

enamel are more common for studies of the African Pleistocene. Nonetheless, we have incorporated these quality control parameters into the dataset in anticipation of future research.

We have additionally included quality control and measurement columns for neodymium ($^{143}Nd/^{144}Nd$) and various lead isotope systems ($^{20n}Pb/^{204}Pb$) in preparation for later updates to include sediment and geologic datasets. For $^{87}Sr/^{86}Sr$ values, some articles report Sr ppm as a quality parameter, and Sr/Ca ratios are reported to determine diagenetic processes that may have introduced exogenous Sr. Samples that do not meet quality control standards will still be included in the repository but indicated as not meeting standards with a pass/fail designation in the **quality_test** column.

Usage Notes

At present, the *PleIStO Arch-AID* data repository encompasses isotopic data from 75 references[6,15,17–52,54,57,75,85,86,90–121]. This repository is intended, not to replace original studies, but to collate published data and serve as a tool facilitating synthesis across isotopic studies. The *PleIStO Arch-AID* datasets are designed for use alongside the Holocene isotopic data stored in the *AfriArch* repository on the Pandora platform[68,69]. To facilitate this linkage, the metadata includes a "Related to AfriArch" column that specifies corresponding data fields between the two repositories. The data included in the *PlIStO Arch-AID* repository is limited to mainland Africa, however, the *IsoMad* repository[71] provides isotopic datasets from the island of Madagascar.

Potential uses of the *PleIStO Arch-AID* datasets include regionally based studies of environmental isotope analyses to assess diachronic changes and ecological responses to climatic oscillations. These datasets provide both archaeological and modern isotopic data which allows for modern comparisons to address need for baseline corrections. These datasets also facilitate synthesis of interregional isotopic studies throughout the Pleistocene to assess potential shifts in subsistence behavior over time. The lead authors are currently preparing a complementary analytical manuscript that uses the collated data within the *PleistoArch-AID* database, together with tools available through the Pandora platform, to examine continental-scale patterns in dietary behavior across Africa through time.

Code Availability

The Pleistocene Archaeology – African Isotope Database (*PleIStO Arch-AID*) data community is available on the Pandora platform and is a member of the IsoMemo network of isotopic repositories. More information on the *PleIStO Arch-AID* Pandora data community can be found here: https://www.doi.org/10.48493/b67d-jc56[122].

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Author Contributions

S.M.F. and G.M.B. oversaw the collection of isotopic datasets, while S.M.F., G.M.B., A.L.N., and K.B.W. carried out data entry. G.M.B. and S.W.H. designed metadata structure. S.M.F. and G.M.B. designed the study. S.M.F. created figures and tables. S.M.F. and G.M.B. wrote the paper. R.F. is the director of the Pandora and IsoMemo initiatives and oversees data management. All authors provided updates to the repository and feedback on the manuscript.

Competing Interests

The authors declare no known competing interests.

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