Grain Boundary Characterization and Interconnected Porosity in Stalagmites: Implications for Fluid Inclusion-Based Paleoclimate Reconstructions

Afonso, Camille

As stalagmites form, microscopic droplets of water can be trapped in the calcite crystal fabric, leading to the formation of fluid inclusions. Enclosed at the same time the surrounding calcite fabric precipitates, the water retains its original composition and physical characteristics, enabling investigations on their formation conditions. Paleotemperature reconstructions are thus made possible using inclusions in stalagmites. However, the reliability of these analyses can be affected by post-entrapment processes (e.g., diagenesis, diffusion reactions, fracturing), which can impact initial equilibria and (partly) reset the system to post-formation conditions.

The presence of interconnected porosity at the nanoscale could induce slow capillary diffusion between fluid inclusions and potentially reaching all the way to the surface of the stalagmite, connecting the inclusions to the cave environment. Such diffusion might promote partial to full re-equilibration of the chemical and/or physical properties of the fluid inclusions over geological timescales, ultimately affecting the interpretation of fluid-inclusion microthermometry, stable isotopes and noble gases.

In this study, we target the (sub)crystal boundaries as fluid inclusions mainly form along the (sub)grain boundaries, i.e., they are inter-crystalline. Multiple analytical approaches are combined to investigate the existence and characteristics of nanoscale porosity.We first apply polarisation microscopy, Scanning Electron Microscopy (SEM), Cathodoluminescence (CL), Electron Backscatter Diffraction (EBSD), and Confocal Fluorescence Microscopy to preliminary characterise the macro- and microscopic stalagmite crystal structure, as well as the distribution of fluid inclusions and organic matter.

Transmission Electron Microscope (TEM) analyses performed at the University of Pannonia, Hungary, have revealed the presence of nanoscale porosities located along (sub)grain boundaries and crystal growth surface in selected samples. These initial findings support the hypothesis that interconnected porosity exists and may facilitate slow diffusion between inclusions. The final objective will be to quantify these porosity networks and develop a simple diffusion model to assess their potential impact on the reliability of paleoclimate reconstructions.

Speleothem-Based Climate Monitoring in the Karst System of Southern Republic of Congo: Insights from Mbelo 1 Cave

Bazebizonza Tchiguina, Nicy Carmel

This study investigates the karst system in the Southern Republic of Congo, focusing on the Neoproterozoic carbonate rocks of the West Congo Belt foreland. Cave monitoring, including continuous temperature measurements and stalagmite coring, provides novel insights into environmental changes. Data from 2023-2024 reveal a shift in seasonal patterns, with the rainy season extending into june and the dry season lasting from June to September. These findings suggest a progressive shift in local climate cycles, marking a first step toward long-term subterranean climate monitoring in the region.

Speleothem Records in Northern Tunisia Caves: Paleoclimatic Reconstruction Since the Last Glacial Maximum

Ben Hamida, Sahar

The project "Paleoclimatic Reconstruction of Northern Tunisia through Speleothem Records" aims to conduct a multidisciplinary study of stalagmites to reconstruct the climate variability since the last Glacial Maximum. Indeed, this North African zone has experienced highly contrasting climatic periods, ranging from wet to very dry conditions on various time scales. The consequences for the evolution of past and current human cultures are significant. Although the causes of these variations are partially known (orbital factors, atlantic oscillations), uncertainties remain regarding interactions with lower and higher latitudes, as well as the origin and nature of current trends (increasing droughts, anthropogenic or natural causes). The selection of Tunisia for this study is due to its well-distributed karstic regions and the efficiency of speleothems as paleoclimatic archives, offering precise dating and decipherable climate signals. The identification of speleothems during various speleological surveys conducted in tunisia has led to the selection of three caves : Kef Sassi cave (Joumine, Jebel Antara), Kef Tout cave (Nefza, Jebel de Douimis), and Mine cave (Oueslatia, Jebel Serj). Placed within their morphostructural and morphoclimatic framework, carbonate concretions remain reliable archives for recording paleoclimatic variations through isotopic measurements of oxygen and carbon ($\delta^{13}C$ and $\delta^{18}O$) in calcite. The results of these markers, combined with dating methods such as U/Th conducted on calcite and/or $\delta^{14}C$, allow the reconstruction of climate evolution within continents.

Interglacial Environmental Changes in the Permafrost Region of Northern Mongolia

Box, Maria

Mongolia's long-term climate history remains poorly understood, hindering efforts to understand the forcings behind the recent rapid warming of its climate and subsequent permafrost loss. Using speleothems, we have reconstructed a timeline of permafrost degradation in northern mongolia over the past 500,000 years and offer new insight into the environmental conditions that contribute to permafrost vulnerability in this sensitive region.

Preliminary investigation of flowstones from Cueva Victoria, south-eastern Spain, by CT imaging and microthermometry

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Cueva Victoria is located in the semi-arid region of southeastern Spain near Cartagena, one of the driest regions in Europe, with annual precipitation averaging just 200-300 mm and pronounced seasonality. The cave is hosted in Triassic dolomites and limestones of the Alpujarride Complex (part of the Inner Betic Cordillera, where karstification has enabled the development of extensive cave systems and flowstone formations) (Gibert et al., 2016). Cueva Victoria offers a unique speleothem archive, which has been shown to be sensitive to past climate change.

Previous research has established robust flowstone chronologies for the last ca. 450,000 years, using ^{230}Th/U dating via multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS). These results indicate that speleothem growth occurred predominantly during past interglacial periods, reflecting phases of enhanced regional moisture availability (Budsky et al., 2019).

As part of a preliminary collaboration with the University of Bergen, we aim to expand the potential of these speleothems as climate archives through high resolution X-Ray computed tomography (CT) imaging. This non-destructive technique will allow us to identify and visualize internal structures and zones enriched in fluid inclusion (du Preez et al., 2018). These zones will be targeted for microthermometric analyses of inclusion water with the aim of extracting direct paleoenvironmental information, such as formation temperature and humidity (Krüger et al., 2025). Although CT and fluid inclusion techniques have been applied to speleothems in other global contexts, this represents a novel application for the Cueva Victoria speleothem archive and one of the first in a semi-Mediterranean cave system.

This preliminary work provides the foundation for developing an advanced, multi-proxy paleoclimate archive in a region, where precisely dated high-resolution terrestrial climate records are still rare. The integration of structural and geochemical methods will significantly enhance the paleoclimate value of speleothems and improve our understanding of past climate dynamics in the western Mediterranean region — an area highly sensitive to hydroclimatic change.

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What can Stalagmite Strontium Isotopes tell us about Chinese Monsoons in the Time of Super-Volcanoes?

Burnham, Andrew

The youngest Toba super-eruption ~74 kyr BP was the largest volcanic eruption of the quaternary period. This eruption took place at the end of mis 5a and has been hypothesised as a major contributor to the shift to mis 4. Using a highly resolved record of Sr isotopes (obtained by la-icp-ms) in the well-dated xt5 stalagmite from the southeastern clp, we can see how climate changed during the 10 kyr period (80-70 kyr BP) spanning the ytt event. We discuss the agreement of Sr isotope data when compared with existing palaeo-monsoon proxy data in C and O stable isotopes, as well as statistical

identification of changepoints, and whether the YTT eruption had a major long-term influence.

Speleothem Isotope Record in Eurasia: Implication for Neanderthal Extinction

Cheli, Giulia

The extinction of Homo neanderthalensis occurred in Eurasia around 42 ka. Among the possible causes, the role of climate needs further studies. This work presents $\delta^{18}O$–$\delta^{13}C$ data from two stalagmites (Ag1 and Zak9) collected in Agios Georgios (Greece) and Zakariaskldee Cave (Georgia) caves, deposited from 57.7 ± 0.24 to 12.1 ± 0.36 ka and Zak9 between 84 ± 0.31 and 34.6 ± 0.53 ka respectively. Both records present a possible hiatus between 45 and 35 ka, matching with he 4. These novel high-resolution records are discussed in the context of eurasian paleoclimate and neanderthals population dynamics.

Three Hundred Thousand Years of Multi-Millennial Hydroclimate Change in Northern Africa, Insights from Tunisian Speleothems

Chung, Yun-Chuan

Hydroclimate changes in Northern Africa reflect the interplay between mid-latitude westerlies and the west African monsoon, along with their intensity variations. The response of these atmospheric circulation systems to changing boundary conditions and their impacts on the precipitation during past episodes of climate change remain unconstrained, because of scarcity of well-dated terrestrial hydroclimate records from Northern Africa that reach beyond the Holocene interglacial. We present a 300,000-year hydroclimate record inferred from periods of speleothem formation from Tunisia, located in the northernmost Africa. This record captures the alternation of humid and arid phases during glacial and interglacial climate states, as well as the superimposed millennial-scale events. Humid conditions prevailed during the interglacial periods, while arid conditions were associated to glacial boundary conditions. Cave evidence suggests that these humid phases in northernmost Africa could mainly be attributed to the southward shift and strengthening of the mid-latitude westerlies and the mediterranean storm track during interglacials, and vice versa in glacials. A combination with palaeolake records in the Sahara suggests that the interglacial moisture sources from winter westerlies and the summer west African monsoon are critical hydrological contributions in the central and southern regions of northern Africa.

Automating Lamina Analysis in Annual and Sub-Annual Aragonite Stalagmites using Contrast-Enhanced Image Processing

Dildi

Speleothem laminae serve as valuable archives of past climate variability, preserving seasonal to decadal environmental changes. However, traditional methods for counting and measuring lamina thickness remain time-consuming and subjective, limiting their reproducibility in paleoclimate studies. This research presents an automated python-based image processing approach for lamina detection and thickness measurement, improving efficiency and accuracy. To evaluate its feasibility, we first develop this technique and test it on a set of annual laminated and sub-annual aragonite stalagmites from Meghalaya, India, where growth layers reflect monsoon variability. The approach integrates contrast enhancement

techniques, including adaptive histogram equalization (clahe) and edge sharpening, to optimize lamina visibility before applying contour-based segmentation. Additionally, polarized light microscopy (plm) is used to assess mineralogical variations and validate that detected layers correspond to primary depositional features rather than diagenetic overprinting. By comparing results across different stalagmite samples, we assess the method's applicability for both annual and sub-annual laminae and its potential for extracting climate-driven growth patterns. If successfully implemented, this technique could be extended beyond speleothems, offering a standardized approach for other natural archives such as tree rings and varved lake sediments, where layer thickness reflects past environmental conditions. Attending the s4 speleothem summer school will provide an opportunity to refine this methodology through discussions with experts in proxy development, stable isotope analysis, and computational techniques. By integrating automated image processing with contrast-based imaging, this study aims to advance reproducible and standardized digital techniques for lamina-based paleoclimate reconstructions.

Palaeoclimate Studies In Parts of Nigeria

Egesi, Ndukauba

The distribution of karst of the Mfamosing limestone has been obtained by extensive surface and subsurface geological exploration for cement production and speleothem studies. Caves have been identified at Etankpini, Mfamosing, Ewen, and Nyong areas but the stalagmites are dry and only drips during the rainy season. This may be due to thickness of limestone or the mineral composition because the area receives high annual rainfall.

Hydrochemical Drivers of Bimineralic Rafts in Hypogenic Lakes Within a Coastal Cave in Mallorca (Western Mediterranean)

Entrena, Ana

Carbonate rafts are an underexplored type of speleothem that develop at the air–water interface in calm bodies of water such as cave lakes, gours, and ponds, primarily as a result of CO_2 degassing. These thin and flat speleothems remain buoyant due to surface tension but eventually sink either upon reaching a critical mass or when the water is physically disturbed. Calcite is the predominant mineral phase in most rafts, aragonite is rare, and the coexistence of both minerals in the same raft is exceptionally uncommon. This study examines the physicochemical characteristics of the water associated with the rare occurrence of bimineralic calcite-aragonite rafts currently forming on the surface of hypogenic lakes with brackish waters inside Cova Dets Ases, a coastal cave in Mallorca (Western Mediterranean) carved into Miocene calcarenite materials. The physicochemical parameters measured include pH, temperature, total dissolved solids (tds), conductivity, partial pressure of CO_2, along with water sampling to analyze variables such as the Ca/Mg ratio, alkalinity, and Cl^- and SO_4^{2-} concentrations. Raft samples were collected concurrently with the water and environmental measurements to assess the relative abundance of each polymorph. Specifically, the hydrochemistry of the lakes in these coastal caves appears to be primarily influenced by the mixing of freshwater and seawater. This mixing ratio, together with the CO_2 degassing from the lake water, seems to play a key role in the precipitation of carbonate rafts. Notably, the dominant bimineralic composition appears to be strongly influenced by a specific range of the Mg/Ca ratios in the waters. These conditions facilitate the precipitation of both polymorphs, and their proportion in the samples depends on slight variations in this ratio as well as on other factors such as the oversaturation degree and the CO_2 degassing rates.

Late Pleistocene High Resolution Speleothem Record from the Philippines provides Insight Into Southeast Asian Monsoon Dynamics

Geraldes Vega, Monica Margarita

Climate teleconnections between the ITCZ, the Asian Monsoon system, and other influences on hydroclimate over the IPWP region are poorly understood. A 1.26m, late Pleistocene, ~24kyr speleothem $\delta^{18}O$ record from se Philippines shows inconsistent precipitation responses to abrupt climate change. $\delta^{13}C$ and trace elements are considered to evaluate precipitation amount vs moisture source changes. U-series ages reveal a fast growth rate (~7 year/mm). This tropical record from the Philippines spatially links previously published climate records from East and Southeast Asia, filling in important spatial gaps for published records across the IPWP.

Cave-analogue Experiments Advance Speleothem Proxy Research

Hambsch, Pascal

Speleothems are among the most extensively studied archives of past continental climate dynamics. Depending on the research question, scientists utilise (isotope) geochemical and petrographic proxies. While the petrographic features of speleothems, including mineralogy and crystal fabric, have been investigated to some extent, the direct relationship between dripwater geochemistry and the mineralogy and crystal fabric of cave carbonates remains a matter of debate. Previous studies indicate that various physicochemical parameters—such as pH, carbonate growth rate, drip rate, supersaturation, the Mg/Ca ratio of the fluid, and the presence or absence of organic matter—play significant roles in determining the mineralogy and crystal morphology of speleothems. One of the most influential factors affecting crystal fabric and mineralogy (specifically the ratio of calcite to aragonite) is the Mg/Ca ratio in the drip water. That said, in cave environments, Mg/Ca ratios in drip water can fluctuate over time and interact with a multitude of other parameters, adding to the complexity that characterises these archives. To address these complexities, a series of cave-analogue experimental studies were conducted, and the initial results are presented here. These experiments took place at 15 °C and 70% humidity within a climate cabinet under atmospheric co2 conditions. The experimental solutions were free of organic material, set to a concentration of 2.50 mm $CaCO_3$, and maintained a constant pH of 7.9. The drip rates on watch glasses within the climate cabinet were kept constant. The only variable changing between individual experimental designs was the Mg/Ca fluid ratio, set at 0.25 for the first experiment and 0.50 for the second. Each experiment lasted for 90 days, during which parameters such as temperature, humidity, CO_2 levels, drip rate, conductivity, pH values, and concentrations of elements in the outflow were carefully monitored and controlled.

Preliminary Evidence of the 8.2 Ka Event in Speleothem Records from Cueva Fantasma, Atapuerca (Spain)

Hasozbek, Altug

The 8.2 ka event, a major Holocene climatic anomaly linked to freshwater discharge into the North Atlantic, is well-recorded in ice cores but exhibits regional variability. This study presents preliminary evidence of the event from a speleothem in Cueva Fantasma (Atapuerca, Spain) using U-Th dating, geochemical proxies, and microstructural analyses. The speleothem spans 12.7–5.7 ka, with a

distinct transition at ~8.5 ka, marked by a shift from spar calcite to micritic calcite with black organic-rich laminae. Geochemical and microscopy analyses reveal sulfur- and carbon-enriched zones within these layers, indicating hydrological and environmental changes between 8.5 and 7.7 ka. While high detrital content complicates precise dating, the geochemical perturbations suggest localized environmental responses that warrant further investigation.

Laboratory-derived Partition Coefficients and Calcium Isotope Fractionation Factors for Speleothem Aragonite

Hollowood, Samuel

We provide partition coefficients for Ba, Mg, Sr, U and fractionation factors for Ca isotopes from stalagmite aragonite grown in controlled, cave-analogue conditions with measurements on solids and solutions, a first for speleothem aragonite samples. These partition coefficients and the calcium isotope fractionation factor have been added to the forward modelling tool cavecalcv2.0 to facilitate environmental reconstructions using aragonite speleothems.

Calibrating Stalagmite Stable Iisotope Records from West and Central Africa

Ilesanmi, Fatai

West and Central Africa's long-term climate dynamics remain poorly understood due to a lack of observational and palaeoclimate data. While stalagmites are valuable palaeoclimate archives, and karst landscapes are present across the region, no stalagmite records currently exist for west and Central Africa. Two National Geographic society-funded caving expeditions to Gabon in 2023 and 2024 yielded several stalagmites for palaeoclimate reconstruction. Current efforts are focused on calibrating these records using the global network of isotopes in precipitation (GNIP) dataset to enhance the interpretation of stalagmite isotope profiles. Monthly rainwater isotopes ($\delta^{18}O$, δD), temperature, and rainfall amount data from 30 GNIP stations across 12 countries in west, central, and southwestern Africa, compiled between 1961 and 2022 with record lengths ranging from 8 to 167 months (mean = 53 months) were studied. Eleven countries had at least one year of data post-2000. Spearman's rank correlation analysis ($\delta^{18}O$ vs rainfall amount) revealed a strong and significant amount effect at 66% of stations ($-0.87 \leq rs \leq -0.52$, $p \leq 0.05$). A significant temperature effect was observed at 60% of these stations ($rs \geq 0.5$, $p < 0.05$), with the temperature effect occurring over a narrower and more northerly mean latitudinal range (10°) than the amount effect (30°). All stations except Pout, Senegal ($rs = -0.62$, $p = 0.05$) show a positive $\delta^{18}O$ – temperature correlation, though only 1/3 of Senegalese stations exhibited a temperature effect. $\delta^{18}O$ - climate mode (AMO, NAO, IOD, ENSO) correlations revealed limited spatial coherence. Thirteen percent of stations showed a significant $\delta^{18}O$ – IOD correlation, but all were weak to moderate except Maroua, Cameroon ($rs = 0.6$, $p \leq 0.05$). Only 20% of stations with rainfall and temperature effects showed a significant $\delta^{18}O$-AMO correlation of varying strengths ($-0.52 \leq rs \leq -0.18$). A weak positive $\delta^{18}O$ – NAO correlation ($p \leq 0.1$) was observed at 17% of stations, with the strongest correlation at Luanda, Angola (2020-2021). A significant $\delta^{18}O$ – ENSO correlation of varying strength was observed at 17% of stations ($0.2 < rs < 0.56$). In Gabon, a strong amount effect and no temperature effect suggest stalagmites from this region should record long-term rainfall belt dynamics. Stalagmite $\delta^{18}O$ records may also weakly reflect IOD and ENSO. These findings will contribute to stalagmite isotope proxy interpretations and enhance the accuracy of models predicting future climate change.

Reconstructing Glacial Influence on a Limestone Landscape: Insights from My Malham Mapping Project

Khan, Amani

My independent mapping project explored how glacial processes shaped the sedimentary and structural features of the Malham limestone region. Using stratigraphic logging, petrography, and GIS mapping, I reconstructed the paleoenvironmental conditions and assessed how glaciation influenced post-depositional features in carbonate terrains.

Late Glacial to Holocene Stalagmite-Based Paleoclimate Record of Mountainous Environments in the Northern Levant: Insights from Qadisha Cave, Western Flank of Mount Lebanon

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The Eastern Mediterranean region, due to its geographical context on the arid/semi-arid boundary and its steep topography, is highly sensitive to hydroclimatic changes and therefore identified as a major climate hotspot by the IPCC's Sixth Assessment Report. The region hosts mature karstic landscapes which offers numerous natural archives for assessing past climates and environments. Particularly, paleoclimate studies based on vadose carbonate cave deposits have enable high-resolution reconstructions of paleoclimates at both local and regional scales, especially for the Late Glacial and the Holocene. However, the majority of speleothems originate from low-altitude environments, mainly from sites in the southern Levant. First, recent publications (Cheng et al., 2015) highlight discrepancies in paleoclimatic trends between the south and the north during the same period. Second, the available regional records cannot adequately reflect changes affecting mountainous areas, since high-altitude environments are more vulnerable to hydroclimatic variations. To address this knowledge gap, speleothems from Qadisha Cave, located on the western flanks of Mt. Lebanon (1720 m a.s.l.), have been studied with the aim of reconstructing paleoclimate trends since the Late Glacial. Three stalagmites (Qad3, Qad4, and Qad5), collected in 2014 and 2023, have been analyzed and dated, covering a period from 13,000 to 6,000 years BP. Variations in $\delta^{18}O$ and $\delta^{13}C$ along the growth axes (sampled at 1 mm resolution) are being investigated together with speleothem growth rates in order to evaluate climate variability in terms of general trends in humidity and soil activity during this time interval. The purpose of this poster is therefore to present the first insights from the ongoing research: composite isotopic curves and their potential paleoclimatic interpretation at a local geographic scale, considered in light of the current understanding of the regional paleoclimatic significance of calcite $\delta^{18}O$ in Mount Lebanon (Cheng et al., 2015; Nehme et al., 2023), the paleoenvironmental significance

of $\delta^{13}C$ in mid-latitudes (Genty et al., 2003), as well as within the geographical context of Mount Lebanon during the Holocene (Nader et al., 2007), and, finally, the assessment of the cave environment together with the study of recent calcite (the current study and Nehme et al., 2019).

Keywords:

Eastern Mediterranean; Mount Lebanon; Qadisha cave; Speleothems; Paleoclimate; Late Glacial; Holocene

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Extreme rainfall events recorded in stalagmites from Oman during the last two millennia

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Understanding human-climate interactions over the past two millennia is critical for arid areas like Oman, where water has been a valuable resource and has shaped societal resilience and adaptation strategies. Oman's unique geographical location, at the pathway of monsoonal activity, Mediterranean frontal systems and tropical cyclones, makes it an ideal area to investigate the links between climatic variability and extreme rainfall events.

During the last decades, Oman has been affected by several tropical cyclones, with the more recent Cyclone Mekunu in May 2018, which killed seven people and caused 1.5 billion USD in damage due to flash floods. Gathering information about tropical cyclone and flash flood activity in the past is needed to place present-day cyclone activity and flash flood frequencies into a meaningful historical context, and allow us to detect significant changes in their occurrence rates. The scarcity of historical and instrumental records in Oman highlights the need for a complementary record, such as stalagmites, which can serve as palaeoflood archives (e.g., Denniston and Lütscher, 2017). During flooding of caves, sediment and biogenic particles coat the stalagmite, thus creating distinct detrital layers, which are preserved as the stalagmite grows.

Here we present first results from two Uranium-series dated, actively growing stalagmites from Hoti Cave in northern Oman and Qunf Cave in southern Oman (Fleitmann et al., 2022) to explore the frequency of extreme rainfall events and their possible climatic drivers. Both cave systems are frequently affected by flooding (Al-Kindi et al., 2023) and the two stalagmites exhibit frequent detrital layers along their growth axes. Using digital image analysis of thin sections and high-resolution trace element profiles, we develop a precisely dated record of cave flooding related to tropical cyclones and regional heavy rainfall events over the last two millennia.

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Rapidly Growing Stalagmites from Curaçao Provide Insights into Modern Climate Controls on Tropical Speleothem Geochemistry

Lodge, Bethan

Here we present trace element (Mg/Ca, Sr/Ca, U/Ca) and stable isotope ($\delta^{18}O$, $\delta^{13}C$) data of a modern stalagmite from Hato cave, Curaçao, to investigate climate controls on speleothem geochemistry in the understudied Southern Caribbean—notably hotter and drier than the surrounding region. Developing an understanding of stalagmite growth histories and calibrating proxy records using modern climate data will lay the groundwork for developing older Holocene climate records from curaçao stalagmites that will contribute to a deeper understanding of climate teleconnections in the Southern Caribbean.

Towards a comprehensive record of interglacial climate variability in the tropics during the last 330.000 years

Mielke, Aaron

To better estimate the effects of current climate change on the vegetation and water cycle in highly diverse tropical regions, past interglacial periods of similarly warm climate conditions can provide unique insights of natural variety of different climate configurations and give us insight into the present. Several reconstructions of past interglacial periods are available, but most do not represent terrestrial and particular tropical regions. Speleothems offer a unique record of eco- and climate system changes and interactions across seasonal to millennial timescales, resolutions typically beyond the reach of climate model simulations.

This project aims to further close this research gap by investigating stalagmites from Cueva Larga, Puerto Rico. Cueva Larga is a well-monitored location, and speleothem records from this cave have demonstrated a high sensitivity to regional and global climatic variations, such as changes in the position of the ITCZ, Atlantic Sea Surface Temperatures, and ocean circulation.

Here we present the ongoing development of a comprehensive climate archive for the interglacial periods of the past 330,000 years. Precise 230Th/U ages of stalagmites collected during recent field campaigns pave the way for this effort, enabling detailed investigations of the periods from 8ka to modern (MIS1), 127–54 ka (MIS5), 229–190 ka

(MIS7), and 310–280 ka (MIS9). To this end, high-resolution time series of trace element, stable carbon and oxygen isotope (δ18O and δ13C values), and fluorescence measurements are being conducted. Since the archive will incorporate data from multiple stalagmites, adjusting for intra-cave variability, such as prior calcite precipitation and CO2 exchange, will be essential.

The resulting multi-proxy speleothem time series will allow us to improve the quantitative and qualitative understanding of vegetation changes as well as precipitation intensity and variability during past interglacial periods and will help to constrain both the sensitivity of the Earth system in the tropics to different climatic drivers and the extent of current climate change compared to natural variability.

The Dimba Cave, a Major Karst Geosite and a Heritage Site to Protect

Ngala Ntambwe, Nadège

The Dimba Cave (Mbanza-Ngungu, Kongo Central, DRC) is a major geosite of the Kongo Central karst, with significant scientific, educational, and cultural values. It features a remarkable underground network, notable for its morphology and speleogenesis. This geological setting makes Dimba a natural laboratory for understanding karst evolution in Central Africa.

The potential of this cavity was recognized early on: as far back as 1954, the Traveler's Guide mentioned it, and during the same period, archaeologists and biologists showed interest in it due to its exceptional archaeological deposits.

Dimba has yielded the longest known cultural sequence in the region, dated up to ~18,000 years BP, bearing witness to continuous human occupation and ritual practices associated with the ancient Kingdom of Kongo. The geological, biological, and archaeological values are inseparable: the preservation of material archives depends directly on the hydrogeological and sedimentary stability of the karst. This complementarity justifies the inclusion of Dimba and the nearby Ngovo cave on the UNESCO World Heritage Tentative List since 1997.

Recent studies highlight increasing pressures on the site's integrity. Tourist visits, which are still poorly regulated, cause physical degradation and alter the underground environment. Moreover, the use of the cave's water by local communities affects hydrogeological stability and increases the risk of pollution. A recent hydrochemical and ecotoxicological study (Mudinga et al., 2024) revealed worrying signs of chemical and microbiological contamination, confirming the vulnerability of the karst system and the threats to the quality of its archives.

These pressures pose a risk both to the quality of the paleocultural archives and to the subterranean ecosystem. Considering international recommendations on geoconservation, the Dimba Cave can be considered a priority geosite in the DRC.

Its management should include:

- A protocol for hydrogeological and hydrochemical monitoring;
- The establishment of a differentiated access zoning (scientific, touristic, sacred);
- The development of an educational and geotourism program based on scientific interpretation of the site;
- The active involvement of local communities to ensure sustainable conservation.

The Dimba Cave is one of the rare examples in Central Africa, where geological, archaeological, and cultural values are combined.in an unique way. Its recognition as a reference geosite represents a strategic opportunity to promote interdisciplinary research, strengthen geological heritage conservation, and support sustainable territorial development based on responsible geotourism.

Reconstructing Holocene Indian Summer Monsoon Variability Using Lacustrine Multi-proxy Data from Eastern India: Implications for Terrestrial Palaeoclimate Synthesis

Parhi, Arpita

The Indian Summer Monsoon (ISM) is an essential component of the global climate system. Its variability directly impacts agricultural productivity and water availability, significantly shaping the lives and livelihoods of the south asian population. Moreover, the intensity of the ism has also exhibited notable fluctuations in the past. To comprehend this variability, our research focuses on multi-proxy records of ~5m long core sediment obtained from Hansadanga lake in Eastern India, spanning the last ~12,190 cal yr BP. This is also a region with limited palaeoclimate records across the entire Holocene epoch. The multiproxy dataset from the lake includes the parameters like grain size, major and trace element ratios (Fe/Mn, Si/Al, Ti/Al, Mg/Al, Zr/Rb, Mg/Ca, Rb/Sr, Al/Ca, Ca/Ti), and environmental magnetism (χlf, χarm, χarm/sirm, χarm/χlf, sirm/χlf), supported by radiocarbon dating. The results reveal an increasing trend in ism intensity during the early Holocene, consistent with rising Northern Hemisphere summer insolation. Notably, the record captures several millennial to centennial scale weakening phases of the monsoon that align with major North Atlantic cooling episodes, including bond events 1 through 5. Among these, the 8.2 ka and 4.2 ka events are especially prominent in the dataset, both of which are characterized by marked geochemical, prevailing energy condition and magnetic shifts indicative of decreased precipitation, reduced sediment inflow, and decreased catchment weathering. While lake sediments provide information on hydrological and catchment responses, speleothems offer insights into monsoon intensity through high-resolution, precisely dated records of isotopic changes. Integrating these distinct yet interrelated archives is essential for improving spatial coverage, cross-validate climate signals, and unravel complex regional climate dynamics. Bridging insights from both lake sediments and speleothem records will be crucial to refine the understanding of monsoon variability and its global teleconnections during the Holocene, particularly in regions with limited palaeoclimate data coverage. Keywords: Indian Summer Monsoon (ISM), Holocene climate variability, bond events, terrestrial palaeoclimate archives, monsoon teleconnections, lacustrine.

Drip Water Isotope Variability in a Core Monsoon Zone Cave and Its Implications for Paleomonsoon Reconstruction

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Speleothems serve as valuable archives of past climate variability. Still, their reliability as paleomonsoon proxies depends on a thorough understanding of local cave hydrology and isotopic ratio changes from

precipitation to drip water to speleothem. This study presents the first cave monitoring investigation from the Core Monsoon Zone (CMZ) of India, focusing on Dandak Cave. We analyzed the stable isotopic composition ($\delta^{18}O$ and $\delta^{13}C$) of drip water collected during 2004 and 2005 from three distinct sites, each varying in ventilation and drip rate, aimed at evaluating how local conditions influence the $\delta^{18}O$ and $\delta^{13}C$ signatures of drip water feeding speleothem growth. The $\delta^{18}O$ values across all sites remained within analytical uncertainty, indicating minimal overprinting from site-specific effects. A Rayleigh distillation-based box model, applied using ERA5 reanalysis and Indian Meteorological Department (IMD) gridded rainfall data, was used to calculate the $\delta^{18}O$ of precipitation over Dandak Cave. The $\delta^{18}O$ of precipitation and drip water closely replicate, indicating that the oxygen isotopic signal of rainfall is well preserved. In contrast, $\delta^{13}C$ values showed significant site-specific variation influenced by drip rate and cave ventilation. Site 3, located deep within the cave and poorly ventilated, exhibited the clearest seasonal response, making it the most suitable for paleoclimate reconstruction and illustrating the complexity of carbon isotope behaviour in cave environments. Dead Carbon Contribution (DCC) in the speleothem was estimated using radiocarbon (^{14}C) content of actively growing speleothems and $\delta^{13}C$ values of soil organic carbon, bedrock, and speleothem, and a mass balance equation. Both methods yield more or less consistent results. This study highlights the importance of cave-specific monitoring in speleothem studies. The findings affirm the use of $\delta^{18}O$ as a robust proxy for paleomonsoon reconstruction in the CMZ and suggest that $\delta^{13}C$, when interpreted in context with local hydrology and ventilation, can serve as a valuable secondary proxy. These results underscore the importance of incorporating environmental context into speleothem-based paleoclimate studies in monsoon-dominated regions.

Age Constraints on Antarctic Ice-sheet Meltwater Pulses During the Last Interglacial Period

Passelergue, Maddalena

This project aims to constrain the timing of Last Interglacial (LIG) Meltwater Pulses (MWPS) using speleothems. Changes in atmospheric circulation related to MWPS will be identified by multiproxy analysis of australasian speleothems and dating via U-Th and synchrotron x-ray fluorescence lamina counting. Synchronisation between speleothem and Southern Ocean sediment data (which preserve direct mwp evidence) will produce a new well-constrained chronology of MWPS. This will be used to determine the conditions leading to mwps, which is crucial for evaluating ice-sheet models and future responses to global warming.

Morpho-sedimentary and paleoenvironmental evolution of Wadi Akka (Drâa Basin, Morocco) from the Recent Pleistocene to the Holocene

Saadi, Fatima

The fluvial evolution of southern Morocco during the Late Quaternary, particularly in non-Mediterranean basins such as the Akka wadi, a tributary of the Drâa, remains poorly documented. We present the first chronostratigraphic framework for the Wadi Akka formations, based on a high-resolution reconstruction of fluvial dynamics and paleoenvironmental changes since the end of the last interglacial period. The analysis follows a multiproxy approach, combining geomorphological, sedimentological, and geochemical data, and is supported by 13 radiocarbon and 4 optically stimulated luminescence (OSL) ages. Nine main stratigraphic units reveal alternating phases of aggradation, pedosedimentary stability, and

incision, associated with climatic fluctuations from Marine Isotope Stage (MIS) 5b (~82 ka) to the late Holocene. During MIS 3 (~40 ka cal BP), a low-energy hydromorphic environment prevailed, marked by fine sedimentation and soil development under relatively humid conditions. The early African Humid Period (11,400-9 700 cal BP) is characterized by fluvio-lacustrine settings, peat layers, and tufa deposits, indicating stable, wet environments. Conversely, arid phases are marked by significant incision and sedimentary hiatuses, particularly between 9 500-8 500 and after 6000 cal BP. Alluviation phases are also dated to around 7 200 and 656-579 cal BP. The presence of tuf deposits and travertine dams indicates peaks in humidity, especially during the beginning of Little Ice Age.

Keywords: Fluvial geomorphology, multi-proxy analysis, MIS 5b and MIS 3, Holocene, Akka Plain, Drâa Valley

Mean Annual Air Temperatures During Central Arabian Humid Periods Over the Past 8 Million Years

Schröder, Julian

Several archeological studies in the Arabian Desert revealed past periods of wetter and greener conditions that sustained human population on the Arabian Peninsula (eg. Petraglia, 2003; Bailey, 2009; Armitage et al., 2011; Bailey et al., 2015; Breeze et al., 2016; Groucutt et al., 2015; Bae et al., 2017; Crassard and Hilbert, 2013; Clark-Balzan et al., 2018; Parton et al., 2018; Scerri et al., 2018; Inglis et al., 2019; Stewart et al., 2020). Speleothem-based paleoclimate reconstructions of the Arabian Peninsula confirm the existence of short-lasting humid periods during interglacial phases in the late Pleistocene (Fleitmann et al., 2011, Nicholson et al., 2020, Markowska et al., in revision). While these paleoclimate reconstructions provide valuable qualitative insights into hydroclimate variability, quantifying the amount of precipitation during humid periods has remained challenging due to the absence of key climatological information. Particularly mean annual air temperature (maat) is a key component of potential evapotranspiration estimates and hence the overall regional water balance. In this study we have taken an existing late Miocene to late Pleistocene speleothem record (Markowska et al., in revision) to which we applied multiple newly developed paleothermometers: fluid inclusion isotopes and microthermometry, tex86, and dual-clumped isotopes. The data indicates that in the late Miocene and Pliocene, wet episodes in central arabia were up to ~4 °c warmer than current maats. The transition from Pliocene to late Pleistocene central Arabian humid periods is marked by a cooling trend towards modern maats of ~25 °C. These temperature estimates imply that potential evapotranspiration was significantly higher during the late Miocene and Pliocene as compared to the late Pleistocene. Based on the temperatures we calculated potential evapotranspiration and estimate realistic precipitation amounts for the humid periods in central Arabia.

Assessing different Glycerol dialkyl glycerol tetraethers (GDGT) distributions in Amazon rainforest speleothems

Silva, LPN[1,2]

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The Amazon Basin has emerged as a critical region for paleoclimate reconstructions, offering key insights into long-term climate variability and its implications for ongoing climate change. The characterization of organic matter preserved in cave minerals is essential for interpreting past land use and climatic changes. Nevertheless, reconstructions based on molecular organic proxies

remain scarce in this region. Among organic-based proxies, microbially derived lipids specifically branched and isoprenoid glycerol dialkyl glycerol tetraethers (brGDGTs and isoGDGTs) have recently been identified in speleothem deposits. These compounds can provide information on the relative contributions of terrestrial versus aquatic organic matter, soil pH, and air paleotemperature. The TEX_{86} index is a paleothermometer based on iGDGTs widely used and robust molecular indicator, enabling the development of independent temperature records. In this study, we analyze the GDGTs distributions in two speleothem records from the Amazon Basin: Paraíso Cave, located in the Brazilian Amazon floodplain, and Shatuca Cave, in the Peruvian Amazon. We apply the TEX_{86} index to produce new paleotemperature reconstructions and assess their potential as climate archives. Additionally, we address methodological challenges and preservation issues associated with the study of organic-based proxies in Amazonian speleothems and outline future research directions for advancing this field.

A Detailed Climatic Context for the Growth and Decay of Cretan Civilizations

Skoulikari, Dimitra

Located in the Eastern Mediterranean, Crete, Greece exhibits immense topographic, climatic, and floral diversity. Although the overall climate is considered typically mediterranean, ranging from subhumid to semiarid, with mild wet winters and hot dry summers, the island experiences a pronounced seasonal variation of precipitation and an east-west spatial gradient of precipitation leading to various microclimates due to its mountainous topography. Equally complex, crete's archaeological record spans ~9,000 years, from the early Neolithic (~7000 BC), and exhibits many cycles of societal growth, decay, and transition. Like in many other areas throughout the eastern mediterranean, societal collapse/decline is often linked to climate change. Despite its complex climatic and cultural history, crete lacks long-term, well-dated and high-resolution climate records and current interpretations of its past climate are primarily derived from paleoclimate data coming from the broader eastern mediterranean region. This highlights the need for locally derived climate records to better understand Crete's past climate variability and its impacts on past societies of the island. This project aims to produce a detailed paleoclimate record for Crete spanning the Holocene. Five stalagmites from three cave sites (Chainospilios, Sarchos, and Skotini) in western and Central Crete are being precisely 230Th-dated and analyzed using a multi-proxy approach. Coupling stable isotope ($\delta^{18}O$ and $\delta^{13}C$,), trace element, greyscale, and fluid inclusion analyses will allow for the identification of both local and regional changes in the hydrological cycle, and for the exploration of past vegetation changes, temperature, and drought episodes. By employing multiple proxies the achieved record will be comparable to other paleoclimate studies that have utilized stable isotopes in the wider region and will also provide a robust characterization of the local climate variability, shifts, and extreme events that are likely to have affected past societies on the island. Additionally, a detailed examination of the archaeological evidence available for crete, focusing on periods of significant cultural change, will be incorporated into the study to contextualize the past climate characteristics of crete and identified climate shifts and extreme climatic events within its cultural history.

Cryogenic cave carbonates from discontinuous permafrost: Mirichun cave (Eastern Siberia, Russia)

Steck, Maria Magdalena

Discovered in 2019, Mirichun Cave is situated in the central East Sayan Highlands of Eastern Siberia, Russia (54.07°N; 97.62°E). The region is characterized by a cold continental climate with a mean annual air temperature of approximately -6°C and falls within the discontinuous permafrost zone. Formed within Lower Cambrian limestone, the cave contains a notable Lower Gallery located at a depth of around 130 metres, which can be accessed via various shafts and chambers. Temperature in the Lower Gallery remain constant at 0.6°C, with ice patches present, suggesting current near-permafrost conditions in this part of the cave.

Cryogenic cave carbonates (CCC) were identified at two distinct levels: 45 m and 130 m below the surface. These formations occur as discrete patches covering areas ranging from several m² to several tens of m². The CCC display diverse morphological characteristics and range in size from sub-mm to several cm. First results of U-Th dating suggest that CCC formation in Mirichun Cave took place during late stages of interglacial periods (MIS 9, MIS 7, MIS 5e) and the early stages of glacial periods (MIS 5c-d).

This data from Mirichun Cave indicates that in regions currently experiencing or approaching permafrost conditions, such as the Eastern Sayan Mountains, CCC formation is associated with phases of permafrost expansion that followed significant thawing events during interglacial warmings.

Unravelling past hydroclimate changes across Australian drylands

Stevens, Kimberley

Dryland expansion driven by anthropogenic climate change is increasing the size of Australia's population exposed to droughts and bushfires. Accelerated expansion is expected under a projected decrease in mean rainfall across subtropical Australia (medium confidence) in response to the poleward shift of Southern Hemisphere westerlies (SHW) driven by anthropogenic warming (IPCC, 2022). In contrast, the poleward shift of SHW during the Last Glacial Period has been linked to increased rainfall and groundwater recharge at subtropical dryland caves, suggesting future hydroclimate dynamics may not be straightforward. Our ability to predict the hydroclimate impacts of future SHW displacement is limited by a lack of data on dryland groundwater recharge under atmospheric conditions analogous to future projections. This project aims to reconstruct groundwater recharge periods over the past 5 Ma using a precisely dated (U-Th and U-Pb) dataset of speleothems from a range of dryland regimes (dry sub-humid to arid). Reconnaissance dating of speleothem growth at the Cliefden, Naracoorte, and Nullarbor Caves highlights their potential to reconstruct groundwater recharge periods during the Holocene, Pleistocene, and Pliocene, providing the first reconstruction of Australian dryland hydroclimate that spans multiple ages and dryland regimes. Our results will provide insights into Australian dryland moisture source and boundary changes that can enhance confidence in future projections of dryland hydroclimate.

Extending the Utility of Clumped Isotopes to Assess the Microclimate of Different Caves

Subba, Rachana

Carbonate-clumped isotope thermometry (Δ_{47}) records carbonate formation temperature along with being a potent tool for identifying kinetic or disequilibrium conditions. The extensive cave systems of North-East India present an ideal experimental platform to verify the application of stable and carbonate-clumped isotope techniques for understanding the importance of factors like relative humidity and temperature which influence the cave's microclimate and in turn effect

the isotopic composition of speleothems. This study aims to disentangle the various processes governing speleothem $\delta^{13}C$, $\delta^{18}O$ and Δ_{47} values.

Using X-ray Fluorescence Analysis (XRF) For Speleothem Research.

Taimanov, Aleksandr

X-ray fluorescence analysis (XRF) has been used in various sciences. It allows to quickly determine the content of chemical elements in the object under study. The object can be speleothems, in the study of which the knowledge of the content of chemical elements in different layers becomes a key to numerous paleoclimatic data, such as temperature, humidity, etc. The authors show the possibilities of this method on the example of speleothems from under the village of Padovka, Samara region, using the bruker "M4 Tornado" unit.

Evaluating the drivers of Early Pleistocene Glacial-Interglacial Cycles by combining Speleothems and Ocean Sediment Records.

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During the Quaternary Period, Earth's climate oscillated about 50 times between glacial and interglacial states. The low-amplitude, 40-kyr pendulum of this sequence during the Early Pleistocene switched dramatically at around 1 million years ago – the Middle Pleistocene Transition (MPT) – when longer 100-kyr cycles became dominant. The cycle amplitude also increased at this time, and a more pronounced saw-tooth pattern to the cycles emerged. Several hypotheses have been proposed for the Early Pleistocene 40-kyr cycles, with recent work suggesting that insolation intensity in the Northern Hemisphere (NH) high latitudes, rather than the more typically presumed obliquity, triggered each termination. Notwithstanding this, determining the most important orbital parameter remains a problem due to uncertainties over the precise timing of these terminations. North Atlantic marine sediment records possess the best-preserved imprints of these terminations, but precise dating is lacking. Thus, there is a need to build paleoclimate proxy time series using precisely datable archives (such as speleothems) that preserve terminations and combine these series with ocean-core data to resolve phase comparisons with orbital/insolation metrics.

In this study, we compare speleothem data from the Corchia Cave (Italy) spanning Terminations XVII and XVIII with an ocean-sediment record for the same interval from site U1385 (Iberian Margin). The termination is well recorded at site U1385 via meltwater-driven changes in planktic-benthic δ18O and alkenones and is contained to between 1195 and 1190 ka according to the latest chronology. In the Corchia record, the termination-like response evident in the speleothem δ18O and δ13C occurs about 15 kyr earlier, highlighting the chronological uncertainties for ocean-sediment records of Early Pleistocene terminations. We synchronise the ocean record to the speleothem chronology and discuss the likely insolation forcing of T-XVII and XVIII in the context of prevailing theories of Early Pleistocene ice-age cycles. Our study highlights the important

role for speleothems in resolving the timing and forcing of glacial-interglacial cycles.

Keywords: Glacial termination, chronology (U-Pb), Early Pleistocene, speleothem, Corchia, Cave, Ocean-sediment records.

Indian Summer Monsoon Variability in Northeastern India During 722 to 1251 AD: Insights from Multiproxy Speleothem Records.

Verma, Yachna

The U-Th dated speleothem record from Bylliat Cave from Northeastern India (NEI), spanning 722 to 1251 AD (Anno Domini), offers valuable insights into Indian Summer Monsoon (ISM) variability during the dark ages cold period (dacp, ~400-900 AD) and the Medieval Climate Anomaly (MCA, ~900-1251 AD). The $\delta^{18}O$ record, corroborated by petrographic analysis, highlights significant sub-decadal to centennial-scale ism shifts. A pronounced reduction in precipitation is observed between ~722 and 890 AD, with an extreme drought event around 850-890 AD. The onset of the MCA (~890-980 AD) marks a period of intensified ISM, followed by a more stable trend. These multi-decadal to centennial scale ISM fluctuations are primarily driven by solar activity, influencing the Intertropical Convergence Zone movement, and teleconnections from Bay of Bengal and North Atlantic Sea Surface Temperatures. The sub-decadal ism variability in NEI is linked to El Niño Southern Oscillation, which drives contrasting ism patterns between nei and Central India. Spectral and cross-spectral analyses further confirm these diverse forcing factors. The study also notes significant correlation between socioeconomic changes of Eastern India-based Pala dynasty and ISM variability during the studied time frame.

Groundwater Isoscape of The Northern Guam Karst Aquifer System

Villareal, Maria

Freshwater security in Small Island communities depends heavily on understanding groundwater systems, particularly in karst settings like Northern Guam, a sole-source aquifer that supplies over 80% of the island's water. This study investigates the spatial variability of stable isotopes ($\delta^{18}O$ and $\delta^{2}H$) in groundwater to identify recharge sources, seasonal influences, and flow pathways within the island's karst aquifer. Groundwater samples from approximately 100 wells across Northern Guam will be used to develop an isoscape, to characterize spatial patterns of recharge and dynamics of coastal discharge. Beyond supporting groundwater management, the isoscape will provide a modern reference for interpreting stable isotope variations in speleothems, enhancing paleoclimate reconstructions in tropical karst settings.

Storminess and Flooding Reconstructions from Metamorphic Cave-Grown Speleothems on the West Coast of Scotland

Xie, Kang

Speleothems are not only valuable archives for reconstructing paleoclimate but can also witness climatic events including storms and floods. Two speleothems have been collected from nearshore caves on the islands of Jura and Islay, on the west coast of Scotland. The Jura Vave is ~62 km northeast of the one on Islay, yet intriguingly U/Th dating shows that both speleothems began to grow at ~2,400 yr BP. This simultaneous start in calcite deposition could be related to

relative sea-level change due to post-glacial isostatic uplift and/or to the onset of climate conditions that made the growth of the speleothem possible. Both speleothems have a fine-scale light-dark colour banding, possibly offering annual records of temperature and precipitation over millennial timescales. The dark layers in the Islay speleothem have higher (less negative) $\delta^{18}O$ values (-2.47 vs -3.73 ‰) and higher concentrations of Cl and Na (660.68 vs 429.27 ppm) compared to the white layers, which confirms that these dark layers formed in warmer conditions and contain seawater-derived ions. Coincidentally, Islay dark layers correlate well with storm events identified from the island's peat bogs only 5 km from the cave (Kylander et al., 2020). In addition, black layers in the Jura speleothem contain manganese oxides and are thought to be indicative of cave flooding (Belli et al., 2017; Gázquez et al., 2011). We therefore suggest that periodic changes to the chemical composition and oxygenation of dripwaters in the Jura and Islay caves reflect near-synchronous late Holocene storm events and associated sea flooding on the West coast of Scotland. Belli, r., et al. (2017). Investigating the hydrological significance of stalagmite geochemistry (Mg, Sr) using Sr isotope and particulate element records across the late glacial-to-Holocene transition.

Committee Members Abstracts:

A Monte Carlo PCA Approach for Speleothem-Based Hydroclimate Reconstruction

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We present a Monte Carlo Principal Component Analysis (MC-PCA) framework for extracting coherent hydroclimate signals from speleothem $\delta^{18}O$ records across hemispheric domains. This approach, modified from Wolf et al. 2023 explicitly incorporates an age model ($\pm2\sigma$) and analytical uncertainties ($\pm1\sigma$) using 2000 realizations of $\delta^{18}O$ time series per site, based on U-Th dating or band uncertainty ensemble modeling for high-uncertainty records. Speleothem records are smoothed, interpolated, and normalized to enable consistent PCA computation. PC sign-flipping and mode-mixing artifacts common in MC-PCA are resolved using k-means clustering, yielding robust estimates of principal components and explained variance. We apply this method to $\delta^{18}O$ records from India, the Mediterranean, and southern Africa/SW Indian Ocean spanning 1374–1962 C.E. Across domains, the leading MC-PC1 modes explain substantial portions of variance (e.g., 30-39% for India, 25-30% for Mediterranean and 40-50% for southern Africa), with site-specific loadings consistent with regional climate variability. Calibration of the Indian leading modes with instrumental rainfall data enables a high-confidence reconstruction of regional and local monsoon convection. This approach captures coherent hydroclimate variability at multi-decadal to centennial scales and the role of natural variability and anthropogenic forcing shaping the Indian Summer Monsoon, and its response to future warming.

Speleothems reveal staggered freshwater pulses shaped the Younger Dryas structure

Azennoud, Khalil; Ait Brahim, Yassine; Wassenburg, Jasper A.; Bouchaou**,** Lhoussaine Bouchaou; Cruz, Francisco W.; Cheng, Hai

The Younger Dryas (YD, ~12.9–11.7 ka BP) marked a sudden return to near-glacial conditions in the Northern Hemisphere. Resolving its timing, causes, and internal structure is key to anticipating future abrupt change. Most paleoclimate records lack the dating precision to distinguish between competing proposed mechanisms that may have initiated the YD and explain its intrastadial variability. We analyzed a subdecadally-resolved stalagmite from Morocco, whose chronology matches Greenland and Iberian benchmarks. The record reveals a W-shaped structure, best explained by two discrete freshwater pulses at ~12.74 and ~12.05 ka, each weakening the Atlantic ventilation (AMOC). Our data support the northwestward drainage scenario and freshening of the Arctic Ocean as the initial YD trigger. Superimposed 200-year solar cycle modulates rainfall through solar–atmosphere–ocean coupling. These findings show that staggered freshwater inputs and solar–atmosphere–AMOC interactions explain YD climate, and they underscore the need for future models to incorporate both pulses and solar forcing to reproduce the multicentennial-scale instability.

Late Pleistocene evolution of interglacial warmth in the Tropical West Pacific

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The Earth climate over the last 800 kyr is characterized by its typical 100 kyr glacial-interglacial cycles, featuring long glacial periods and short interglacial periods. At around 430 ka (ca. end of MIS 12), a fundamental change in the climate system took place, where the amplitude of the glacial-interglacial cycles has significantly increased with the interglacials experiencing more intense conditions (higher CO_2 and higher high-latitude temperature and/or lower ice volume) compared to the “lukewarm” interglacials before. This transition has been termed as Mid-Brunhes Transition (MBT; Yin, 2013), and evidence of this transition can be observed in various climatic archives (e.g. Barth et la., 2018). While tropical hydroclimate appears to be insensitive to the interglacial differences induced by the MBT (Meckler et al., 2012), precise temperature records especially from land are still needed to provide a more thorough insight into the response of tropical climate to MBT.

In this study we reconstruct tropical temperature from stalagmite GC08 from northern Borneo, which covers interglacial periods before and after MBT (MIS 13 and MIS 11). Three methods are used for the reconstruction: fluid inclusion microthermometry, fluid inclusion water isotopes, and GDGTs. Fluid inclusion microthermometry is often considered the most precise temperature proxy in stalagmites. However, preliminary measurements on GC08 show larger-than-expected errors. Our multi-proxy approach is designed to alleviate this challenge and may yield additional insights into proxy behavior.

The reconstructed temperatures will be compared to the previously retrieved calcite $\delta^{18}O$ data, as well as to other climatic records, such as atmospheric CO_2 concentration, high-latitude temperature and West Pacific Warm Pool Sea surface temperature. The study of these two

interglacial periods will be particularly important to better understand the response of tropical land temperature to greenhouse forcing.

Mineralogical and petrographical controls on Uranium-Thorium in-equilibrium dating of cave carbonates: Insights from speleothems of Northeastern and Central India

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Uranium–Thorium (U–Th) dating of cave carbonates is a key tool for resolving late Quaternary paleoenvironmental changes. Aragonitic speleothems generally provide more reliable U–Th chronologies than calcitic forms, as UO_2^{2+}—the dominant mobile uranium species in near-surface waters—adopts a more stable structural position in aragonite. Consequently, aragonitic speleothems often contain 5–10 times higher ^{238}U concentrations than calcitic counterparts, as documented in Indian karst systems. However, calcitic speleothems from Mawmluh Cave (northeastern India) and Sahiya Cave (northwestern Himalaya) exhibit anomalously high ^{238}U, likely reflecting uranium-enriched drip water sourced from epikarst soils. The precision of U–Th dating is primarily governed by the concentrations of ^{238}U, radiogenic ^{230}Th, and detrital ^{232}Th, which in turn are influenced by epikarst lithology, drip regime, detrital influx, and speleothem mineralogy and fabric.

This study presents U–Th chronologies, mineralogical data, and microfabric analyses of two speleothems: SYN-2 from Syndai Cave (NE India) and KC-1 from Kailash Cave (central India). SYN-2 exhibits a mineralogical transition from basal primary columnar calcite to acicular and ray aragonite, followed by late-stage vein-filling calcite. Older calcite layers show intense dissolution and micrite deposition. Of 15 dated layers, two are compromised by high detrital ^{232}Th, two by uranium loss via intercrystalline porosity in acicular aragonite, and one by uranium loss from aragonite-to-calcite transformation. KC-1 is entirely calcitic, with ^{238}U concentrations 40–50 times lower than aragonite-rich SYN-2, and shows a transition from basal columnar calcite to diagenetic dendritic and mosaic fabrics. U–Th dating of five layers reveals uranium loss in all but the oldest sample, attributed to diagenetic alteration and high microporosity, leading to stratigraphic age reversals.

The results confirm that aragonitic speleothems generally yield higher-precision U–Th dates than calcitic equivalents, yet both mineralogies can experience open-system behaviour during any depositional stage, as indicated by ($^{234}U/^{238}U$) activity versus ($^{230}Th/^{234}U$) activity systematics.

NAOi - WeMOi Balance as a Modulating Factor of Storm Tracks and $\delta^{18}O_W$ of Meteoric Precipitation within the Iberian Peninsula

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The isotopic composition of meteoric precipitation ($\delta^{18}O_w$) across the Iberian Peninsula reflects the integrated effects of large-scale atmospheric circulation and regional moisture source variability. However, disentangling the dominant drivers of $\delta^{18}O_w$ variability remains challenging due to the concurrent influence of both Atlantic and Mediterranean synoptic systems. Here, we propose that the *joint interaction* between the North Atlantic Oscillation Index (NAOi) and the Western Mediterranean Oscillation Index (WeMOi) exerts a first-order control on the isotopic characteristics of winter precipitation. To test this hypothesis, we propose a NAOi–WeMOi Balance Index, designed to capture the integrated influence of both atmospheric modes regardless of their sign or phase opposition.

Applying this index to winter (November–March) $\delta^{18}O_w$ records reveal a spatially coherent and statistically robust pattern of correlations, with coefficients exceeding 0.25 across most of the Iberian Peninsula and locally reaching 0.75. This enhanced coherence, compared to individual correlations with NAOi or WeMOi, indicates that the Balance Index acts as an effective descriptor of the composite atmospheric dynamics modulating storm-track trajectories and moisture advection. We interpret this relationship as the atmospheric imprint of alternating dominance between Atlantic frontal systems and Mediterranean retrograde incursions, which collectively determine the isotopic signal in meteoric precipitation. Our findings provide a physically consistent framework linking large-scale circulation modes with the isotopic hydrology of the western Mediterranean, offering new perspectives for paleoclimate reconstructions based on $\delta^{18}O$ records from speleothems and other continental archives.