

Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our [Editorial Policies](#) and the [Editorial Policy Checklist](#).

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a Confirmed

- | | | |
|-------------------------------------|-------------------------------------|--|
| ☐ | ☒ | The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement |
| ☐ | ☒ | A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly |
| ☐ | ☒ | The statistical test(s) used AND whether they are one- or two-sided
<i>Only common tests should be described solely by name; describe more complex techniques in the Methods section.</i> |
| ☒ | ☐ | A description of all covariates tested |
| ☐ | ☒ | A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons |
| ☐ | ☒ | A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals) |
| ☐ | ☒ | For null hypothesis testing, the test statistic (e.g. F , t , r) with confidence intervals, effect sizes, degrees of freedom and P value noted
<i>Give P values as exact values whenever suitable.</i> |
| ☐ | ☒ | For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings |
| ☒ | ☐ | For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes |
| ☒ | ☐ | Estimates of effect sizes (e.g. Cohen's d , Pearson's r), indicating how they were calculated |

Our web collection on [statistics for biologists](#) contains articles on many of the points above.

Software and code

Policy information about [availability of computer code](#)

Data collection Microsoft Excel 2021

Data analysis All software packages used for analysis are cited the Methods section and all used package are publicly available:
Mimics17.0, Avizo7.0, ParaView5.6.0, Deformetrica4.3, R4.4.0 and 4.1.0, RStudio IDE2.6.8, and Tilia2.1.1.
OSF: <https://doi.org/10.17605/OSF.IO/PFWNR>

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio [guidelines for submitting code & software](#) for further information.

Data

Policy information about [availability of data](#)

All manuscripts must include a [data availability statement](#). This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our [policy](#)

The raw data used for analysis are available in Supplementary Information and can be accessed online via OSF at <https://doi.org/10.17605/OSF.IO/PFWNR>.

Research involving human participants, their data, or biological material

Policy information about studies with [human participants or human data](#). See also policy information about [sex, gender \(identity/presentation\), and sexual orientation](#) and [race, ethnicity and racism](#).

Reporting on sex and gender	N/A
Reporting on race, ethnicity, or other socially relevant groupings	N/A
Population characteristics	N/A
Recruitment	N/A
Ethics oversight	N/A

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see [nature.com/documents/nr-reporting-summary-flat.pdf](#)

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Human fossils, cultural remains, chronology, and palaeoenvironmental analyses of Bianfu Cave in Yunnan, southwestern China
Research sample	Archaeological samples include seven hominin fossils, 1,366 stone artefacts, 10 bone tools, rich faunal remains (including 1654 identifiable animal bone fragments). In addition, 20 U-series dating samples (including two samples collected from human teeth, one from human limb bone, and one from human skull fragment), 12 optical dating samples, and eight pollen samples were collected for analysis.
Sampling strategy	Three trenches (T1–T3) were established following the cave topography. Cultural deposits and fossil remains were preserved only in T2. All archaeological materials analysed in this study were excavated from T2. Excavation was conducted in spits of 5–10 cm within each lithologically defined layer. All sediments were dry-sieved and recorded using a 1 × 1 m grid system. Excavation documentation included systematic photography, real-time kinematic (RTK) recording of three-dimensional coordinates, measurements of artefact orientation (strike, dip direction, and dip angle), and three-dimensional modeling of excavation surfaces using Agisoft Photoscan. Aerial photography was employed to generate ortho-images of the site and surrounding landscape. Chronological and environmental samples were systematically collected for optically stimulated luminescence (OSL) and uranium-series (U-series) dating, as well as for pollen analysis.
Data collection	Dental metric data from human fossils were collected using a sliding calliper. High-resolution three-dimensional imaging data were acquired using a 225 kV micro-computed tomography (μCT) scanner with an isotropic voxel size of 30 μm. Comparative μCT datasets for Neanderthals and fossil Homo sapiens were obtained from the NESPOS database and the European Synchrotron Radiation Facility (ESRF). Stone artefacts were measured using digital calipers, electronic scales, and goniometers. Zooarchaeological and bone tool data were collected through macroscopic and microscopic examination, including high-resolution surface imaging using a Laowa Ultra Macro 25 mm F2.8 lens and morphometric measurements obtained with a digital calliper. Optical dating data were derived from quartz grains extracted from sediment samples and measured using single-grain optically stimulated luminescence on a Risø TL-DA-20 reader equipped with a 532 nm laser and a calibrated ⁹⁰ Sr/ ⁹⁰ Y beta source. U-series data were obtained from carbonate flowstone samples and bone powder drilled from hominin tooth roots and analysed using multi-collector inductively coupled plasma mass spectrometry (Thermo Fisher Neptune MC-ICPMS).
Timing and spatial scale	The excavation was conducted in 2019, and the data collection was continued carried out during 2023 and 2024. The data were taken from the Heqing County, northwestern Yunnan Province, China
Data exclusions	No data was excluded during the study
Reproducibility	All primary analyses reported here are fully reproducible: the raw data, analysis code, and a documented workflow guide are archived in an OSF repository, allowing independent researchers to regenerate all main results.
Randomization	Randomization was not relevant to this study

Blinding

Blinding was not relevant to this study

Did the study involve field work?

☐ Yes☒ No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

- | | |
|-------------------------------------|---|
| n/a | Involved in the study |
| ☒ | ☐ Antibodies |
| ☒ | ☐ Eukaryotic cell lines |
| ☐ | ☒ Palaeontology and archaeology |
| ☒ | ☐ Animals and other organisms |
| ☒ | ☐ Clinical data |
| ☒ | ☐ Dual use research of concern |
| ☒ | ☐ Plants |

Methods

- | | |
|-------------------------------------|---|
| n/a | Involved in the study |
| ☒ | ☐ ChIP-seq |
| ☒ | ☐ Flow cytometry |
| ☒ | ☐ MRI-based neuroimaging |

Palaeontology and Archaeology

Specimen provenance

Permission was granted to Qijun Ruan from the Yunnan Provincial Institute of Cultural Relics and Archaeology.

Specimen deposition

Yunnan Provincial Institute of Cultural Relics and Archaeology, Kunming, China

Dating methods

Both optical and U-series dating were applied in the study. Full analytical procedures and age calculations are provided in the Methods section and Supplementary Information.

☒ Tick this box to confirm that the raw and calibrated dates are available in the paper or in Supplementary Information.

Ethics oversight

The study of hominin fossils and cultural remains were approved by Yunnan Provincial Institute of Cultural Relics and Archaeology and the researchers from this institute have been affiliated.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Plants

Seed stocks

N/A

Novel plant genotypes

N/A

Authentication

N/A