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ABSTRACTS

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Session 1:

Geochronology: analytical improvements, novel approaches, and innovative age modelling

Speakers:

Denis Scholz
Georgina Luti
Christopher Kinsley

Keynote: John Hellstrom

Posters:

1. Nick Scroxton
2. Ellen Corrick
3. Carolina Silveira de Moraes

Linking the Greenland ice core and speleothem timescales during the last glacial using an annual layer-counting model

Denis Scholz

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The last glacial period was characterised by millennial-scale climate oscillations, the Dansgaard–Oeschger (DO) events. These events were recorded in Greenland ice cores and many other climate archives from the northern hemisphere. The ice core chronology (GICC05, Svensson et al., 2008) is based on annual layer counting and associated with relatively large uncertainties (maximum counting error of 2611 years at 60,200 years). Several studies systematically tested the synchroneity of the DO events in Greenland with more precisely dated speleothem records (Corrick et al., 2020) and also developed corresponding transfer functions (Adolphi et al., 2018; Muschitiello and Aquino-Lopez, 2024). However, these functions do not explicitly rely on the layer counting data of the GICC05 timescale.Here I present a Monte Carlo algorithm, which directly simulates the uncertainty of the GICC05 timescale using the published layer counting data. I use the algorithm to construct continuous transfer functions using the tie points of the aforementioned studies. This approach (i) enables to test the accuracy of both GICC05 and the speleothem chronologies, (ii) allows to quantify the probability of the individual ice core layers, and (iii) substantially reduces the uncertainty of the transfer function compared with previous studies.

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Petrographic classification of speleothems: a case study from the Cradle of Humankind, South Africa

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Speleothems are ubiquitous features of caves in the Cradle of Humankind (locally referred to as the Cradle). Dominantly composed of calcite and some remnant aragonite crystals, these deposits are interbedded with clastic sediments which host a rich collection of hominin, faunal and archaeological materials. The flowstones have laid the foundation for establishing a U-Pb based chronology for both the formation history of the caves and the important fossil materials they preserve. Here we aim to test whether speleothems from the Cradle represent an homogenous lithology, assess the presence/absence of diagenesis and identify whether similarities exist between the speleothems from different sites. We analyse flowstones (n=63) and stalagmites (n=4) from twelve caves across the Cradle, focussing on classifying their macro-fabrics and assessing if the proposed classification scheme holds for micro-fabrics. Five main categories are identified, based on the micro-fabrics, namely: macro-layered, micro-layered, detritally interbedded, rare (raft and microbially influenced) and diagenetic. Based on the characteristics of the fabrics, we identify the existing heterogeneity among speleothem samples and identify the influence of diagenesis on the extent of use of samples in climatic and chronological studies. Further, hand sample and petrographic analysis also support alternating deposition between speleothem and clastic deposits. The results presented here show that the cave sequences studied are conformable, with intrusive flowstones being rare. This work creates a foundation to test the validity of the Cradle speleothem fabric classification scheme using trace elements mapping, stable light isotopes and other proxies.

Application of IBIS [Integrated Bayesian approach for unique Initial thorium corrections and age-depth models in U-Th dating of Speleothems] to Hato Cave, Curaçao stalagmites

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Proxies recorded in speleothems offer insight into past patterns of rainfall and other components of the terrestrial climate system. For these records to be effective they must be accurately and precisely dated. Uranium-thorium (U-Th) dating is commonly applied to create chronological models for speleothems, including stalagmites, from present-day to ~650 ka. Making accurate and precise corrections for initial thorium (i.e., 230Th that is not a result of in-situ decay of uranium within the sample) can be the limiting factor in building robust speleothem age models. Two methods are broadly used to correct for initial thorium: (1) direct estimation using isochron techniques; or (2) assuming a constant, model value of the initial 230Th/232Th ratio. However, isochron approaches are resource-intensive, while corrections made using a single, assumed initial thorium value with arbitrary uncertainty may fail to characterize significant variations in initial thorium, leading to inflated age uncertainties and potentially inaccurate ages, thereby limiting speleothems that can be utilized for climate reconstruction.IBIS is a Bayesian model that uses a probabilistic approach to constrain the initial thorium isotopic composition of each sample, thereby facilitating the derivation of accurate U-Th ages and robust age-depth models for speleothems. The model framework formulates priors for all model parameters, including systematic priors (e.g., decay constants) and sample-specific priors (e.g., a likely range of initial thorium compositions expressed as 230Th/232Th ratios), and uses a likelihood that penalizes violations of stratigraphic order. To test the validity of the approach, we show the efficacy of IBIS when applied to case studies from the published literature that exhibit rapidly changing growth rates, uranium-loss, growth hiatuses, and very young (<1 ka) samples with heterogeneous initial thorium. The ability of the IBIS modeling framework to make accurate, precise, and unique corrections of the initial thorium for each sample within a speleothem has the potential to extend the application of U-Th dating to more complex speleothem systems and provide more accurate and precise age information. We apply IBIS to young (Holocene), initial thorium-sensitive stalagmites hosted in an uplifted Pleistocene coral terrace from Hato Cave, Curaçao, generating robust age-depth models in a challenging geochronological environment.

Dating difficult speleothems

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Uranium-Thorium dating of speleothems has become spectacularly successful, both in speleothem paleoclimate records themselves and in transfer of their chronologies to other Quaternary archives. Speleothem environmental proxy records can now be dated with speed, precision and accuracy unimaginable for most other Quaternary record types. Advances in mass spectrometry have improved the efficiency of U-Th analysis by more than four orders of magnitude and are approaching a limiting level of precision at which speleothems cannot be relied on to appear as perfectly closed systems.

U-Th dating requires a closed system, and that the effect of any initial thorium is accounted for which imparts uncertainty to calculated ages. Following from this, the most impactful published speleothem records have come from clean, well-preserved stalagmites which grew away from cave entrances. Flowstones, near-entrance stalagmites and speleothems formed within young tropical reef limestones all tend to be considerably more difficult to date.

Archaeological, palaeontological, palynological, and palaeoseismological applications all typically require work in the near-entrance zone of caves. Elevated and sometimes isotopically variable initial thorium is a given, and post-depositional alteration is common. It is straightforward to correct for elevated initial Th of a single phase given sufficient dating, rescuing precise chronologies from what appear to be hopelessly contaminated records. U mobility and isotopically variable initial Th can be detected (often not distinguished from each other) but cannot be corrected for other than by identifying and disregarding affected analyses.

Reliable age-depth models can be formed for difficult speleothems subject to variable Th and/or open-system U, but it is an iterative process requiring subjective decisions. Often there are unambiguous outliers present which can be clearly identified by human or machine. Beyond that, presumed likely outliers can be manually removed before determination of a most probable initial Th ratio from remaining samples. On recalculation of ages using this ratio, all samples can then be reassessed as outliers, and the most likely initial Th ratio reassessed, and so on. Where different decisions about outlier rejection during this process lead to significantly different final results then a record cannot be confidently dated without further U-Th analyses, if at all.

Creating robust 20th century chronologies with mixed methods dating: challenges and insights from stalagmites from Australia, Madagascar, and Ireland

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Comparing speleothem geochemical records to independent 20th century observations can help determine which components of the hydroclimate system speleothem proxies are sensitive to, furthering our ability to reconstruct past climate variability. This includes local and regional rainfall amount, seasonality, extreme events, tropical cyclones, evaporation, in-cave kinetic effects and more. However, at such young ages low ^{230}Th accumulation reduces the precision of U-Th ages that make speleothems such powerful paleoclimate archives at other timescales. In this study we adopt a mixed methods approach to dating 20th century stalagmites. Our approach combines annual trace element cycles, radiocarbon bomb-pulse detection and modelling, known priors such as date of collection, and conventional U-Th ages. Age-modelling is then conducted using a specialised version of the Undatable software. We developed and tested our method on recently growing stalagmites from Careys Cave in Australia, Anjohibe in Madagascar, and Crag Cave in Ireland. In Australia we show good coherence of stalagmite $\delta^{18}O$ and trace element ratios with historical droughts recorded at local meteorological stations. Seasonal correlations allow us to begin estimating potential seasonal biases in the stalagmite proxies. In Madagascar we show a tight coupling of stalagmite $\delta^{18}O$ and satellite rainfall estimates with less than 2 years age offset. This potentially opens the door to a paleotempestology record identifying tropical cyclone activity. Overall, coupling speleothem proxy records with recent independent rainfall indicators, which we term paleo-monitoring, allows us to build more robust and nuanced proxy interpretations, giving confidence in paleoclimate reconstructions of the more distant past.

Key considerations in developing precisely dated uranium-thorium chronologies from speleothems

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As speleothem scientists we are all well aware of the ability of speleothems to provide accurate and precisely dated uranium-thorium based chronologies. This has positioned speleothems as a key archive for precisely constraining the timing of climate changes, such as Dansgaard-Oeschger events, the Younger Dryas and glacial terminations. Given this key role that speleothem chronologies play, it is important to reflect on the decisions and processes in developing speleothem chronologies to ensure we are producing the most robust chronologies possible for a given study objective. Here we present a number of simulations to explore the potential effect of various factors on the accuracy and precision of speleothem uranium-thorium based chronologies. These considerations include: correction of ages for initial thorium activity ($^{230}Th/^{232}Th$); sample depth uncertainty; and accounting for growth rate variability in depth-age models. Under certain conditions, each of these considerations can have an important effect on the precision and accuracy of the final chronology, and, consequently, the quoted age of specific events arising from it. It is thus critical that we pay close attention to our methods of constructing depth-age models and U-Th chronologies, especially as the use of speleothem chronologies to provide precise constraint for events, tune other archives, and assess leads and lags between locations becomes more common.

Remanent Magnetization on Synthetic Stalagmites

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The Earth's geomagnetic field, represented mainly by a geocentric axial dipole over long periods, shows excursions and intensity anomalies on shorter time scales, particularly evident in the South Atlantic Magnetic Anomaly (SAMA) of the Southern Hemisphere. Speleothems offer stable remnant magnetization, providing continuous records of high-resolution climate and magnetic field intensity over millennia. In stalagmites, magnetic particles are transported by dripping or flooding, along with clay materials and colloidal organic compounds. As in sediments, the acquisition of natural remnant magnetization (NRM) in speleothems has a low efficiency of about 1-2%. In addition, uncertainties remain regarding the acquisition of magnetic remanence in speleothems, including factors such as flocculation, Brownian motion, and the influence of calcite crystals on the orientation of magnetic particles, which requires further experimental investigation. Our study aims to synthesize artificial stalagmites to quantify the process of acquiring magnetic remanence in speleothems. We precipitated speleothems in the laboratory, producing three different sets of samples: (i) samples without added magnetic material, (ii) with synthetic magnetite, and (iii) with cave sediments. The experimental setup consists of two boxes with controlled temperature, relative humidity, and atmosphere, analogous to a cave. The configuration makes it possible to simulate, as closely as possible, a karst environment and the natural processes that can influence the formation of speleothems (Hansen et al., 2019). Five Helmholtz coils were added to the arrangement, each with a magnetic field of different intensity and inclination. The parameters of temperature, relative humidity, and partial pressure of carbon dioxide (pCO2) were recorded continuously during the experiment. For each solution produced, we recorded measurements of oxygen and carbon isotopes from the high and low pCO2 atmospheres and dissolved inorganic carbon (DIC) from the solution. We aim to improve the investigation of the parameters that control the acquisition of remnant magnetization in speleothems, thus increasing the reliability of paleomagnetic data.Hansen, M., Scholz, D., Schöne, B.R. and Spötl, C. (2019) Simulating speleothem growth in the laboratory: Determination of the stable isotope fractionation (δ13C and δ18O) between H2O, DIC and CaCO3. Chemical Geology 509, 20-44.

Session 2:

Innovation and developments in the lab, field, geochemical modeling and data processing

Speakers:

Silvia Frisia
Adam Hartland
Gang Xue
Andrea Borsato
Michael Hren

Keynote: Nele Meckler

Micheline Campbell
Jens Fiebig
Jessica Oster
Sam Hollowood
Sameera Musa
Dorina Murgulet

Posters:

4. Zhao Wang
5. Sebastian Höpker
6. Maximilian Hansen
7. Silvia Frisa
8. Chloe Snowling
9. Alfredo Martínez-García
10. Bryce Belanger
11. Tara Edwards
12. Leonardo Pasqualetto
13. Celine Kolb
14. Warren Sharp

Cook Islands Late Glacial flowstone: the influence of nanopores in speleothems on the capture of proxy data

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We have used High Resolution Transmission Electron Microscopy (HRTEM) to study the two most common calcite fabrics in a Late Glacial flowstone collected from Atiu (Cook Islands) for palaeoclimate research. Our aim is to check whether crystallization models drawn from modern speleothems (up to 300 years ago) are valid for the deeper past. Our HRTEM data support the hypothesis that particle attachment is an important crystallization pathway, and highlight a role for nanoporosity in entrapping C-rich phases (potentially organic macromolecules). Nanopores are aligned on crystallographic planes and some nanopores are rounded in shape suggesting the presence of amorphous precursors. These findings point to a role for nanopores in shaping the observed alignment of fluorescent organics and organic-associated trace elements in speleothems. They also explain observed “non-equilibrium” uptake of some trace elements [DS1] with both crystallographic control and random patterns as highlighted by Synchrotron XRF maps. Here, we purport that nanoporosity is one of the key properties shaping how speleothems capture climate and environmental data[DS2] . [DS1]Maybe give examples here? [DS2]It feels to me that this statement maybe seems a bit strong unless you are specifically saying that the ‘bread-and-butter’ proxies (d18O, Mg+Sr) are also affected by nanopores. I feel that in general, trace elements (particularly those complexed by organics) remain somewhat ‘fringe’ palaeoclimate proxies,.Acknowledgements. The Authors acknowledge Grant MFP-VUW1904: Drought or Deluge? How did Rainfall in the Tropical South Pacific Respond to Sudden Climate Change During the Glacial Period to Dan Sinclair for financial support and Illes Levente, HUN-REN Centre for Energy Research, for the cutting and milling of FIB lamellae to electron transparency.

Trace metals encode paleoclimatic drip rates in stalagmites

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Speleothems contain a large, and growing number of tracers that inform environmental changes above caves. While routinely measured oxygen and carbon isotope ratios can often be interpreted only qualitatively, several novel proxy systems are now developed that might allow quantitative estimates of past hydrological changes. One promising tracer are organic-metal complexes (OMCs), which have garnered interest due to their kinetic properties. Dripwater-associated OMCs limit the ability of transition metals (Co, Ni) to enter carbonate crystal lattice during speleothem formation, because the time dependent decay of OMCs means that these elements remain in the liquid phase and are (partially) unavailable for the solid phase (i.e., precipitating carbonates). We suggest this process (OMC decay) leads to a kinetic overprint on stalagmite metal concentrations, driven by variations in drip rate, with more transition metals becoming available for incorporation into calcite with lower drip rates (and thus more time for OMC decay). A statistical treatment of the decay of a population of trace element ions from OMCs allows us to model the rates of dripping on a stalagmite's surface. But this problem is made more challenging due to inherent difficulties in calibrating this process to real-world systems. Here, we present a semi-heuristic, semi-theoretical approach that estimates drip rates using a theoretical model based on the population-level chemical kinetics of trace element decay from OMCs, and a heuristic choice of calibration datasets based on rainfall and temperature from a nearby weather station. Applying this approach to trace metal data from the HS4 stalagmite (Heshang Cave, southeastern China), we reconstruct a quantitative drip rate time series for the Holocene that overall shows remarkable continuity with speleothem d18O. The results suggest that with local or regional calibration datasets it might be possible to derive quantitative infiltration reconstructions using transition metals in stalagmites.

The potential of speleothem organic carbon 14C as an ecological proxy

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Understanding the preservation and transport of terrestrial organic carbon is of great significance to understand the role of ecosystems and climate on soil carbon dynamics within terrestrial systems. Cave secondary carbonate deposits, particularly stalagmites, serve as unique archives that preserve dissolved organic carbon (DOC) from the terrestrial surface and trace past organic carbon export at specific sites. The 14C dating method can be employed to provide ages of the DOC in speleothems, which may reflect the ages of soil DOC, therefore providing a powerful means to reveal past soil organic carbon cycling.Here, we present 14C dating results of organic carbon from stalagmites covering the Holocene and the last deglaciation in the Chinese monsoon region. First, based on the deviations of speleothem 14CDOC ages from U-Th ages through three caves located on a north-south transect through China, we show the relationship between speleothem 14CDOC and soil organic carbon turnover time during the Holocene, and the underlying links and mechanisms. Second, we will show a comparison between the deviations of speleothem 14CDOC and speleothem carbonate δ13C during the last deglaciation to highlight the potential of using speleothem 14CDOC ages to understand the driving forces behind variations in speleothem carbonate δ13C.

Integrating high-resolution imaging, optical and fluorescence microscopy: a new multiproxy approach to speleothem petrography

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High-resolution imaging can be utilised as fast and inexpensive tool for a most accurate classification of speleothem fabrics, whose detrital content, colour, internal structure, lamination and porosity define speleothem facies.Here, colour, translucency and porosity properties of a Holocene stalagmite from Nurau cave (Atiu, Cook Islands) are coupled with optical and fluorescence microscopy to identify growth hiatuses and fully characterise speleothem calcite fabrics and facies.The 165 mm tall stalagmite was characterised by an unusually high initial 230Th/232Th ratio that rendered the U-series dating particularly challenging. It was optically scanned at high-resolution in both reflection and transmission mode and subsequently investigated by optical and fluorescence microscopy. This approach identified several growth hiatuses, which separate distinctive growth phases characterised by different mean growth rates, RGB colour, translucency, porosity and lamination.Overall, the geochemical and textural properties are influenced by prior calcite precipitation (PCP), which causes large positive shifts in δ13C and δ18O values, as observed in other stalagmites and cave-farmed calcite from Cook Islands caves. The positive shifts in δ13C and δ18O values are commonly recorded within compact, translucent fabric, which is characterized by low growth rate and greyscale values, faint to absent optical lamination and larger fluid inclusions. By contrast, negative shifts in δ13C and δ18O values are associated with micro-porous, opaque fabric characterized by high growth rate and greyscale values, and highly fluorescent, particulate organic matter (POM) annual laminae. These characteristics, however, are not persistent, although they tend to be consistent within a single growth phase, and each of the five scan modes (reflection, transmission, PPL, XPL, fluorescence) can be utilised as an independent proxy provided that all images are acquired with the same setting.

Organic Molecular Records of Fire and Climate in a California speleothem: Production and Alteration of Molecular Signatures from Source to Sink

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Sedimentary organic molecular biomarkers provide critical insight into past ecosystems, climate and fire, and recent work demonstrates considerable preservation potential of organic molecular biomarkers in stalagmites. For example, surface-derived biomolecules—including fire markers such as polycyclic aromatic hydrocarbons (PAHs) and molecular indicators of vegetation such as alkanes, fatty acids and sterols — have all been identified in stalagmites dating to over 100 ka BP.There are several key challenges to developing and interpreting organic molecular records of past environment in stalagmites. These include 1) analytical limitations relating to sample size and molecular detection limits, 2) issues related to molecular polarity and optimal measurement tools and/or techniques, and 3) challenges in relating the molecular signature preserved in stalagmites to the processes of molecular formation and alteration during transport from source to sink. In California's fire-prone regions, fire and other biomarkers have been identified in stalagmites across various caves dating from the Late Pleistocene to Holocene. Recent research on PAHs from a stalagmite in McLean's Cave in the central Sierra Nevada foothills (ML-1) indicates a connection between fire intensity and climate changes during Heinrich Stadial 1. Despite the clear preservation of fire-related and other organic molecules in stalagmites, investigations of contemporary cave systems and surface environments in California demonstrate that fire markers from recent events vary in their mobility through soils and the epikarst. Additionally, plant lipids generated at the surface experience substantial degradation before reaching cave drip water.Here, we present laboratory and modern surface-to-cave organic molecular data from several cave sites in California to examine: 1) the factors influencing the terrestrial production of organic molecular markers for ecosystems, fire, and climate; 2) the mobilization of organic markers through soil, epikarst, and cave environments; 3) the effects of microbial activity or selective mobilization on the alteration of surface-generated molecular signatures; and 4) the incorporation of organic fire and climate markers in stalagmites. These data and processes are used to examine the molecular record of ecosystem-fire connections in the ML-1 stalagmite since the last deglaciation.

Nucleation-assisted fluid inclusion microthermometry in speleothems – advances and limitations

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Nucleation-assisted (NA) microthermometry allows applying the classical liquid-vapor homogenization technique to speleothems and thus provides a uniquely robust and precise paleo-thermometer (Krüger et al., 2011). The method is based purely on the well-understood physics of water enclosed in fluid inclusions and does not require empirical calibration. In well-suited samples it is highly precise, with a typical 2 SE of the mean temperature from populations of coeval fluid inclusions of < 0.5 °C. In addition, the approach offers the rare opportunity to derive mean annual temperatures not affected by seasonal biases, due to the year-round stable temperatures in the caves. However, the technique is limited to warm caves with temperatures above ~10°C and poses strict requirements on the samples in terms of fluid inclusion abundance, size, and stability.In this talk I will give an overview over recent successful applications of NA microthermometry, including our progress towards a 500-kyr long temperature record for Northern Borneo (4°N, 115°W), and resulting new insights into the evolution of tropical land temperature. While these data attest to the reliability of the approach, the technique does not always yield precise or even meaningful results. This is likely due to violations of the assumptions that fluid inclusions were closed off at the same time as the surrounding calcite and have preserved their volume over time. I will present the status of our ongoing work to understand non-thermal effects and biases, with the aim to improve our ability to pre-select ideal samples for this technique.

Krüger, Y., et al., 2011. Chem. Geol. 289, 39-47.

Speleothem inorganic elements as high-resolution proxies of past fire

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In southwest western Australia (SWWA), a long-running cave monitoring project in Yanchep National Park (Yanchep NP) revealed changes in dripwater chemistry and hydrology following a wildfire (Nagra et al., 2016). These findings, supported by a controlled experiment (Bian et al., 2019), led to a four-year project funded by the Australian Research Council to establish whether speleothems record past fire events. Here, we summarise key project outcomes to date for the karst palaeoclimate community and outline future research.The project has produced three main outputs related to the inorganic proxy signal: (1) a 245-year climate and fire record (McDonough et al., 2022), (2) an investigation of wildfire ash and soil leachates to characterise the proxy source (Campbell et al., 2024), and (3) a comprehensive review of speleothem-based fire proxies (Campbell et al., 2023). McDonough et al. (2022) verified that speleothem trace element data recorded evidence of small and large modern fires impacting a shallow cave in Yanchep NP, with a change in fire regime recorded after colonisation. In contrast, deeper caves in SWWA's Margaret River region recorded only intense fires, suggesting karst hydrology attenuates the fire signal (Campbell et al., 2023). Analyses of ash and soil leachates showed that wildfire ash is the likely source of inorganic fire proxies in speleothems, and that ash leachate chemistry varies with burn severity and location (Campbell et al., 2024). Variation with burn severity also suggests that speleothem geochemistry may record burn severity. Future work aims to validate this on modern samples with known fire histories from Yanchep NP. Preliminary results from a well-characterised sample from Kangaroo Island (KI), South Australia, demonstrate that the inorganic proxy signal can be replicated at multiple sites. To date, no comparisons have been made between pyrogenic biomarkers and inorganic proxies. Future work aims to compare the inorganic and organic proxy signals from a well-characterised sample from KI. Ongoing development of the speleothem palaeofire proxy response will facilitate the development of high-resolution fire records, contributing to the development of effective fire management strategies.

Dual clumped isotope thermometry of speleothems

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Dual clumped isotope thermometry, i.e., the analysis of Δ48 alongside Δ47 in CO2 evolved from phosphoric acid digestion of carbonate [1], makes it possible for the first time to detect and quantify kinetic departures from equilibrium without having to know the oxygen isotope composition of the parent water, and, moreover, to correct for kinetic biases in carbonate formation temperatures [2].We applied dual clumped isotope thermometry to speleothems to test to which extent isotopic disequilibrium is recorded in Neogene and Quaternary stalagmites, flowstones, pool carbonates and cryogenic carbonates. In Δ47-Δ48 space, the dual clumped isotope compositions of slowly grown cryogenic and pool carbonates plot within fully propagated 2 SE indistinguishable from the equilibrium line, and Δ47 derived temperatures agree with known formation temperatures. The dual clumped isotope compositions of subrecent stalagmites sampled at the top close to their growth axis also imply formation without significant kinetic isotope fractionation, but Δ47 derived temperatures are often slightly higher than modern mean annual cave temperatures. In addition, Hendy tests indicate the presence of kinetic isotope effects in some of these samples. Correlation slopes of δ13C vs δ18O and disequilibrium Δ47/Δ48 values agree pretty well with those predicted by IsoCAVE [3] for early-stage precipitation under the conditions characteristic of the investigated caves. Our preliminary results imply that isotopic disequilibrium occurring closest to the growth axis may not be resolvable by Δ47/Δ48 measurements alone, due to the current limitation in Δ48 precision. Nevertheless, quasi-equilibrium stalagmites might be identifiable for accurate temperature determinations considering a combination of Δ47, δ13C and δ18O measurements. Dual clumped isotope thermometry might become powerful for the reconstruction of cave temperatures from stalagmites showing relatively large δ18O gradients along growth layers.

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Calcium isotope ratios (δ44Ca) in coeval California stalagmites record hydroclimate shifts and reveal soil-to-cave carbon transformations during the last glacial period

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Calcium isotopes (δ44Ca) in speleothems are thought to solely record changes in prior carbonate precipitation (PCP) along the seepage water flowpath. This unique sensitivity makes δ44Ca a useful tool for both reconstructing past hydroclimate and exploring the influence of PCP on other proxies where it can be one of several influences. Here we present δ44Ca records for two partially coeval stalagmites from Lake Shasta Caverns (LSC) in northern California that grew between 37,000 and 14,000 years BP. Both δ44Ca records display similar mean values and temporal variations, and significant positive correlations with δ13C (ρ = 0.74, 0.73) and δ18O (ρ = 0.49, 0.77), suggesting PCP also influences these traditional stable isotope proxies. However, neither stalagmite displays significant correlations between δ44Ca and trace element proxies (Mg/Ca, Sr/Ca, Ba/Ca) indicating these do not solely reflect PCP at this site.LSC sits on the boundary between two hydroclimate regimes in the northwestern and southwestern United States. Stalagmite δ44Ca and δ13C suggest wetter conditions during warm Dansgaard-Oeschger interstadials, similar to paleoclimate archives from the Pacific northwest. However, LSC proxies also indicate wet conditions during colder Heinrich Stadials, similar to archives from the southwest. Values for the fraction of Ca remaining in solution after PCP (f) calculated using a Rayleigh fractionation model for δ44Ca calibrated with modern monitoring data indicate that 0 to ~60% of dissolved Ca is lost to PCP. We compare stalagmite f values with modern PCP rates and measured rainfall to generate quantitative estimates of past rainfall. However, unreasonable f values during the wettest intervals indicate that the calcite-water calcium isotopic fractionation factor may have varied in the past, particularly during intervals of faster stalagmite growth. Using calculated f values, we estimate the δ13C of dissolved inorganic carbon prior to PCP which agrees with modern dripwater values. Notably, these δ13C estimates are higher during wetter warm interstadials and cold Heinrich Stadials, when PCP is lowest. This suggests that during wet intervals, seepage water has little time to equilibrate with soil CO2 leading to lower carbonate saturation and less PCP, likely due to sparse soils and steep terrain above LSC.

Presenting CaveCalcv2.0, with ‘DataAnalyser’ functionality for facilitating speleothem paleoclimate interpretations

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CaveCalc is a PHREEQC-based software tool that forward models chemical and isotopic processes along the flow path, from the soil to speleothem (Owen et al., 2018). It models all major elements and their isotopes (δ18O, δ13C, δ44Ca) as well as trace-elements, Mg, Sr and Ba. CaveCalc helps to assess, and quantify, the environmental and in-cave processes that impact these speleothem values (e.g. Lechleitner et al., 2021, Tabor et al., 2021, Stoll et al., 2023). There are three main additions to CaveCalcv2.0: (i) an optional database for forward modeling aragonite precipitation, (ii) the incorporation of Uranium for interpretation of speleothem U/Ca and, (iii) a new DataAnalyser mode. The DataAnalyser (DA) automates the assessment of the environmental variables (e.g. soil pCO2) that can be matched to the user's speleothem measurements. The user provides CaveCalcv2.0 with speleothem data (from one or multiple time-periods), and initiates DA model runs based on expected environmental input variables (e.g a soil pCO2 of 400-8000ppmv). The DA identifies all model outputs that match measured speleothem values, presenting results in both graphs and tables. This streamlines the interpretation of which environmental conditions (e.g. soil pCO2, δ13Csoil, δ18Orain, gas/solution ratios during bedrock dissolution, fCa, temperature) that best agree with measured speleothem elemental and isotopic values. This work follows-on from previous, similar data-model comparison functionality (Lechleitner et al., 2021), with that earlier functionality external to CaveCalc. This new work seeks to simplify the process by integrating this type of functionality within a single software tool. Here we provide a demonstration of this new functionality, as applied to real-world examples of speleothem data from Chile and North Africa.

Triple oxygen isotopes and carbonate clumped isotopes of a Late Quaternary Cango Caves speleothem in southernmost South Africa

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The Late Pleistocene paleoclimate and paleoenvironmental reconstructions of Africa are poorly constrained due to limited terrestrial proxy records. In southernmost South Africa, a 1.5 m calcite speleothem from the Cango Caves is a valuable potential high-resolution archive that spans the last 40 000 to 100 000 years (Chase et al., 2021). In this study we present new results for the triple oxygen isotope ($\Delta'^{17}O$, $\delta^{18}O$) composition of the CAN1 speleothem using a tunable infrared laser direct absorption spectroscopy (TILDAS) instrument at the University of Cape Town. In addition, we analyzed the carbonate clumped isotope composition (Δ_{47}) of the same samples at the University of California, Los Angeles. Preliminary triple oxygen isotope results of the calcite at ~95 000 years yield $\Delta'^{17}O$ values that range between -83 and -93 per meg and $\delta^{18}O$ values that range between 25.507 and 25.775 ‰ (n=4) on VSMOW2-VSLAP2 scale. The repeatability of the standards was 10 per meg (1 s.e. n=3) for $\Delta'^{17}O$. In addition, we present measured Δ_{47} values of fossil lake gastropods from Tsodilo Hills, Botswana, from 40 000 years with an average of ca. 15.6 ± 2.2°C (n=3). We discuss our findings in terms of the cave kinetics, mineralisation temperature and seasonality. The use of combined triple oxygen and clumped isotopes has potential to improve regional and global climate reconstructions, as well as understanding the dominant forcing mechanisms in South Africa during Marine Isotope Stage 5.

Seasonal Hydrogeochemical Dynamics and Contamination Risks in the Yucatán Peninsula's Karst Aquifer System

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Karst aquifers, which cover approximately 10% of the global land surface, exhibit complex geomorphology and hydrology due to carbonate rock dissolution. This study investigates the hydrogeochemical dynamics of the Yucatán Peninsula's Ring of Cenotes, a karst feature shaped by the Chicxulub impact, focusing on groundwater flow, contamination risks, and marine influences. Water samples were collected from cenotes, caves, wells, and coastal/submarine springs during the wet summer of 2022 and the extremely dry summer of 2023. Samples were analyzed for isotopic tracers (radium, radon, strontium), dissolved inorganic nitrogen (DIN), and major elements.Results show significant spatial and temporal variations in groundwater quality. Coastal areas consistently exhibit elevated salinity and elemental concentrations, indicating strong marine influence, intensifying during the dry season due to seawater intrusion. Water-rock interactions, evidenced by carbonate mineral dissolution, impact groundwater chemistry across seasons. During the wet season, increased concentrations of ammonium (NH_4^+) and nitrate (NO_3^-) suggest anthropogenic inputs from agriculture and sewage, with NH_4^+ elevated in cenotes and wells and NO_3^- higher in coastal springs. In the dry season, NH_4^+ concentrations decrease except in wells, revealing localized contamination and reduced dilution capacity, while NO_3^- remains elevated, reflecting continued nitrification under oxic conditions.Principal Component Analysis (PCA) for 2023 indicates intensified water-rock interactions, with increased radium activities and Ca/Mg ratios suggesting enhanced carbonate dissolution, likely due to longer groundwater residence times and reduced recharge. This study highlights the influence of seasonal shifts on hydrogeochemical processes and nutrient dynamics in karst aquifers. It underscores the importance of sustainable water resource management to mitigate contamination risks in vulnerable karst systems.

Understanding of links between hydroclimate, wildfires, and ecosystem in the past using terrestrial-derived molecular fingerprints archived in stalagmites

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Terrestrial-derived organic molecules are shown to be archived in stalagmites and are increasingly applied as novel proxies for paleo-hydroclimate, wildfires, and terrestrial ecosystems. However, the interpretation of the links and feedbacks between molecular records in stalagmites and surface climate variables is still not well understood. Here, we investigate a suite of high-resolution hydrocarbon biomarkers preserved in stalagmite samples spanning ~18.7 to 10.9 ± 0.5 ka BP collected from McLean's Cave, central Sierra Nevada foothills, California. Specifically, we quantify a suite of biomarkers that include polycyclic aromatic hydrocarbons (PAHs) and their alkylated derivatives as incomplete combustion products, isoprenoid hydrocarbons (i.e., pristane and phytane), and bicyclic and pentacyclic terpanes (tentatively as coniferous and flowering/grass inputs, respectively) in the stalagmite (ML1). Our results show that during the first phase of Heinrich Stadial 1 (HS1a, ~18.0 to 16.1 ka BP), lower molecular PAHs (lower temperature burning and/or distal transport) are elevated relative to long-term values, while higher molecular PAHs (higher temperature burning and/or local fire signals) increase during this time and maintain higher concentrations. ML1 records a slightly elevated 2-methylnaphthalene/1-methylnaphthalene (2-MN/1-MN) ratio as a higher ratio implied a higher burning temperature and a sharp decline of pristane/phytane (Pri/Phy) ratio during HS1a, as a lower ratio might indicate lower anaerobic microbial degradation under increased aridity. Together, these suggest an increased contribution of both distal and local fire events and increased aridity during HS1a. As for vegetation source burning, retene (an alkylated PAH) concentrations, a proxy of conifer or softwood burning products, are high during the dry HS1a interval and are associated with higher bicyclic terpane (coniferous inputs) values, indicating increasing conifer or softwood inputs as fuels contributing to fires. A general declining trend of PAHs and retene is observed during the transition to the subsequent phase (HS1b, up to ~ 15 ka BP) with elevated 2-MN/1-MN and lower Pri/Phy ratios, implying less frequent but hotter fires during superimposed discrete intervals of increased aridity. This broad spectrum of terrestrial-derived molecular fingerprints could provide another invaluable lens to understand changes in surface ecosystems archived in stalagmites.

More data, less work: The Syp automatic fluid sampler

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Regular water sampling is critical to a range of applications and sectors – whether for scientific research in laboratory and field settings, routine water quality monitoring, or environmental impact assessments. However, frequent manual sample collection over prolonged periods quickly becomes unfeasibly expensive and time-consuming, particularly when study sites are remote or difficult to access. Moreover, access to sites may not always be possible over the course of a project, for instance due to adverse weather conditions, hazardous operations, or restrictions for ecological or cultural reasons. To help researchers and professionals to achieve their desired sample frequency, we present the purpose-built Syp automatic fluid sampler (www.waikatoscientific.com/syp). Designed and manufactured in Aotearoa New Zealand's Waikato region, Syp fluid samplers allow for the automated collection of up to 58 water samples at user-defined time intervals, with a lifespan of over 12 months per deployment. Sample collection (up to 15 mL) occurs passively using a funnel (e.g., suitable for cave dripwater or rainfall), which directly collects and stores incoming water drops. Alternatively, sample collection can be achieved via a peristaltic pump, which allows sampling from an artificial reservoir (e.g., rain gauge, wells) or natural water bodies, such as streams and lakes. In addition to sampling at regular intervals, in-built sensors enable event-based sampling via user-defined environmental thresholds (e.g., for targeting low atmospheric pressure rainfall associated with tropical cyclones). Samples are stored in individual vials with self-sealing rubber bungs, which minimise alteration and (cross-)contamination during storage (e.g., negligible evolution of stable water isotope or chemical composition). Syp's modular design allows for easy and safe transport of the instrument even through tight cave passages and rough terrain, while an intuitive browser-based interface (accessible via any smartphone or laptop) facilitates convenient programming of the unit without the need for a physical connection. With a growing global user community, we strive to continuously improve Syp and take feedback and suggestions on board!

Drip rate-dependent stable isotope fractionation during formation of (speleothem) $CaCO_3$

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The stable carbon and oxygen isotope ($\delta^{13}C$ and $\delta^{18}O$) signals recorded in speleothems depend on a variety of regional and climatological factors. In addition, various processes occurring in the soil, the karst and inside the cave, such as prior calcite precipitation (PCP) as well as disequilibrium isotope fractionation processes, may obscure the 'original' climate signal (e.g., Hansen et al., 2019). There have been a number of theoretical (e.g., Dreybrodt and Scholz, 2011; Sade et al., 2022) and laboratory studies aiming to disentangle these fractionation processes (e.g., Day and Henderson, 2011; El-Shenawy et al., 2020; Hansen et al., 2019). Here we present laboratory experiments investigating the influence of temperature and drip interval on the $d^{13}C$ and $d^{18}O$ values during formation of (speleothem) calcite. The experiments were performed in a completely controlled cave-analogous enclosure, at temperatures of 10, 20, and 30 °C and with an atmospheric pCO_2 of 1000 ppmV. Speleothem growth was simulated by simultaneously dripping a 5 or 8 mmol/l $CaCO_3$-CO_2-H_2O solution onto 5 sandblasted watch glasses, with each drip site having a different drip interval. The results of the $d^{13}C$ and $d^{18}O$ values of the precipitates clearly show a dependence on drip rate and temperature.

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Aragonite to calcite phase transformation in speleothems: A role for nanoporosity

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Both calcite (cc) and aragonite (ar) are calcium carbonate ($CaCO_3$) polymorphs that form in speleothems, even though ar is stable at high temperature and pressure. Their different crystallographic structures influence speleothem geochemical properties. Both minerals can potentially be powerful climate indicators, albeit the conditions in which either one or the other of these two polymorphs form are not fully understood. To date, there has been an assumption that aragonite should transform into calcite in a cave environment (the rate at which the transformation occurs is little known) through dissolution-re-precipitation. This commonly leads to a loss of “heavy” C and O isotopes and heavy elements (including U), whose subsequent fate remains an unsolved issue. Here, we present first in situ observations of ar being replaced by cc in a flowstone under the electron beam of a high-resolution transmission electron microscope. We observed the phase transformation without the typical beam damage of calcium-carbonates when CaO forms. The transformation was triggered by the electron beam and started at pre-existing ar/cc boundaries, with calcite growing at the expense of aragonite. Transformation was not influenced by lattice defects, as previously reported (Frisia-Bruni and Wenk, 1985). Interestingly, the relative crystallographic orientations of cc and ar appeared to be random. In contrast, transformation seemed to occur where micro and nanopores were present in both phases. Although the transformation we observed was caused by exposure to the electron beam, we noted that “beam damage” reported at other cc/ar interfaces was never observed. Thus, we believe that the dynamic changes reflect an inherent property of the speleothem, most likely nanoporosity, which was observed elsewhere (McDonough et al., 2024). We also speculate that nanoporosity influences diagenetic processes in speleothems and mobilization of chemical species during changes in climate conditions.

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A Multiproxy Approach to study Vegetation and Temperature Changes since the Last Glacial in Central Vietnam

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Speleothems are invaluable archives of past climate variability and offer important insights into monsoon dynamics across Southeast Asia. Different isotope systems have been employed to characterise autumn monsoon in this region, but multiple influencing factors render the interpretation of isotope proxy records ambiguous. To gain novel insights into regional vegetation and temperature changes, novel proxies are required. Here, we combine traditional speleothem stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) with speleothem thermometry (TEX_{86}) and lignin oxidation products (LOP) analyses, to provide a more comprehensive understanding of past environmental changes in Central Vietnam. Specifically, we aim to:Reconstruct cave air temperature variations using TEX_{86}.Assess vegetation and environmental changes through LOP analysis.Evaluate the response of these proxies to known climate forcing mechanisms, including Northern Hemisphere summer insolation, sea surface temperature anomalies, and shifts in the Intertropical Convergence Zone.A stalagmite record from Central Vietnam, spanning the last glacial and onset of the Holocene (35 – 10 ka BP), provides a unique opportunity to reconstruct glacial to Holocene temperature changes and the response of regional hydroclimate and vegetation. Preliminary TEX_{86} results suggest a temperature shift of at least 2°C from fully glacial to Holocene conditions. LOP results suggest that the vegetation in Central Vietnam changed from hardwood deciduous vegetation types (0.37 S/V, 0.33 C/V) to an increase in softwood vegetation types (0.1 S/V, 0.11 C/V), respectively. Our findings have implications beyond Southeast Asia's paleoclimate. Validating these novel biomarker systems (TEX_{86} and LOP) against more traditional stable isotope ratios ($\delta^{18}O$ and $\delta^{13}C$), we aim to elucidate changes in moisture budget and sources, and seasonality.

The TEX86 paleothermometer in speleothems

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The TEX_{86} index has shown great promise as a paleotemperature proxy in different environmental settings, including speleothems. TEX_{86} measurements in modern speleothems from caves located in different climate settings show a strong correlation with mean annual cave and air temperatures. However, so far, the application of the TEX_{86} index to reconstruct past temperatures has been limited. One of the main limitations for a widespread application of this technique has been the large sample size used in previous studies (approximately 10 g of calcite) due to the low concentration of these organic compounds in speleothems. Here, we show that, in most speleothem samples, accurate TEX_{86} measurements can be obtained using around 1 g of speleothem calcite. We report measurements of modern speleothems that extend the geographical coverage, as well as, the temperature range of existing calibrations. Our measurements confirm the robustness of the speleothem TEX_{86} paleothermometer, and reduce the uncertainty of previous calibrations.

Evaluation of stable (δ13C, δ18O), triple oxygen (Δ′17O), and clumped (Δ47, Δ48) isotope compositions in speleothems grown under cave analog conditions

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Triple oxygen isotope ($\Delta'^{17}O$) and clumped isotope (Δ_{47}, Δ_{48}) compositions are relatively new proxies in speleothems that hold potential for reconstructing past climate conditions in terrestrial environments. Measurements of speleothem $\Delta'^{17}O$ may help elucidate the source location of past precipitation and disentangle the influences on speleothem $\delta^{18}O$, improving interpretations of this frequently used proxy. However, previous investigations of speleothem $\Delta'^{17}O$ have been limited to geochemical modeling and a handful of ancient stalagmites. In this study, we employ cave analog experiments to grow speleothem $CaCO_3$ under known, climate-controlled (temperature and pCO_2) conditions using the Geological Microclimate ("GeoMic") system. We seek to determine if trends in $\Delta'^{17}O$ vs. $\delta'^{18}O$ due to changes in cave temperature, pCO_2 and drip rate align with those previously hypothesized based on geochemical modeling. We also measure speleothem Δ_{47}, Δ_{48} to assess the utility and fidelity of this proxy in reconstructing cave temperatures during calcite formation.In our experiments, calcite was precipitated on sand-blasted watch glasses via dripping water under 30 unique combinations of "cave" air temperature, pCO_2 and drip rate. Experiments were executed at temperatures ranging from 15-30°C and 500-3000ppm pCO_2 in order to span the majority of observed global cave temperature and pCO_2 values as recorded via cave monitoring efforts. During each experiment, we dripped water onto convex glasses at rates ranging from 1 to 60 drips per minute for approximately one week. Initial analyses of traditional stable isotopes ($\delta^{13}C$ and $\delta^{18}O$) indicate isotopic exchange between cave air CO_2 and the bicarbonate pool in the drip water prior to calcite precipitation, similar to observations in some natural caves. Preliminary clumped isotope measurements support this hypothesis. Slower drip rates provide more time for exchange and drive isotopic values further from equilibrium. Higher "cave" air pCO_2 may also accelerate this exchange. Preliminary $\Delta'^{17}O$ analyses via tunable infrared laser direct absorption spectroscopy suggest that neither changes in temperature nor drip rate changes generate measurable shifts in $\Delta'^{17}O$ vs. $\delta'^{18}O$ slope. The results of this study will be critical for further development of these proxies and the effective interpretation of $\Delta'^{17}O$ and dual clumped measurements in ancient speleothems.

A new in-situ U-Pb dating facility: implications for research and capacity building

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We present the new laser ablation, high resolution mass spectrometer facility in the Department of Geological Sciences at the University of Cape Town. This is a national facility, under the direction of the BIOGRIP - Biogeosciences Research Infrastructure Platform - funded by the South African Government Department of Science and Innovation. In the original proposal, South African palaeoscience was identified as a key area of research excellence, with particular emphasis on the need to develop in-country expertise and capacity to perform high quality geochronology. The Nu Instruments Attom ES HR-ICP-MS is coupled to an Applied Spectra RESOlution-SE 193nm excimer laser ablation system. The facility is a fast, highly sensitive instrument (i.e., <105ms), purposely designed to measure rapid and precise isotope ratio and quantitative analysis of trace elements in solid and liquid matrices. To produce dry plasma from solution we use a Cetac Aridus 3 desolvating nebuliser system. Calibration standards used are NIST610, NIST 612 and for in-situ U-Pb dating we use the established matrix matched reference material WC-1 and are experimenting with a new reference material RA138, in collaboration with colleagues at the ETH, Zurich. In terms of a workflow, this facility can accept carbonate samples that are sliced and polished; these may need to be trimmed to fit the laser cell (15x15cm). We routinely collect trace element data by coupling the laser to the nearby Thermo-Fisher X-Series II quadrupole ICP-MS. The distribution and concentration of U and Pb determines which layers are suitable for U-Pb dating, which is then done by laser ablation, with isotopes analysed by the Attom. This in situ laser ablation approach represents a significant breakthrough in terms of time needed for analysis (1 hour vs previously several weeks). We present comparison data between previously dated solution results and new laser ablation U-Pb data for speleothems from the Cradle of Humankind.

How does cathodoluminescence help us understand speleothem fabric and growth history?

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Cathodoluminescence (CL) is a well-established technique for petrographic and mineralogic analyses, including investigation of fabrics, growth zones, and deformation features. The technique relies on the ability of minerals to produce luminescence in the optical spectrum when subjected to an electron beam. CL has been applied to speleothems to identify laminations and Mn^{2+}/REE^{3+}-enriched layers, as well as recognizing different mineral phases like calcite-aragonite and exogenous detrital material (e.g., Richter et al., 2003; Wassenburg et al., 2012). However, a systematic characterisation of CL structures in stalagmites is still missing.Here, we propose a novel classification and interpretation of CL features in calcite stalagmites, based on SEM-CL imaging on thick sections from stalagmites of different ages and locations. We define four main classes: (i) fluid inclusion-related zoning, (ii) grain boundary zoning, (iii) sector zoning and (iv) seasonal zoning. Group (i) and (ii) refer to microstructures associated with fluid inclusions and grain boundaries, which are characterised by higher concentrations of organic matter and crystal defects and can localize calcite-water reactions, cementation and dissolution/reprecipitation processes. Group (iii) appears in fabrics with relatively fast crystallisation rates and occurs when different crystal faces incorporate different amounts of trace elements. Finally, group (iv) relates to variations in the concentration of specific ions in the drip water during different seasons or climate patterns, and is already well-documented by trace element mapping and fluorescence microscopy.These results show that CL can provide additional information on growth conditions and environments, allowing for a more comprehensive understanding of speleothem fabrics. Indeed, stalagmite petrographic analysis aids paleoclimate studies where isotope- and fluid inclusion-based proxies are utilised. This is because the occurrence of dissolution/recrystallization phenomena, or exchange reactions between the calcite and water, can induce a re-equilibration of the fluid inclusions and the host calcite, potentially affecting the information extracted through nucleation-assisted microthermometry and oxygen isotope measurements on fluid inclusions.

Richter, D.K., et al., 2004. Holocene 14.5, 759-768.Wassenburg, J.A., et al., 2012. Geochim. Cosmochim. Ac. 92, 23-47.

AI-Driven Reverse Modeling of Paleoenvironmental Conditions from Geochemical Records in Speleothems

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This study introduces a novel reverse modeling approach leveraging artificial intelligence to reconstruct paleoenvironmental conditions from geochemical data in speleothems. By applying Random Forest regression, a machine learning method that builds an ensemble of decision trees to improve prediction accuracy, this approach estimates past climate variables from isotopic and chemical records. The model averages the predictions of numerous decision trees, reducing overfitting and enhancing robustness against data outliers — a frequent challenge in paleoclimate research. This framework provides an alternative to traditional forward models, allowing new insights into climate and ecosystem dynamics over time. The approach builds on data generated by CaveCalc (Owen et al., 2018), which simulates environmental conditions to create a foundation for estimating key parameters with flexibility to handle complex, non-linear relationships.As a case study, the reverse modeling framework was applied to stalagmite samples from a cave in the northern part of the Yucatán Peninsula, Mexico, yielding estimates of environmental variables, such as soil pCO_2 and vegetation type over the last few thousand years, derived from isotopic proxies like $\delta^{13}C$ and Dead Carbon Fraction. The model's predictions align closely with expected trends, demonstrating its accuracy and stability across varying environmental scenarios.This AI-driven framework offers a scalable tool for paleoclimate reconstruction, applicable across diverse geographies and timeframes. By accommodating additional proxies, such as $\delta^{18}O$ and trace elements, this method broadens the potential for future studies, enhancing our understanding of climate-ecosystem interactions and the long-term environmental changes recorded in speleothems. This work establishes machine learning as a critical asset in paleoclimatology, extending the scope of paleoclimate reconstructions and ecological insights

Flexible, Comprehensive, Transparent U-Th Data Reduction and Calculation of U-Th Ages and Errors

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U-Th dating is widely used in studies of Pleistocene-Holocene paleoclimate, paleo sea-level, and other contexts. The technique plays a unique role in calibrating records of terrestrial paleoclimate in speleothems and paleo-sea level in shallow water corals by virtue of its unrivaled accuracy and precision in suitable samples. Advantages of the technique include: no need for reservoir corrections or external calibration (unlike ^{14}C), no need to quantify external radiation fields (unlike trapped charge techniques), precise measurement of the relevant isotopic ratios (c. ±0.1%), and simple assumptions so accuracy may closely approach precision. Improved measurement protocols and refined half-life values have propelled advances in U-Th dating over the past ~40 years, however, U-Th data reduction has received less attention.

Calculating accurate U-Th ages requires making a series of corrections to measurements obtained by mass spectrometry including those for procedural (chemistry) blanks, instrumental backgrounds, peak-tails, mass fractionation, tracer impurities, and distinct U and Th instrumental sensitivities. In addition, any initial ^{230}Th present (i.e., ^{230}Th not produced by in situ decay) must be subtracted from the measured ^{230}Th.

Determining accurate age-errors is arguably as important as the accuracy of the ages themselves. This requires combining the raw isotopic ratio measurements with effects of the many needed corrections, estimating the uncertainty stemming from correction for initial ^{230}Th, and rigorously propagating all such sources of error to provide a robust error estimate.

We are developing a Python application for this purpose. We plan to include: flexible data input to accommodate diverse measurement protocols; user selectable options for statistically valid outlier rejection; rigorous, comprehensive linear and Monte Carlo error propagation; user selectable options for initial ^{230}Th corrections; and options for internal and external age-errors. Sources of uncertainty in individual analyses will be visualized to guide optimization of analytical protocols.

The application will employ a modular structure so that users may make use of, for example, the module for calculating ages with different initial ^{230}Th corrections without engaging with the entire U-Th data reduction workflow. Vetting of the application via publication in a peer reviewed journal will ensure that computations are transparent and robust.

Session 3:

Cave monitoring and implications for palaeoarchives

Speakers:

Sebastian Höpker
Patricia Piacsek
Jin Liao
Virgil Drăgușin

Posters:

15. Mohammed Hssaisoune
16. Nitesh Sinha
17. Kristina Krklec
18. Haowen Fan
19. Jessica Oster
20. Ana Entrena
21. György Czuppon

Climate extremes in Aotearoa New Zealand: Insights from hydrological monitoring and speleothem analysis

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The northeast of Aotearoa New Zealand's North Island is one of the country's regions most impacted by extreme weather. In recent years, this has tragically been exemplified by the widespread devastation caused by several major floods, most notably during Cyclone Gabrielle (February 2023). However, little information is available on past climate extremes in this region beyond instrumental records to put frequency and magnitude of recent events into historical perspective. Working closely with the small remote community of Te Reinga (Hawke's Bay region), we address the scarcity of regional palaeoclimate records by investigating past and present hydroclimate dynamics in the karst environments of Mt Whakapunake. Holding considerable cultural significance, the mountain's numerous cave systems are also major vectors for water transfer and storage in the catchment and have been confirmed to help feed two resurgent springs located downslope. Importantly, these resurgences supply Te Reinga's Marae (Māori meeting grounds) and several households with freshwater.Our study firstly seeks to characterise the present-day hydrological and chemical variability of these springs and an associated stream in response to local weather. In light of potential threats of severe weather and land-use changes in the catchment to the spring's water quality and sustainability, these datasets serve as a novel baseline for risk and impact assessments. To quantitatively link spring discharge with subterranean flow on Mt Whakapunake, observations from our spring monitoring are further integrated with regular water chemistry and drip rate measurements in the extensive Te Reinga Cave located on the mountain. Finally, we aim to use insights from spring and cave monitoring programs to corroborate speleothem-based climate reconstructions from Te Reinga Cave. Collectively, our data are aimed to support a new Holocene climate record for northeastern Aotearoa New Zealand, focusing specifically on historic extreme climate events and rainfall variability.Our preliminary results depict a pronounced sensitivity of the monitored karst environments to local and regional-scale weather patterns. Moreover, water level monitoring and stable isotope analyses have helped identify key differences between the two adjacent Te Reinga springs, supporting a shift in location for water extraction.

Long-term cave monitoring in central Brazil for accurate paleoclimate insights from stalagmites

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This study presents findings from an eight-year cave monitoring project (2012–2019) conducted at Lapa dos Anjos cave (15º S, 44º W) in central Brazil, a shallow cave with limited ventilation located within the core of the South American Monsoon System (SAMS), a region critical for paleoclimate research. Although stalagmite-based paleoclimatic records are available across Brazil, long-term, high-resolution monitored data from caves remain scarce. Here, we integrate local rainfall, drip water from four distinct sites, and form calcites to elucidate the primary processes influencing $d^{18}O$ and $d^{13}C$ variability in tropical stalagmites. Distinct hydrological controls over drip regimes were observed, with some sites exhibiting continuous year-round dripping and others showing intermittent patterns. The seepage pathways at each site dictate water residence time within the epikarst, modulating $d^{13}C$ variability significantly based on drip rates across hydrological regimes. These findings enhance the interpretive framework for $d^{18}O$ and $d^{13}C$ records, providing critical insights for accurate paleoclimatic reconstructions from Lapa dos Anjos and similar tropical cave systems, thereby advancing our understanding of past climate dynamics within the SAMS region.

Response of karst soil organic carbon mineralization to climate change and human activities: insights from cave monitoring and speleothem records

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Soil organic carbon (SOC) mineralization is a key component of the global carbon cycle. However, how its temperature sensitivity responds to the simultaneous and interactive effects of warming and altered precipitation remains unclear. In karst systems, organic matter in cave dripwater ultimately derives from the overlying soil. Therefore, the fluorescent humification index (HIX), an indicator of organic chemical properties, can potentially evaluate the degree of overlying SOC mineralization. In this study, we leverage 19 years of continuous dripwater monitoring (Heshang Cave, China) to investigate the effect of climatic fluctuations on fluorescent dissolved organic matter (fDOM) properties, and by extension of SOC dynamics. We found that the HIX value of dripwater decreased by 0.05±0.005 (apparent temperature sensitivity) for every 1℃ increase, suggesting that warmer temperatures result in higher proportions of more decomposed fDOM (lower HIX values), characterized by biochemically labile substrates with low molecular weight. Wetter conditions tend to restrict the oxygen supply for soil microorganisms, further increasing the proportion of high molecular weight moieties in fDOM with higher HIX values. We therefore concluded that warmer and drier climatic conditions can promote karst SOC mineralization and result in the loss of SOC. Based on the multivariate regression model, the intrinsic temperature sensitivity (0.033±0.004) was assessed, which is lower than the apparent, suggesting that rainfall would amplify the effect of air temperature on karst SOC dynamics. Using established empirical relationships between HIX and SOC mineralization rate, we assessed the temperature sensitivity of SOC mineralization ($Q_{10\text{-}MAT}$, fitted to the local mean annual temperature), finding that the intrinsic $Q_{10\text{-}MAT}$ value of 1.84±0.11 is lower than the apparent $Q_{10\text{-}MAT}$ value of 2.28±0.15. We further apply this proxy to Heshang stalagmite (HS4) and find that the HIX record in the Holocene can sensitively respond to past climate change and regional human intensities. Overall, our study provides a unique long-term perspective on the climate sensitivity of SOC dynamics in the karst critical zone.

Isotopic and elemental variability of water and calcite at Ascunsă Cave, Romania, under unusually warm conditions

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Since 2017, Ascunsă and Isverna caves, parts of the same cave system, are experiencing recurrent warming cycles. These cycles are defined as rapid increases and decreases of ~2-3°C, separating periods of elevated, stable temperature that persist for about two years. These temperature changes could be resulting from the influence of the nearby thermal aquifer at Băile Herculane, with warm gasses such as H_2O and CO_2 rising along open karst fractures. To test this hypothesis, we analyzed the carbon isotopic composition of cave air CO_2 and of CO_2 dissolved in drip waters during a limited measurement campaign of four visits between February and August 2023. We obtained an average value of -24.0 ±0.4‰ (VPDB) in dissolved CO_2, which is explainable by an input from decomposed organic matter. Cave air CO_2 had a similar isotopic composition with average values of -23.9 ±0.1‰ (VPDB), with slightly higher values close to the entrance, due to ingress of outside air. The $\delta^{13}C$ of dissolved CO_2 measured by us in the thermal aquifer has values of -30‰ (VPDB) but its mixing into the drip water is not clearly discernible.The rise in cave temperature allowed us to study the oxygen isotope fractionation factor between water and calcite under natural conditions. Preliminarily, we provide here the value for the temperature dependence of calcite $\delta^{18}O$. After analyzing 43 farmed calcite samples taken between 2015 and 2023 at temperatures between 7.3°C and 10.6°C, we obtained a value of -0.219‰/°C (r=0.93). Integrating data from Isverna Cave will allow us to study the temperature dependence up to 12.5°C. Moreover, we can also study the partition coefficients of chemical elements such as Mg and Sr, and their relationship with temperature or precipitation rate.

Hydro-Climate Dynamics of the Wintimdouine Cave Karst System (Western High Atlas, Morocco): Monitoring Insights for Paleoclimate Research

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The Wintimdouine cave in Morocco, located within a semi-arid region, contains the longest-known underground river in Africa and faces significant anthropogenic and climate-related pressures. Understanding the aquifer system's dynamics and regional climate impacts on this environment is essential. Over a 4-year monitoring period, we investigated the cave's hydrochemical properties, stable isotope content of water samples, internal climate conditions, and moisture trajectories. The chemical analysis revealed that cave water, rich in bicarbonate and calcite, is of excellent quality, indicating active recharge of the aquifer, which serves as the region's primary drinking water source. Stable isotope profiles align across rainwater, cave water, and nearby groundwater, with minimal evaporation effects likely due to the rapid infiltration of surface water through the epikarst and vadose zones, supported by extensive exo-karstic formations above the cave. Seasonal monitoring shows that higher drip water flow increases temperature and humidity inside the cave, particularly in spring and summer. High relative humidity and stable temperature support carbonate deposition in equilibrium with drip water. Moisture trajectory analysis further indicates that predominant air masses arrive from the North Atlantic, aligning with rainwater deuterium-excess values and NAO-related westerly winds. These findings highlight the potential of Wintimdouine speleothem $\delta^{18}O$ as a proxy for past regional climate variability.

Cave monitoring and calcite farming to validate regional Δ47-palaeothermometry

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To reconstruct paleo temperatures from speleothem calcite samples, one can exploit the temperature sensitivity of ^{13}C-^{18}O bonds in the carbonate minerals, forming the basis of many recent clumped isotope (Δ47) studies. Even though the theoretical foundation of this powerful proxy is well established, clumped-isotope-based temperature estimates in speleothems are often associated with large error bars. Moreover, the regional conditions inside a cave do not necessarily reflect the general calibration curve due to non-equilibrium calcification effects and processes that may occur in the vadose layer and the cave. To overcome this issue and calibrate clumped isotopes on regional scales, we propose a new approach that combines calcite farming, cave monitoring, and drip water sampling. We aim to elucidate the in-situ calcification processes of active speleothems and determine the relationship between stable oxygen, clumped isotopes, and cave temperature.To this end, we grew calcite samples on watch glasses in the deeper non-tourist part of Ondal Cave, South Korea, and carried out a monitoring program between June 2021 and June 2024. A Site with a relatively fast drip rate, clean calcite precipitation, and stable temperature (monitoring) was chosen to check the suitability of the location and cave environment stability for the clumped analysis. Watch glasses from this site were collected in Aug 2021, Apr 2022, and Jan 2023 and analyzed for Δ47 at the IBS Center for Climate Physics using a Thermo MAT253Plus IRMS + KIEL IV. The average temperatures from Δ47 thermometry, the temperature calculated using $\delta^{18}O$ of drip water and calcite, and the temperature from the Vaisala sensor show a remarkable match. Further, the study explores the possible role of site-specific fractionation within the cave by installing several watch glasses; the reconstructed clumped temperatures are similar to the cave temperature for most sites within the ±1.6°C long-term uncertainties. Based on the proximity of the individual isotope-based temperature estimates and the in-situ temperature, we consider Anderson et al. (2021) clumped isotope calibration appropriate for our cave environments and concluded that speleothem clumped isotopes in the central to north-eastern part of South Korea can indeed be used as a proxy for temperatures.

Cave ventilation dynamics in Eagle Cave (Spain) and controls affecting the cave air CO_2 concentration

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We studied the ventilation regime in Eagle Cave (Spain) to understand the sources and variability of CO_2 in the cave. We continuously monitored cave and soil air CO_2, external and cave basic meteorological parameters, as well as essential soil parameters. Like many caverns, Eagle Cave has a seasonal ventilation regime where warmer months have higher cave air CO_2 values, a condition that is reversed during the cooler months. The difference between the external and cave temperatures (DT_a) has a good correlation with cave air CO_2 at daily resolution. The air density, mostly controlled by air temperature, is thought to be responsible for this correlation. However, we found a lower correlation between the difference in external and cave air density (Dr_a) compared to cave air CO_2. In addition, when exploring sub-daily resolution, the correlation of DT_a is even worse, supporting that Dr_a cannot be the cause of ventilation. On the other hand, we found an excellent correlation between the difference of ground air temperature at the base of soil and the cave temperature (DT_s) when compared to the cave air CO_2. This correlation is persistent at daily and sub-daily scales, as well as when air density differences between the soil and the cave (Dr_s) are calculated. So, the driving mechanism of cave ventilation in Eagle Cave is not directly the density gradients related to DT_a but to DT_s. The ventilation of the cave is active during the whole year, because the density of the cave is always lower than the soil air density. Thus, Eagle Cave has dynamic ventilation even in summer months, although ventilation is more effective during winter, when the Dr_s is higher. The relationship between the Dr_s and cave air CO_2 is linear. We identified two main sources of CO_2: external and ground CO_2. A simple mass balance suggests that during summer almost 20% of the cave air is sourced from ground CO_2, whereas in winter this percentage is less than 5%. Tourist and soil CO_2 variations are also identified, but they have secondary roles in the CO_2 concentration.

Seasonal and interannual variations in the precipitation isotopic altitude effects in the East Asian monsoon region

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The altitude effect on the stable isotopes in meteoric precipitation, generally used as stable isotope paleoaltimetry, has been widely applied to reconstruct the paleoelevation of the plateaus at high altitudes. However, in low-altitude East Asian monsoon region, in which a large number of speleothem records are distributed, regional characteristics of the altitude effect on precipitation isotopes remain elusive, hindering a better understanding of the altitude effect on variations of speleothem isotopes and inter-cave comparisons. This study presented monthly resolved precipitation isotope data monitored at multiple stations along an altitudinal profile in East Asian monsoon region to investigate seasonal and interannual changes in the altitude effect on precipitation isotopes and driving forces. The results show that the altitude effect is significant on seasonal to interannual timescales, characterized by an intensified isotopic depletion with increasing altitude. The altitude effect on precipitation isotopes is stronger in warm seasons than in cold seasons, which coincides with the annual cycle of temperature gradient and sea surface temperature anomalies in the tropical Pacific Ocean. Moreover, we reveal that the relationships between precipitation isotopes and local climate (precipitation and temperature) are also significantly influenced by the altitude effect, featuring a strengthened correlation at higher altitudes. This study provides vital observational evidence for the altitude effect on precipitation isotopes in the East Asian monsoon region, facilitating an accurate assessment of altitude effect induced isotopic difference in paleo-proxy records and more reliable quantitative reconstructions of regional hydroclimate.

Examining fire fingerprints and impacts on carbon cycling in a semi-arid karst landscape through a controlled burn experiment

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Chemical records from stalagmites can illuminate the relationship between climate change and wildfire from past intervals when human influence on climate and land surface was greatly reduced compared to today. However, limited knowledge exists regarding the spatial and temporal transport of fire biomarkers through karst systems and fire's influence on radiocarbon and stable isotopic signatures of dissolved inorganic carbon in cave dripwaters and speleothem calcite. To better understand the signal of fire in karst landscapes and speleothem records, we have implemented a long-term monitoring program of the soil microbiome, soil and cave gas and dripwaters before and following a Fall 2024 prescribed burn above Titan Cave, Wyoming, USA, where ongoing dripwater sampling has occurred since 2019. Most investigations of fire impacts on karst systems have occurred in forests, whereas Titan Cave is covered by sagebrush steppe. Our monitoring approach includes pre- and post-burn seasonal analysis of biomarkers and radiocarbon and stable carbon isotopes in soil CO_2 in groves of juniper trees and patches of native grasses and sagebrush in the burn area and in a control (unburned area). The soil microbiome will be characterized pre- and post-burn using 16S and ITS-based amplicon sequencing for bacteria and fungi, and the vigorousness of soil respiration assessed with biodegradable sensors. Inside the cave, a dripwater autosampler will collect water for chemical and isotopic analysis at 4-day intervals. Initial pre-burn results illustrate differences in stable and radiocarbon signatures of soil CO_2 within the juniper and grass dominated areas above the cave. Soil CO_2 below the junipers is higher and has a modern radiocarbon age, consistent with deep roots transferring atmospheric CO_2 deeper into the soil. Bulk soil organic matter radiocarbon ages, on the other hand, highlight the higher carbon storage capacity of the soil beneath juniper compared to grasses. Tracking changes in different soil carbon species through the post-fire recovery will help identify fire impacts on soil carbon dynamics. Understanding the interplay between soil microbial populations, carbon cycling, and fire and how these would be captured in a stalagmite record will illuminate the relationship between climate and fire activity in diverse pre-colonial landscapes.

Selection of suitable oxygen isotope fractionation equations for paleotemperature reconstructions from present bimineralic rafts in Mallorca (western Mediterranean)

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Rafts are an under-studied type of speleothems that form due to CO_2 degassing at the water-air interface in calm bodies of water, such as lakes, gours, and ponds. Morphologically, they exhibit two distinct sides: the upper part (in contact with air), formed by smooth and flat crystals, and the lower part (in contact with water), composed of elongated crystals aligned along the C-axis downward into the water column, giving a rough and coarse appearance. The thin rafts float on the surface due to surface tension before sinking when they become too heavy or when the water is disturbed. They are typically composed of calcite, rarely of aragonite, and even more rarely contain both minerals.

This work focuses on the uncommon calcite-aragonite bimineralic rafts, currently being precipitated on the surface of hypogenic lakes in the coastal cave of Cova dets Ases, Mallorca (western Mediterranean). Oxygen isotope composition of the rafts, as well as that of the parent water and its temperature, have been analyzed over time during precipitation events in the lakes.

Previous studies suggest that raft precipitation occurs at or very near isotopic equilibrium, implying that the oxygen isotopic values of the rafts record the water temperature at the moment of their formation. The current growth of these floating rafts on the surface of the lakes of Cova dets Ases provides an opportunity to compare the temperature results from different isotopic fractionation equations (a total of 5 calcite-water equations and 10 aragonite-water equations) with the temperatures measured in the lake waters. This comparison allows for the selection of the most suitable equations for paleotemperature reconstruction.

The selected equations, which yield the closest values to the actual temperatures, can be considered the most appropriate for reconstructing paleotemperatures from old raft deposits. Additionally, they can be applied in combination with results obtained from other types of speleothems in Mallorca´s caves and tested in other cave environments across the Mediterranean basin.

Mg, Ca and Sr isotopes in cave environments: preliminary results from monitoring of three different caves in Hungary

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Caves represent a complex environment, in which speleothems can form and preserve information relating to the past climate and environmental changes. Therefore, speleothems are considered one of the most important climate archives from continental areas. In order to use speleothems in the reconstruction of past climate and environmental changes it is necessary to understand the environmental and hydrological processes that determine the physico-chemical conditions of carbonate precipitation and hence speleothem formation. Therefore, cave monitoring research has been conducted in three caves in Hungary since 2013. To expand the set of speleothem-based proxies the monitoring activities, which included monitoring of climatological parameters (e.g., temperature, CO_2) measured inside and outside the caves, drip rate, the chemical, trace element, stable hydrogen and oxygen isotopic compositions of drip waters, stable carbon and oxygen isotope analyses of newly formed carbonates, was complemented with calcium, magnesium and strontium isotope measurements of drip waters and newly formed carbonates since 2022.Climatological investigation revealed seasonality in CO_2 concentration related to outside temperature variation indicating variable ventilation regime in the studied caves. The comparison of the stable isotope composition of the drip waters and the amount-weighted precipitation indicated that the epikarst above the studied sites is generally well mixed and the dominant infiltration takes place during the winter half year. Moreover, the long-term monitoring of the stable isotope composition of drip water in Baradla Cave and the precipitation indicates slight changes in the precipitation over the years. Although the seasonal isotopic signal observed in precipitation is generally not transmitted to drip water, inter-annual variability can be recorded in drip water and hence in the precipitating carbonate (e.g., speleothem).The Mg and Ca isotope analyses of the drip water revealed systematic differences among the caves. In addition, the preliminary results suggest that the isotopic composition variability depends on the hydrological conditions. The research was financially supported by the National Research, Development and Innovation Office, Hungary (OTKA FK 138626). We are also grateful for the support and permission of the Aggtelek National Park Directorate.

Session 4:

Understanding climate and environmental dynamics: insights from palaeo-data and models

Speakers:

Calla Gould-Whaley
Elizabeth Patterson
Samuel Nicholson
Timon Kipfer
David Domínguez-Villar
Artur Stachnik
Julian Schröder
Chaoyong Hu
Bryce Belanger
Monika Markowska
Kathleen Johnson

Posters:

22. Sophie Warken
23. Elisa Hofmeister
24. Benjamin Tiger
25. Stephanie Gutmayer
26. Hubert Vonhof
27. Sarah Pederzani
28. Monika Markowska

Subaqueous speleothems suggest Heinrich 5 triggered enhanced tropical moisture delivery to southern Australia when people first settled the region

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Central Australia is currently characterised by aridity. The assumption that the region was just as dry, or even drier, during the Last Glacial Period led archaeologists to theorise that subsequent to their arrival ~ 65 kyr, humans must have settled the continent via coastal routes. However, the distribution of archaeological sites, as well as linguistic and ethnographic studies, suggest Australia's First People may have taken an inland route. Additionally, there is a growing body of evidence to suggest that, in an Australian context, glacial periods are associated with a more positive moisture balance, while interglacials are associated with aridity. A cave in the Ikara-Flinders Ranges (South Australia) contains subaqueous speleothems that shed light on the palaeohydrology of Australia's southern arid margin through the Last Glacial Period. The timing of subaqueous speleothem growth phases reveals three multi-millennial periods of positive regional water balance, each broadly aligning with peaks in Southern Hemisphere summer insolation. This suggests that moisture delivery to the region was governed by the Indo-Australian Summer Monsoon, the implication being that all of central Australia would also have been receiving enhanced tropical rainfall, potentially creating a pathway of perennial water reservoirs through the continental interior. Upticks in speleothem growth rates and initial uranium isotope activity ratios suggest there was a period of especially high moisture availability during Heinrich Event 5 (~ 49 to 47.5 ka), which coincides with the earliest evidence of human presence in southern Australia (~ 48 ka). Preliminary results from a North Atlantic freshwater hosing experiment support this hypothesis of enhanced tropical moisture delivery across central Australia in response to Heinrich 5.

Constraining equilibrium climate sensitivity with speleothem $\delta^{18}O$ and other paleorecords

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Equilibrium climate sensitivity, the temperature change that occurs in response to a doubling of atmospheric CO_2 concentrations, is a commonly measured model metric that is important for understanding the long-term climate response to greenhouse gas emissions. However, uncertainties in parameterized cloud and convective processes in climate models cause substantial spread in simulated equilibrium climate sensitivity values. To address this issue, we explore the potential of using paleoclimate records, which allow for an evaluation of model uncertainties over a broader range of climate forcing, as constraints for parameter settings in the cloud and convective parameterizations. Using global $\delta^{18}O$ datasets from speleothems, ice cores, and sediment cores, this study constrains cloud and convective parameterizations in a perturbed parameter ensemble of the ocean-atmosphere version of the NASA GISS Model E2.1. We find that certain parameter sets outperform the default under different conditions, but no single set consistently excels across all time periods. Other parameter sets consistently underperform relative to the default, suggesting they would not provide accurate estimates of equilibrium climate sensitivity. Paleoclimate data assimilation further refines these analyses by integrating proxy and model data, providing posteriors that identify “proxy-optimized” cloud and convective parameters. Altogether these analyses represent significant progress towards effectively utilizing paleodata to refine and constrain cloud and convective parameters in climate models, and ultimately equilibrium climate sensitivity.

Climatic predictors of speleothem deposition in SW Asia

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Speleothems are high-quality archives of past climatic information. In arid regions, such as southwestern Asia (SW Asia), they have been crucial to revealing past changes in annual precipitation (AP) and evaporation balance. However, there have been very few studies which provide clear climatic parameters for their deposition. One AP-based threshold of 300-350 mm yr^{-1} has been applied to desert speleothems; however, the applicability of this threshold has not been tested at a regional level, and other environmental and topographic factors may also be influential for speleothem deposition. Here, we compared the modern distribution of active and inactive speleothem cave sites to modern climatological information (precipitation, evaporation, temperature and topography) and use statistical techniques to assess the constraints on speleothem deposition in SW Asia. Logistic Regression (LR) reveals no clear AP threshold acts as an “on/off” switch for speleothem deposition. Instead, there is a probabilistic relationship, where the likelihood of speleothem deposition increases with rainfall. We analysed the distribution of cave sites relative to their terrain wetness index (TWI) to show that even sites with low recharge may have active speleothem deposition with rainfall below 300 mm yr^{-1}. We suggest cave-specific processes explain variable activation thresholds between sites. RF combines the effects of precipitation, aridity indices, temperature, evaporation and topography to provide a prediction of active vs. inactive speleothem deposition in SW Asia, achieving 75% accuracy. We highlight the requirements for a better understanding of karst processes and climatological factors in understanding the local activation and termination of speleothem deposition.

Central European water isotope lapse rate for past interglacials revealed using speleothem fluid inclusions

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Cave carbonate deposits such as stalagmites constitute a powerful tool to investigate the past water cycle. They contain micrometric sized fluid inclusions which are filled with past cave drip water, which is closely related to past precipitation water. One advantage of speleothem fluid inclusions is their ability to deliver absolute temperature estimates by using the oxygen isotope fractionation between the water and the calcium carbonate (Affolter et al., 2019). To analyze speleothem fluid inclusions, we used an improved speleothem fluid inclusion extraction line in order to measure hydrogen (δ^2H) and oxygen ($\delta^{18}O$) stable isotopes of released water amounts down to 0.20 µl. The past water isotope lapse rate of central Europe remains unknown to date. Thus, the principal focus of this study is to reconstruct a cave drip water lapse rate, which is the rate at which a parameter (isotopes or temperature) changes with altitude. Using speleothem fluid inclusions, we want to explore whether it has changed during past interglacial periods. To reconstruct the lapse rate, we measured fluid inclusions on ten stalagmites coming from different caves in the Jura Mountains and the Alps from Switzerland and France. The caves span elevations between 373 and 1750 meters. Furthermore in 2023, we launched the Citizen Science Project “Cave Drip Water” in close collaboration with various caving clubs in Switzerland and France to collect drip water samples from caves across Switzerland and in neighbouring regions. To date, we received more than 700 samples coming from over 120 caves at different altitudes. The drip water analyses will provide additional information about the spatial distribution of water isotopes in karst systems, allowing us to compare it with the most recent water isotope patterns in precipitation and karst water from Switzerland. Furthermore, the close collaboration with cavers and scientists allows us to reconstruct a modern cave drip water lapse rate, which can then be employed for comparison with the paleo lapse rate. Preliminary results indicate that modern and paleo lapse rates present similar slopes.

Quantitative paleotemperature reconstruction based on welt speleothems from a cave in central Spain

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We studied a relatively shallow cave in central Spain which temperature is approximately the mean annual temperature outside the cave. The cave records smooth seasonal oscillations with peaks delayed in relation to the external temperature, which indicates that thermal conduction dominates the cave temperature. Although advection occurs, it does not produce any high frequency thermal variability, since cave air is always denser than the external air and consequently cold spells cannot enter the cave interior by advection. Flowstones of a particularly shallow sector of the cave interior show welts that indicate that those speleothems were fractured, and that the calcite that forms the welts, occurred from fluids ascending by capillarity through speleothems cracks. The cracks of the thin flowstone resulted from the freezing of pore water in the clays underneath the speleothem. Calcite precipitation as welts at the surface of cracks postdate the freezing event. U-Th dating showed that flowstone was not fractured before 75 ka BP, whereas welts are Holocene in age. Since the gallery only can reach freezing conditions by reducing the mean annual temperature outside the cave, the freezing conditions likely occurred during extreme events of the last glaciation. A drop of 10.6 ºC in the mean annual temperature is required to freeze the gallery where welt speleothems were found. Paleotemperature reconstruction based on alkenones sampled in sediments from the Alboran Sea suggests that the colder period (9.8 ºC cooler than nowadays) took place during the HS2, around 24 ka ago. This date is compatible with the chronological frame of our speleothems and the magnitude of thermal anomalies for this event have similar magnitude. Our research shows clear evidence of freezing conditions in the cave and suggest that certain continuous paleotemperature reconstructions in ocean sediments can be transferred to the Iberian Peninsula without a significant effect of continentality. This study represents an interesting ocean-continent calibration that supports using certain ocean core paleotemperature reconstructions to validate other continental paleotemperature data from methods that require further assumptions and are consequently more interpretative.

Machine Learning and AI approaches to address limitations in modelling rainfall oxygen stable isotopes for paleoclimate reconstructions

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Stable isotopes constitute one of the main proxies used for paleoclimate reconstructions based on karst records. Understanding the spatial variability of oxygen isotopic composition of rainfall is a crucial aspect for the interpretation of ice and carbonate-based proxies. The Iberian Peninsula in Western Europe represents a paradigmatic case of a region subject to complex atmospheric dynamics influencing rainfall characteristics and distribution. In particular, the North Atlantic and the Western Mediterranean Ocean and atmospheric dynamics affect the isotopic composition of rainfall (and snow), an essential factor for calibrating paleoclimatic proxies and improving the accuracy of climate reconstructions.However, available models for simulating isotopic rainfall data often present significant limitations, mainly because they are based on static corrections, —i.e., they adjust values in a fixed manner without considering to dynamic changes and climate variability which limits their ability to capture the complexity of climate processes. Additionally, these methods frequently require the modeling of intermediate parameters, such as moisture uptake, which increases complexity and the risk of making interpretive errors.In this work, we aim to integrate Machine Learning and Artificial Intelligence as an innovative strategy to maximize the use of available rainfall monitoring data for estimating rainfall $\delta^{18}O$. This approach excels in its ability to model nonlinear relationships among multiple variables without the need to break down intermediate processes. By working directly with input parameters, such as the North Atlantic Oscillation (NAO) and the Western Mediterranean Oscillation (WeMO), this methodology captures, among other factors, the complexity of isotopic variability in rainfall, thereby enhancing the resolution and accuracy of past climate reconstructions. Therefore, the application of Machine Learning and Artificial Intelligence in paleoclimatology overcomes the constraints of conventional available models, enabling more precise and detailed reconstructions, especially in regions with high complex present and past atmospheric dynamics, like the Iberian Peninsula.

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Reconstructing mean annual air temperatures during central Arabian humid periods over the past 8 million years

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Several archaeological studies in the Arabian Peninsula revealed past periods of wetter and greener conditions that sustained palaeolithic human populations (e.g., Petraglia, 2003; Groucutt et al., 2015). Speleothem-based paleoclimate reconstructions of the Arabian Peninsula confirm the existence of short-lasting humid periods during interglacial phases in the Pleistocene (Fleitmann et al., 2011; Nicholson et al., 2020), with the oldest humid phases recorded extending back to the Late Miocene (Markowska et al., in revision). While these paleoclimate reconstructions provide valuable 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 (PET) 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, TEX_{86}, 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 PET was higher during the Late Miocene and Pliocene as compared to the Late Pleistocene. Based on PET estimates, we show that to exceed the modern precipitation minus PET balance, past rainfall must have been much higher. Refinement of this method will permit a more quantitative estimation of minimum precipitation amounts for the humid periods in central Arabia.

Annual mean tropical precipitation variation in Asian-Australian monsoon domain since last interglacial

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Climate models predict that tropical precipitation will increase under global warming, but the extent of increase in annual mean precipitation remains uncertain. Geochemical proxies provide long-term hydroclimatic records in tropics, but the quantitative calibration of these records to annual mean precipitation keeps unsolved, as the climatic information recorded in paleoclimate proxies can vary seasonally, leading to weak link to annual-mean climate changes. Here we quantitatively reconstructed the annual mean precipitation in the Asian-Australian monsoon domain (AAMD, 30S-30N and 65-125E) over the past 118,000 years from spatially separated cave records (Sanbao and Yangzi in central China), to understand the tropical precipitation dynamics at millennial and orbital scales. The difference in speleothem $\delta^{18}O$ between two sites ($\Delta^{18}O_{YZ\text{-}SB}$) robustly responds to the annual average tropical precipitation (dynamic effect) in AAMD, while the seasonal effect of temperature and special humidity (thermodynamic effect) is offset. Since the last interglacial period, AAMD precipitation exhibits orbital and millennial scale variations, consistent with the Greenland ice core $\delta^{18}O$, with an average of 4.01 ± 0.09 mm/day. The annual mean precipitation during the last interglacial period (118.1-70.0 kaBP), the last glacial period (70.0-11.5 kaBP), and the Holocene (11.5-0 kaBP) was 4.06, 3.96, and 4.05 mm/day, respectively, close to the modern observed 4.00 mm/day (1979-2022, GPCP data), indicating that global warming has strengthened the tropical hydrological cycle, but the variation amplitude is relatively small.

Coeval Holocene stalagmites record links between ENSO and western US hydroclimate on multi-centennial timescales

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The El Niño Southern Oscillation (ENSO) has varied in frequency and intensity throughout the Holocene, contributing to shifts in cool-season precipitation across the western United States (US). Previous work has shown that in combination with the Pacific Decadal Oscillation (PDO), ENSO modulates a north-south "precipitation dipole" in the western US. Western US tree ring records show that the dipole pattern has existed for over 500 years, and drought patterns associated with the dipole can persist on timescales of decades to centuries. However, very few high-resolution records of western US precipitation extend beyond the tree ring record of the last millennium, limiting our understanding of the occurrence and persistence of these patterns of natural climate variability on longer timescales and further in the past. In this study, we present precisely-dated, coeval stalagmite records of Holocene hydroclimate from Titan Cave (TC) in Wyoming, located in the northern Rocky Mountains. This area is of particular interest for understanding links between ENSO and western US precipitation, as it falls just north of the current transition zone of the precipitation dipole around 40° N latitude. We analyze trace element (Mg/Ca, Sr/Ca, Ba/Ca, P/Ca) and stable isotope (δ^{18}O, δ^{13}C) data from two coeval stalagmites covering ~5.7 ka to ~1970 CE, extending the hydroclimate record of the northern Rockies into the mid-Holocene. Proxies from TC stalagmites exhibit strong correlations with several coeval climate records, including regional snowpack as recorded by tree rings during the past ~500 years which suggest that the stalagmites record regional winter precipitation. Decreased snowpack and dry conditions at TC correlate with the positive phase of the PDO and more frequent and strengthened El Niño conditions in the tropical Pacific as recorded in Galápagos lake sediment records. The most frequent and variable El Niño conditions of the Holocene from 2.0-1.5 ka align with dry conditions at TC while the proxy records from lakes in the southern Rockies on the other side of the dipole suggest increased winter precipitation. If El Niño conditions are more persistent in the future, our findings show that winter droughts in the northern Rockies may be exacerbated.

Exploring the mechanisms driving humid episodes in central Arabia over the last 8 Ma

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The Saharo-Arabian Desert is the largest dryland barrier on Earth, stretching from western Sahara to the Thar Desert, impeding faunal dispersals between Africa and Eurasia. Recent research suggests this barrier has been in place for at least 11 million years (Ma). However, within the Saharo-Arabian Desert interior, fossil evidence from the Late Miocene and Pleistocene suggests the episodic presence of water-dependent fauna (crocodiles, equids, hippopotamids), sustained by rivers and lakes that are absent from today's arid landscape. Here, we examine desert speleothems to identify recurrent humid phases over the past 8 million years. Further, the isotopic composition of both speleothem carbonate and fluid inclusion water suggests an aridification trend in Arabia from the Late Miocene to the Late Pleistocene. We suggest the long-term aridification trend resulted from a time-transgressive reduction in rainfall during humid intervals, coinciding with enhanced Northern Hemisphere polar ice cover during the Pleistocene. To identify external forcing driving humid phases and the resultant atmospheric dynamics, we compared used simulations from the HadCM3 isotope-enabled model during the mid-Piacenzian warm period (3.264 to 3.025 Ma). We examine model output from a series of sensitivity experiments with different orbital configurations allowing us to postulate the mechanisms responsible for the occurrence of humid episodes, with potential implications for other dryland regions at similar latitudes. Together, our approach unveils the long-term controls on Arabian hydroclimate and may provide crucial insights into the future climate variability.

Speleothem Constraints on Mainland Southeast Asia Hydroclimate Dynamics

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Despite advances in understanding Asian monsoon variability, paleoclimate records from Mainland Southeast Asia (MSEA) remain limited. While past research has primarily focused on the Asian summer monsoon (ASM), regions like central Vietnam receive more rainfall during the autumn/winter monsoon (AWM). This study aims to explore the dynamic response of large-scale ASM/AWM strength and regional precipitation since ~45 ka by integrating multi-proxy speleothem records from Tham Doun Mai, Laos (TM) and Hoa Huong, Vietnam (HH), dominated by the ASM and AWM, respectively, with isotope-enabled paleoclimate model simulations. Our findings indicate that ASM and AWM strength, as inferred from speleothem d^{18}O, exhibit similar variations, except during Northern Hemisphere summer insolation (NHSI) maxima. In the early Holocene, the Laos and Vietnam $\delta^{18}O$ records diverge, with HH $\delta^{18}O$ shifting towards more positive values, possibly reflecting a relative increase in isotopically-enriched AWM rainfall in Vietnam. Additional proxies that are more sensitive to local water balance ($\delta^{13}C$, Mg/Ca, $\delta^{44}Ca$) indicate decreased rainfall in ASM-dominated Laos and increased rainfall in AWM-dominated Vietnam during the early Holocene, further supporting antiphase behavior on orbital timescales. Similar patterns appear during earlier periods, though signals are less clear, potentially due to the impact of sea-level and other glacial boundary conditions on MSEA hydroclimate. On millennial timescales, speleothem results show decreased ASM/AWM strength and locally dry conditions at both sites during Heinrich Stadials 1-4 and the Younger Dryas, suggesting similar impacts on ASM and AWM rainfall from abrupt Northern Hemisphere cooling. Climate model results suggest that regional precipitation amount and $\delta^{18}O$ may be decoupled on orbital timescales, as increased NHSI drives both increased upstream rainout and a northward convection shift, potentially explaining why a strong ASM during NHSI maxima coincides with dry conditions in Laos and a strong AWM and wet conditions in Vietnam. Conversely, model results indicate that ASM/AWM strength and regional precipitation at both sites covary on millennial timescales, albeit with different drivers. Further proxy measurements and climate model analyses will help better constrain the dynamics of orbital and millennial scale variability in the region, contributing to improved climate model projections for this vulnerable area.

Speleothem elemental composition: A global view on dominant drivers and environmental patterns

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The elemental composition of cave carbonates is increasingly applied and acknowledged as independent and valuable proxies to reconstruct past environmental and climatic conditions. Here we use a global dataset from the SISALv3 database (Kaushal et al., 2024) to extract information on dominant drivers and environmental patterns on speleothem Mg/Ca, Sr/Ca, Ba/Ca, U/Ca, and P/Ca ratios. The main SISALv3 database contains data from 90 entities (speleothem records). In addition, 23 high resolution records have been extracted from the repository for this project. In total, 93 Mg/Ca, 83 Sr/Ca, 49 Ba/Ca, 26 U/Ca and 29 P/Ca records from 73 caves are available, of which 25 caves provide multiple entities. As such, the dataset allows a global comparison and also evaluation of in-cave variability.Preliminary analyses showed mineralogy (aragonite vs. calcite) is the main controlling driver of speleothem elemental variations as expected. A growth rate effect on Sr/Ca or Ba/Ca cannot be excluded, and is more evident within individual speleothem records. On a global scale, no clear relationship between element/Ca ratios and host rock geology is observed. For example, similarly high Mg/Ca ratios occur for different lithologies, e.g., limestone, dolomite, or dolomitic limestone. This may be because drip flow paths do not necessarily parallel identified regional lithological units, or because lithology is not everywhere sufficiently characterized. Warmer and more humid sites appear to exhibit higher and more variable Mg/Ca ratios, which could reflect a (hydro-)climatic influence on chemical weathering and dissolution/precipitation processes in the soil and karst zone. In addition, coastal sites also tend towards higher Mg/Ca, Sr/Ca, and Mg/Sr ratios, highlighting sea spray as a potential additional source of these elements.Ongoing efforts focus on increasing the number of

records in the dataset accessible for this project. This will enable more detailed analyses and robust statistical interpretations to further identify and disentangle dominant drivers of elemental variations in speleothems on a global scale.

Kaushal, N., et al (2023). SISALv3: A global speleothem stable isotope and trace element database. https://doi.org/10.5194/essd-2023-364

Absolute paleotemperature estimates for Central Europe over the last 350,000 years using speleothem fluid inclusion water isotopes

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Fluid inclusions are common in speleothems and they constitute a repository for past drip water, which itself provides information about the hydrological cycle and the temperature evolution in the past. Studies showed the potential of the use of hydrogen (δ^2H_{fi}) and oxygen ($\delta^{18}O_{fi}$) stable isotopes of the fluid inclusion water for the reconstruction of absolute paleotemperatures, as for instance from Milandre Cave stalagmites in north-western Switzerland (Affolter et al. 2019).Speleothem fluid inclusion analyses were performed at the Department of Environmental Sciences at the University of Basel. To extract the water, we crushed calcite pieces of approximately 0.5 grams using a hydraulic press in an extraction line. The released water is then transferred directly to the analyzer (Picarro L2130-i or L2140-i instruments) using dry nitrogen for the precise and simultaneous determination of both δ^2H_{fi} and $\delta^{18}O_{fi}$. To reconstruct paleotemperatures, we use the calcite-water oxygen isotope fractionation as a paleothermometer. Considering that numerous temperature records have been produced for the Holocene, there are rarely any pre-LGM records for Central Europe available. Here, we present temperature reconstruction covering the last 350'000 years. The vast majority of estimates are based on fluid inclusion analyses performed on several stalagmites from Milandre Cave in the Jura Mountains. In addition, we also analysed fluid inclusions on two stalagmites coming from Crotot and Grappin caves in France. The new and much longer Milandre Cave Fluid inclusion temperature (MC-FIT) record shows that mean annual air temperatures during marine isotope stages 5 and 9 were up to two degrees warmer than modern-day temperatures. Moreover, our reconstruction is supported by the independent temperature reconstruction based on TEX86 thermometry that also reconstructs cave air temperatures.

Affolter et al. (2019), Sci. Adv. 5 eaav3809, doi.org/10.1126/sciadv.aav3809

Hydroclimate in northern Madagascar over the past 27,000 years: A new composite record and model intercomparison

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To explore the role of different forcings on Madagascar's hydroclimate across timescales, we composited 11 speleothem $\delta^{18}O$ records from Anjohibe (a cave in northwestern Madagascar) to generate a nearly continuous monsoon history from the end of the Last Glacial Period to the present. The composite shows depleted $\delta^{18}O$ during the Last Glacial Maximum compared to the Common Era, indicating relatively wet conditions and a strong monsoon during glacial times compared to the present. At orbital timescales, the monsoon is stronger under higher Northern Hemisphere summer insolation, particularly during the Holocene. The composite also indicates a weaker monsoon during abrupt centennial- to millennial-scale Northern Hemisphere cooling events, such as Heinrich stadials and the Younger Dryas. These responses are surprising for a site in the Southern Hemisphere tropics. Previous work shows that these unexpected responses likely occur due to steepening zonal tropical Indian Ocean temperature gradients rather than meridional shifts of the tropical rain belt.An isotope-enabled transient model simulation and data assimilation product were used for comparison with the new composite record. iTraCE and the Last Glacial Maximum Reanalysis (LGMR) both show $\delta^{18}O$ enrichment during instances of deglacial AMOC weakening during Heinrich 1 and the Younger Dryas, in good agreement with the northern Madagascar composite. However, the magnitude of the modeled response is far smaller than what the proxies reconstruct, possibly due to underestimations of simulated local precipitation. Correcting these model biases will allow for better future predictions in this socioeconomically and ecologically vulnerable region.

Modelling the global distribution pattern of speleothems and its link to soil carbon

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This study combines climate model outputs from the MPI-ESM with SISAL speleothem records and other data sources to holistically identify the climate conditions for stalagmite growth, with a focus on predicting speleothem occurrences under variable climate conditions within carbonate-rich karst environments. A central question concerns the largely underdetermined origins of the dead carbon fraction (DCF) in speleothem carbon isotopes. We use the Hulu Cave 14C record as an ideal atmospheric reference archive and model carbon isotopic behavior through synthetic time series generated using the geochemistry model CaveCalc. This model, coupled with climate-based soil respiration data and a carbon transfer function, allows us to simulate DCF dynamics and achieve a stable DCF pattern consistent with Hulu Cave speleothems. These results suggest a high degree of soil carbon openness and limited climate influence on DCF in this region. Building on this framework, we aim to identify the broader climate boundary conditions that could foster stalagmite formation, mapping key climate parameters to growth patterns across different speleothem sites. By analyzing stalagmite growth and climate parameters from SISAL records using a Random Forest algorithm, we classify periods of growth and non growth, generating a ranked list of climate factors most critical to speleothem development. This integration of speleothem records with climate modeling offers a novel approach to predicting potential stalagmite distribution patterns, providing new insights into the climate dependencies of speleothem formation. Our findings enhance the potential of speleothems as paleoclimate proxies, with implications for identifying undiscovered stalagmites in conditions conducive to growth and for refining DCF-based climate reconstructions.

Speleothem paleoclimate records from the Kenyan coastal forest zone

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The coast between Mombasa and Malindi (Kenya) is part of the East African coastal forest, an area of considerable paleoecological interest [1]. Whereas most of the horn of Africa is believed to go through a regime of wet-dry cyclicity paced by the Earth's precession cycle, the coastal zone likely had a much more equitable climate through time, due to moisture sourced from the nearby warm Indian Ocean surface waters [1, 2]. Such a special climate state for the coastal zone may imply that the area acted as a refugium, that remained habitable in times of regional drought [2]. In recent years, it has become clear that hominin fossils are present in this area [3, 4], and with that, the relation between paleoclimate and hominin presence in the coastal forest zone has become a matter of considerable interest. However, progress is currently hampered by the paucity of coastal forest zone paleoclimate data. Particularly records that span one or more glacial - interglacial cycles are lacking.We here present the first results of paleoclimatological analysis of speleothem samples, from an extended karst area stretching between Mombasa and Malindi (Kenya). U-series dating provides the temporal framework, and climate proxy data (TEX_{86} temperatures, fluid inclusion isotope analysis) will be directed towards quantitatively understanding the climate variability that characterized the Kenyan coastal zone in the late Quaternary. Future integration of paleoclimatological data from speleothems with archeological data is expected to elucidate the role of the coastal forest in hominin dispersal and evolution in East Africa.

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A Bayesian approach to stalagmite proxy system modeling – quantitative multiproxy integration in the StalFire consortium

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Speleothems are powerful paleoclimate archives, in large part due to our ability to measure a large suite of paleoenvironmental proxies from a single sample and to generate coupled records of changes in hydroclimate, vegetation, or even past fire activity. However, quantitative interpretation and multiproxy integration of stalagmite records remains a considerable challenge. Typical comparative assessment of different proxies - while generally effective - often cannot capitalize on the full potential of quantitative integration of multiple proxies and suffers from a lack of robust representation of uncertainty.A powerful way to improve upon this and take a step further towards quantitative interpretation of stalagmite records is Bayesian proxy system modeling. Proxy system models (PSM) are forward models that numerically describe the transformation of climatic forcings through the epikarst and their final recording in speleothem calcite. A range of karst and stalagmite models have been developed to describe some of these processes, and their use has proven a valuable tool to the speleothem community. However, many conventional PSMs offer only limited options for multiproxy integration and accounting for uncertainties in input parameters remains a laborious process in many cases.Here we present a Bayesian approach to stalagmite proxy system modeling, which leverages Joint Bayesian Inversion methods to provide full quantitative multiproxy integration and characterization of uncertainties on input data and model parameters. As part of the StalFire consortium project investigating joint hydroclimate and forest fire regimes in California, our PSM aims to incorporate a range of established and novel proxies of palaeoclimate and fire activity. We present initial model development together with pilot results from model-monitoring comparisons of key proxy systems including δ18O, δ13C, and δ44Ca. In particular we focus on disentangling moisture source and precipitation amount effects and demonstrate the impacts of incorporating uncertainty of input parameters in a Bayesian workflow. Going forward, model inversion will support the exploration of hydroclimate and fire activity documented in multiple stalagmite records across California.

A global compilation of initial $^{234}U/^{238}U$ variability in speleothems using the SISAL database

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The speleothem uranium (U) isotope proxy is based on the radioactive disequilibrium between ^{234}U and ^{238}U, which is routinely measured during U-Th dating, and where the initial ratio at the time of formation $(234U/238U)_0$ can be used to infer past variations in water-rock interactions. This is because natural waters typically exhibit disequilibrium between ^{234}U and ^{238}U which may be recorded in speleothems forming from these waters and track geochemical variations in groundwater driven by changes in water-rock interactions, ultimately providing records of paleo-water balance. Consequently, $(^{234}U/^{238}U)_0$ has been applied in several studies as a hydrological proxy due to its water residence time sensitivity. However, a directed global study to identify the dominant drivers of $(^{234}U/^{238}U)_0$ variability has never been performed. Here, we use the U-Th series data provided by the dating table in the SISAL database to examine the average $(^{234}U/^{238}U)_0$ from 667 unique speleothem records from 304 caves. The average $(^{234}U/^{238}U)_0$ across all calcite and aragonite speleothems were 1.62 ±0.93 and 2.56 ± 1.89, respectively. After controlling for mineralogy, we find no clear relationship with $(^{234}U/^{238}U)_0$ and U concentration. However, speleothems which formed in host rocks of greater geological age had higher and more variable $(^{234}U/^{238}U)_0$. To assess the potential role of climate controlling average $(^{234}U/^{238}U)_0$ values, we compiled a Late Holocene speleothem subset database (0-2 ka). We assumed modern day climate equivalence across sites and calculated a bulk average $(^{234}U/^{238}U)_0$ for each speleothem, which resulted in 177200 individual entities from 126 caves. We examined climate variables such as average annual precipitation, temperature, evapotranspiration, aridity index and water balance. There were no significant relationships between the climate variables and $(^{234}U/^{238}U)_0$ on a spatial distribution. This contrasts with several observations, where the temporal evolution of $(^{234}U/^{238}U)_0$ in speleothems is found to vary with changes in the climate conditions (ie. glacial/interglacial, stadial/interstadial shifts). This highlights that other parameters such as the host rock age and connected processes (i.e., redox-conditions) are more important for the absolute value of $(^{234}U/^{238}U)_0$.

Session 5:

Science communication, public outreach, transformation/EDI, best practices for field work and cave preservation

Speakers:

Juan Pablo Bernal
Sakonvan Chawchai
Robyn Pickering

Keynote: Nkosingiphile Mazibuko and Amy Sephton

Posters:

29. Kathleen Wendt
30. Valeriu Murgulet
31. Shantanise Phepheng

Citizen scientists are essential for successful cave and environmental monitoring in Latin America; examples from Mexico

Juan Pablo Bernal[1], Paola Galindo Avalos[1], Ivan Hernádez García[1], Ofelia Pérez-Arvízu[1], Herminio Rojas[2], Antonio Rey Cruz Santiago[2]

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Cave monitoring is an essential tool to understand the effects of atmospheric and environmental conditions on the different geochemical proxies incorporated during speleothem/stalagmite growth, and thus, vital to understand the proxy variability. This, however, remains a significant logistical and financial challenge due to the remoteness of the monitoring sites, hampering the acquisition of high-resolution monitoring data. To overcome this limitation, collaboration with local guides, residents and high-school teachers and students has proven to provide us with high-resolution high-quality cave atmosphere and environmental data that, otherwise, would have been extremely complex to acquire,Here, we present examples where monitoring by local citizen scientists in three different localities in Mexico has allowed us to obtain long-term, high-resolution records of cave atmosphere and environmental conditions, which are shown to be essential to understand the dynamics of cave ventilation, sulfur inputs, and rainfall isotopic composition, datasets that would have been impossible to acquire without local help, and are proving essential to understand the variability observed in stalagmites. Transparency with the local communities, as well as feedback on the work that is being carried out, is key to maintaining a long-term collaboration with the community, whose main interest is to learn more about their environment and to better preserve it. Such partnership, however, is now also translated into co-authorship of the scientific products stemming from their work, to acknowledge their essential, but long overseen, scientific contribution.

3D mapping and virtual tour development of Klang Cave, Thailand

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Currently, more than 5,000 caves have been discovered in Thailand. The beauty of these caves attracts tourists, making cave tourism a source of income for the local communities. However, caves are vulnerable to destruction from natural disasters and human activities. Therefore, planning for long-term monitoring, management, and development of cave resources is essential. Klang Cave in Southern Thailand is considered one of the most beautiful caves in Southeast Asia. The Permian karst tower limestone and speleothems inside the cave offer valuable insights into the Earth's past, making it an ideal site for study and education. This research aimed to create a 3D model of the Klang cave using a laser scanner to provide guidelines for developing geological tourism spots in the cave area of Krabi Province. To raise public awareness of the cave's importance, 360-degree images of various points in Klang Cave were compiled into a virtual tour (https://www.geo.sc.chula.ac.th/virtual/klangcave), showcasing the shape and sculptures of the cave in detail, along with audio commentary in both Thai and English to guide visitors. The data from the cave floor can be used to create a tourism map that is more accurate and precise than maps from traditional 2D surveys. Additionally, 3D data from the cave ceiling can be used to analyze the fracture system inside the cave. Our results show that the stalactites are aligned in two directions: northeast-southwest and northwest-southeast. When compared to the shape of the Klang cave, it was found that the cave halls are connected in a zigzag pattern along the two fracture directions. This research serves as a case study in collaboration with local communities and government officials to preserve the cave and promote sustainable tourism.

What is scientific neo-colonialism and do we need to care about this in karst research?

Robyn Pickering

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Scientific neo-colonialism, known colloquially as ‘helicopter science’ can be defined as the, almost always inadvertent, practise of exploiting and excluding in-country local researchers and communities from all aspects of the research pipeline by researchers from the Global North. This covers the conceptual phase of a project, funding proposals/applications, fieldwork, data analysis and finally publication. We can place this practice in the context in which research is conducted, where, again inadvertently, remnant colonial mentalities underpin much of our modern thinking. This colonial mentality regards regions now recognised as the Global South, places like Africa, Asia and much of South Africa, as vast, homogenous, un- or sparsely inhabited and underdeveloped. This was used to justify, and indeed support, colonial invasion, dispossession, and subjugation of the local communities. Today in the post-colonial era, we still see the echoes of this in practises like helicopter science, where the former colonizers benefit at the expense of the formally colonised. As the karst research community, we need to grapple with legacy and current research practices and consider who does field work where and who benefits from the study of karst areas. Science and research are not imperial but a product of the community who produces them, so we have an opportunity as the karst community to recognise this issue and work together to develop best practice guidelines and a more equitable framework in which the future of our field can develop.

Socially responsive practice in human evolution: a case study of the HUMANITY museum exhibition at the Iziko Museum, South Africa

Nkosingiphile Mazibuko[1], **Amy J. Sephton**[1], Wendy Black[1,2,3] , Tessa J. Campbell[3,4], Robyn Pickering[1,5], Rebecca R. Ackermann[1,2], Wendy Black[1,3,4]

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Social responsiveness is an umbrella term used to refer to all forms of academic engagement with non-academic constituencies. Although some research is itself socially-responsive, for many researchers such engagement primarily takes the form of dissemination of scientific knowledge to the public through e.g. lectures, workshops, or museum exhibitions. Museum exhibitions in particular can impact large numbers of people from diverse backgrounds, making them a key site for best practice. One challenge in presenting human origins research to diverse communities lies in a disciplinary history that is colonial, and the manifestations of this, including narratives centering White/Western exploration, and the primitivisation of Black bodies. Here we discuss the process by which we produced a new permanent human evolution museum exhibit, entitled HUMANITY, at the Iziko South African Museum in Cape Town. From its inception, this exhibit was co-created with the input of a wide range of people, including curators, researchers, community leaders, artists, educators, students, design teams, and others, using practices of active community engagement. All exhibition components were developed to create a welcoming, inclusive space that shares our human origin story as a collective, with care to avoid approaches, language, and visuals that might suggest that any people are superior or inferior relative to others. This process defined both content and design. Arguably the most striking aspect of the exhibit is its overall build, using a pre-colonial building material, which is a direct result of critical engagement that made it clear that typical Western museum design is alienating to many people. Rather than centering scientists and their discoveries, the multilingual story unfolds by considering the biological and cultural diversity of people in South Africa today, as an inroad for exploring how that diversity came to be evolutionarily. The exhibit openly acknowledges the negative legacies of human evolution researchers and museum practice, including body collection, and encourages critical reflection on race, skin color variation, and privilege. In the place of dioramas, popular art and imagination are used to recreate the past; there are no images or sculptures of dark-skinned primitive-looking hominins. The thread of complex human interconnectedness runs through the exhibit, consistent with our current understanding of the braided stream narrative for human origins, but also relevant to dismantling the idea of biological race. Our hope is that by presenting the science of human evolution in this manner we create a space of engagement, one where future generations can see themselves entering the discipline without feeling alienated or othered, thereby transforming the discipline going forward.

Small-diameter coring of speleothems in Oregon Caves (USA)

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Oregon Caves National Monument and Preserve is located in the Rogue River-Siskiyou National Forest in SW Oregon (USA) and managed by the U.S. National Park Service. The purpose of this study was to determine the age of several in-situ speleothems while minimizing the visual impact of calcite sampling. We drilled 8 small-diameter (~1cm) calcite cores from the base of 6 intact stalagmites in Oregon Caves. In addition, calcite chips were collected from 2 previously broken stalagmites using a small chisel. The age of calcite sampled was determined using uranium-thorium (U-Th) dating at the University of Minnesota. 50-100 mg of calcite powder was hand-drilled from the end of each core that was nearest to the center growth axis. U-Th results reveal growth phases at 7.7 thousand years before present (ka), 40 ka, 132-123 ka, 216 ka, 218 ka, 385 ka, and 522-513 ka. 2σ relative age uncertainties average 2%. One stalagmite is older than the limit of U-Th dating (>600 ka) and is currently the oldest known stalagmite in Oregon Caves. Results confirm that similarly aged stalagmites are clustered together within the cave. Nearly all sampled stalagmites grew during interglacial periods, specifically MIS 1, 5e, 7c, 11 and 13. Our preliminary results are part of an ongoing investigation into the climate history of SW Oregon during previous interglacial periods.

Field Geology Study Abroad Program in the Yucatán Peninsula: Integrating Karst Hydrogeology, Geochemistry, Structural Geology and Cultural Perspectives

Valeriu Murgulet, Dorina Murgulet

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Texas A&M University-Corpus Christi (TAMU-CC) Geology, in collaboration with the Study Abroad Office, has been offering the undergraduate Field Geology course as a faculty-led study program in the Yucatan Peninsula since the summer of 2021. This program aims to provide a capstone experience in the field of Geology with a focus on Karst Hydrogeology, Geochemistry, and Structural Geology. The base camp is in Mérida, Yucatán state, Mexico. It offers fieldwork experience such as sample collection, determining field parameters, karst and cave maps/surveys, measuring spring discharges in the Yucatán Peninsula of Mexico, and laboratory experience on the TAMU-CC campus. The relationship between the Ring of Cenotes and regional fracture and/or local fracture patterns within the Ring of Cenotes are also determined in the field in addition to field observations along the Ticul fault. Several outcrops of highly permeable karst limestone deposits and groundwater seawater mixing locations along the Yucatán coast are within driving distance from Mérida and key for fieldwork projects. This study abroad is critically important to our students as it offers students the best way to develop empathy, broaden perspectives, and expand horizons. Not only is studying abroad an integral part of their development as students and human beings, but it is also a rewarding and inspirational experience that will stay with them for the rest of their lives. During this study abroad, students earn credit for the required field camp (similar to a capstone project), and they also expand their horizons and challenge their preconceived notions of the world. This experience will broaden their scientific and cultural perspectives, which will positively impact their life and those of others around them long after they graduate, potentially for a lifetime.

The Effects of Climate Change on the ‡Khomani World Heritage Cultural Landscape in the Northern Cape Province, South Africa

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The ‡Khomani Cultural Landscape located within the Northern Cape Province of South Africa is home to Southern Africa's longest surviving indigenous population. The delicate cultural and ecological structure of the territory is now facing severe risk because of climate change leading to temperature elevation, extended droughts and landscape dehydration. Environmental transformations have resulted in decreases in biodiversity combined with reduced water availability and diminished state of culturally important sites. The traditional survival of the ‡Khomani people faces socio-economic stress because climate changes alter their entire way of life. The research uses mixed methods by merging climate data investigation with ethnographic research and community member interviews for evaluating climate change effects on the ‡Khomani Cultural Landscape. The results demonstrate an urgent requirement for implementing sustainable conservation practices which unite local wisdom systems with climate adaptation management methods. Studies confirm the need for locally directed strategies as well as governmental policies to reduce the negative consequences of climate change on historical sites. The study brings important insights to worldwide discussions about indigenous landscape preservation during climate change while offering sustainable framework strategies for arid regions.

Session 6:

Clastic Cave Deposits, and caves as repositories for fossils, archaeology and rock art, open air karst records

Speakers:

Kristina Krklec
Neal Mathes
Rafael Lopez
Laurent Bruxelles
Kantapon Suraprasit

Keynote: Megan Malherbe

Posters:

32. Phanindra Reddy Annapureddy
33. Ros Fatihah Muhammad
34. Georgiana Alexandra Grigore
35. Ainhoa Val
36. Kgotlhelelo Seagiso
37. David Domínguez-Villar

Geochronology of Pleistocene tufa deposits from Krka National Park, Croatia

Kristina Krklec[1], David Domínguez Villar[1], Neven Cukrov[2], Hai Cheng[3], Lawrence R. Edwards[4]

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Tufa deposits are freshwater carbonate-rich deposits precipitated in spring, fluvial, lacustrine, and paludal settings. They are good environmental indicators due to their fast response to change in environmental conditions and/or climate. The delicate equilibrium of most tufa systems can lead to erosion or even the complete destruction of tufa sedimentary structures. Erosion episodes resulting in the collapse of tufa barriers are frequent in the geological record, and in some cases, tufa deposits can record the causes of erosion events better than relation detrital fluvial deposits. Here we present the study of a past tufa barrage deposit from Roški slap (Croatia) that is located in the canyon of the Krka River, where fabulous recent tufa barrages are one of the main attractions of a national park. In order to establish accurate chronology and calculate the tufa barrier growth rate, we used U-Th dates and used IsoplotR to apply the isochrone method. Our results show that most of the past Roški slap tufa deposit accumulated during thousands of years of the past interglacial. Our chronology supports that the tufa deposit collapsed because of the erosion caused by the environmental changes that occurred during an abrupt climate change at the demise of the past interglacial. This abrupt change to cold and arid conditions triggered changes in vegetation that impacted the decreased the potential to precipitate tufa and increased detrital sediment supply to the river, which eventually resulted in the erosion of the past Roški slap tufa barrier.

Unraveling the history of the Alps' largest glaciations: Burial dating allochthonous sediments in the Jura

Neal Mathes[1,2], Marc Luetscher[1], Susan Ivy-Ochs[3], Catharina Dieleman[2], Marcus Christl[3], Christof Vockenhuber[3], Naki Akçar[2]

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The glacial history of the Alps is one of the most well studied in the world. However, beyond the last glacial cycle, our knowledge is a patchwork with large uncertainties surrounding glacial extents, timing, and climatic conditions. Despite this, the Middle Pleistocene glaciations are a critical part of Quaternary glacial history. The benthic $\delta^{18}O$ record shows that these glaciations were the largest globally, and local geomorphic evidence suggests that they were responsible for the most significant glacial reshaping of the Northern Alpine Foreland (Schlüchter et al., 2021).Understanding Middle Pleistocene glacial cycles is difficult due to the reworking of glacial deposits by subsequent glaciations. This is made worse by limited sediment preservation in mountainous areas. The karstic record in the Alps, Jura, and surrounding regions, represent an underutilized archive of such glacial sediments. In this study we investigated allochthonous sediments from Grotte aux Fées, located in the central Jura Mountains of Switzerland. Cobble and gravel samples of various Alpine lithologies were collected from the bedload of a subfossil conduit. Alpine material was transported to the area through glacial processes, however Alpine lithologies are not observed in nearby, surficial Quaternary deposits. The burial age of samples was determined using cosmogenic ^{10}Be and ^{26}Al with isochron-burial dating and new P-PINI modeling techniques (Erlanger et al. 2012; Nørgaard et al. 2023). Good agreement on the burial age was found using both methodologies. Results indicate that during MIS-12 the Alpine Ice Field extended into the Jura beyond the LGM extent. Petrographic analysis of recovered allochthonous clasts has provided insights into the catchment area of the upstream glacial system. This has implications for possible paleoclimatic regimes during MIS-12, including a likely southward shift of the North Atlantic Storm Track.

Erlanger, E.D., Granger, D.E., Gibbon, R.J., 2012. Geology. 40, 1019-1022.Nørgaard, J., Jansen, J.D., Neuhuber, S., Ruszkiczay-Rüdiger, Z., Knudsen, M.F., 2023. Quaternary Geology. 74, 101420. Schlüchter, C., Akçar, N., Ivy-Ochs, S., 2021. Landscapes and Landforms of Switzerland. 47-69.

Sediments of Kaua Cave, Mexico

Rafael Lopez[1], Daisy Valera[1], Erick Sosa[2], Michel Vazquez[2], Kayu Vilchis[2]

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Kaua is the most extended cave system in the Yucatán state of México. The cave shows a complex maze pattern that the Maya culture used for ritual and ochre mining activities. Thus, Kaua is a hypogenic cave with many red clastic sediments of a non-clear origin. Investigation shows three main facies: backswamp, slackwater, and thalweg. Sediments are affected by glegic processes in the lower part of the sequence. Microscopic analyses revealed that sediments are composed of soil-derived material entering the cave by vertical movements and only short-distance horizontal transport. After several dives in the underwater part of the cave, we documented the transport of present-day sediments in the cave by vertical transport (mainly suffusion). Nonetheless, the current surface's soil differs from those we found in the cave, revealing some significant changes in the soil formation conditions. The investigation in the process is dating the sediments and a detailed mineralogic characterization to better understand the genetic process and the use for Mayan culture as ochre deposit

Clastic Sedimentation in Karsts: The Example of Fossiliferous Breccias in Southern Africa

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Karst landscapes are unique geomorphological environments, and this distinctiveness extends to their detrital deposits. The formation of clastic slopes below cave entrances results from specific processes, which have been investigated for over 30 years in caves around the world. Understanding clastic and chemical deposit formation processes in karst caves is especially crucial for dating ancient hominin fossils. When direct dating of fossils is not possible, accurate stratigraphic interpretations and control of sedimentary contexts become essential to ensuring coherent interpretations of the associations between fossils and the clastic or chemical sediments being used to date them.In this presentation, we offer a comprehensive review of the processes that lead to the accumulation of colluvial clastic deposits beneath cave entrances. We will illustrate this with straightforward cases, where dating correlates consistently and coherently with stratigraphy, as well as more complex examples that show inconsistencies. We will then explore the processes responsible for these discrepancies, demonstrating the sedimentary complexities of karst systems, especially when dealing with depositional sequences spanning several million years.A multiscalar approach, which integrates geomorphology, stratigraphy, sedimentology, and micromorphology, allows us to reassess certain dates by contextualising them within a broader framework of karst processes. These observations establish foundational stratigraphic relationships on which dating must rely. Accurate dating of deposits, and nuanced intra- and inter-assemblage interpretation requires interdisciplinary approaches that help produce results that have significant implications not only for understanding our origins but also for the dynamics of caves, their entrances, and the surrounding landscapes.

First discovery of a late Middle Pleistocene Pongo-bearing fauna in the cave of Tham Khao Phak Kut, Krabi Province in Peninsular Thailand

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As Peninsular or southern Thailand is regarded as an obligatory pathway for Pleistocene hominins and large mammals during their dispersal across the Indochinese and Sundaic biogeographic subregions, the region has held potential for documenting the evolutionary history and distribution of hominids and large mammals during the Quaternary, particularly in terms of first and last appearance records. Paleoecological and paleoenvironmental investigations linked to the cause of extinction of some species in this region are thus highly relevant.

In 2021, isolated teeth of mammals were collected from the layer of cave breccia within the cave of Khao Phak Kut (or “Tham Khao Phak Kut”), Krabi Province in Peninsular Thailand based on several field excavations. The fauna not only contained several living taxa (e.g., primates, ursids, elephants, rhinocerotids, suids, and large cervids and bovids), but also yielded some locally extinct taxa: Hystrix indica, Pongo sp. and Naemorhedus goral. Preliminary chronological results based on combined ESR/U-series analyses of faunal teeth as well as luminescence dating of sediments with U-series applied to overlying flowstones suggest a late Middle Pleistocene age for the fauna. The stable carbon isotope ratios of mammalian tooth enamel indicate that the area was covered by a wide range of ecosystems ranging from closed forests to open grasslands dominated by C_4 vegetation.

Our findings represent the first record of fossil orangutan Pongo in Peninsular Thailand, indicating a prevailing forest habitat in the area. Although the forest-grassland mosaic was dominant in the region during the late Middle Pleistocene, the study suggests that patches of forests might have been a key role contributing to the survival of orangutans and some forest-inhabiting mammal taxa. The expansion of diverse tropical forest environments or forest mosaics across Sundaland might have facilitated the transequatorial dispersal of orangutans and forest-associated mammals into the islands of Indonesia (Sumatra, Java, and Borneo) during the late Middle Pleistocene, prior to the subsequent isolation of their populations.

Fossil fauna from the caves of South Africa's Cradle of Humankind: understanding ancient ecosystems through functional morphology

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South Africa's Cradle of Humankind contains some of the most important cave sites of human evolution, representing hominin fossils attributed to at least five species. However, lack of a detailed chronology for the sites has meant that these significant fossils are yet to be placed within a precise climatic or vegetative framework. Now, recent uranium-lead dating of cave flowstones has provided radiometric ages for eight of the most vital fossil-bearing sites at the Cradle: Bolt's Farm, Cooper's Cave, Drimolen, Haasgat, Hoogland, Malapa, Sterkfontein and Swartkrans. The dating of these flowstones also revealed that sediment deposition occurred contemporaneously across multiple sites within six narrow intervals between 3.2 and 1.3 Ma. As a result, the fauna can now be analysed on a broader, Cradle-wide regional scale. By extension, the bovid assemblages – crucial indicators of palaeoenvironments and abundant at South African Plio-Pleistocene sites – now have their own time ranges and can be interrogated discreetly. Our research is the first large scale analysis of the bovids and associated environments from these Cradle sites, and the first to do so within a framework of constrained chronological phases. Using ecomorphological analysis, we provide insight on functional adaptations and ecology within specific windows of deposition across the Plio-Pleistocene. Ecomorphology focuses on the genetic potential of taxa rather than their direct behaviour at the time of death, distinguishing it from commonly used methods at Cradle sites by demonstrating more long-term palaeoenvironmental conditions. The method defines a relationship between phenotypic characteristics and habitat in extant taxa, then applies that relationship to fossils to interpret habitat preferences of extinct taxa. We conducted ecomorphology on fossil bovid distal metapodials across Cradle sites using a novel 3D geometric morphometric model. Overall, our results point to a mostly dry adapted fauna from all the caves, from all the time periods we investigated, supporting the model that sediment accumulation time windows were relatively dry. We show that, while the Cradle experienced a shift from wooded to open habitats during the Plio-Pleistocene, this transition may not have been as pronounced as previously suggested. This aligns with findings from cave site formation and flowstone analysis, which indicate fluctuating conditions outside the caves during this period. Overall, our results further support the idea that vegetative transitions were gradual rather than stepwise.

A 3,200-Year Story of Hydroclimatic Variability, Resilience, and Adaptation in Deccan's Ancient Settlements to Modern Times through the Deccan's Water Management

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Understanding the relationship between Indian Summer Monsoon variations, water storage management practices, and ancient communities is crucial for sustainable societal development amid climate change. This study investigates this interplay in Deccan India, using a 3200-year stalagmite-inferred monsoon record from south-central India to explore how past societies adopted the monsoon climate. Analysis of our monsoon record reveals 15 drought and 16 flood episodes at decadal to century scales, significantly affecting settlement patterns. During multi-decadal droughts, communities situated over 35 km from natural water sources were abandoned, while those within 5 km endured, often relocating from hilltops to riverbanks, particularly in the Tungabhadra corridor. Conversely, high rainfall during the South Indian early Iron Age (1100 – 800 BCE) prompted the abandonment of low-lying and cyclone-prone areas. Our monsoon record, combined with historical and inscriptional evidence, suggests that while major empires, such as the Mauryans and Sātavāhanas, struggled to maintain irrigation during periods of internal conflict, later dynasties (Pallava, Chola, Kakatiya, and Vijayanagara) prioritized irrigation infrastructure. The “golden era of tanks” (1000-1330 CE) witnessed extensive irrigation developments aimed at mitigating extreme monsoon variations. This long-term perspective underscores the important link between monsoon climate and the development of water management strategies, offering valuable insights into modern water security challenges in India.

Diverse Fossil-bearing Clastic Cave Sediments in Peninsular Malaysia

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Over the past decade, studies on cave palaeontology in Peninsular Malaysia have revealed notable discoveries such as the finding of extinct/locally exterminated genera of large mammals (Stegodon and Pongo), demonstrating that the Malay peninsula had served as a land bridge between mainland and insular Southeast Asia during Quaternary period. Therefore, palaeontological investigations into the fossil-bearing cave deposits in Peninsular Malaysia can significantly contribute to the understanding of the biogeographic distribution and migration routes of Quaternary faunas. Observations made on 15 sites with estimated ages for the deposits ranging from the Middle Pleistocene to Holocene revealed the diversity of the clastic cave sediments that yield the fossils, including mostly isolated dental remains of medium and large mammals, with minimal occurrence of small species. The sediments were discovered in various levels, ranging from -5 m to the highest chamber at 37 m above ground. The deposits are often non-stratified, grey to brownish in colour. Many fossil-bearing cave sediments in Southeast Asia are remnants of possibly larger mass subjected to post-depositional erosion, with varying degree of cementation. These sediments are cemented by micrite to microsparitic calcite that can also occur as sparry whitish streaks. Most of the sediments are made of a heterogeneous blend primarily consisting of polymictic granule-sized subangular to subrounded clasts, sometimes with pisoliths and iron nodules, both from autochthonous and allochthonous origins. However, the highly indurated cave infill surrounding an almost complete Panthera sp. skeleton reveals micritic calcite, with veins of sparry calcite cemented in an unstratified matrix of clay and fine sand, implying deposition by suspension in a calm cave environment that may help preserve the intact skeleton. In a specific sediment containing isolated rodent teeth and jaw fragments, the composition is predominantly silty-clay and sandy-clay, probably sorted based on the relatively finer grain size of both the clasts and the fossils. The fossil-bearing deposits do not appear to have any distinct characteristics, and their accumulation is influenced by the diverse and dynamic cave sedimentology, as well as post-depositional reworking. Nevertheless, despite the ever-changing environments of tropical caves, they have proven to be a rich source of fossils.

Sedimentary ancient DNA from two Romanian caves

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We present here preliminary molecular data obtained from the sediments of Stoieni and Limanu caves in Romania. Stoieni Cave is a small, 30 m long cave that functioned as a carnivore den during the Late Pleistocene. Its sediment accumulation yielded numerous carnivore and herbivore fossil remains. Limanu is a maze cave that was used as a limestone mine during the Antiquity, and the analyzed sediments belong to two periods, at ~2 ka and ~5 ka. The cave hosts important bat colonies, offering the opportunity to study the presence of both humans and fauna before and during the Greek colonization at 2.3 ka, which induced intense landscape modifications, especially deforestation and agriculture expansion.For each sediment sample, we extracted DNA, converted this DNA into libraries, and enriched (“captured”) for mammalian mitochondrial DNA before sequencing. Each of the sequenced read was assigned to a mammalian family using the quicksand pipeline. Here we report only families with at least 100 reads and significant evidence of ancient DNA damage (95% binomial confidence interval > 10%). Ongoing work seeks to refine these assignments to the genus or species level. At Stoieni, half of the captured ancient DNA belongs to the family Ursidae, 25% to Bovidae, and 14% to Canidae. These results are in partial agreement with previous excavations that documented the remains of Ursus spelaeus and Ursus arctos, Canis lupus, and Vulpes vulpes, as well as deer and ibex specimens. We also identified DNA from the family Cricetidae, with exceptionally high percentages in the lower part of the sediment accumulation. This DNA has high levels of ancient DNA damage, indicating that it is ancient, but it is also possible that individuals from this rodent family borrowed into the sediment after its deposition.At Limanu, DNA was poorly preserved overall, especially in older sediments. Most of the captured DNA belongs to bovids, with only the upper samples preserving canid and felid DNA. This is a good representation of even today’s cave role as both a den for foxes, and a labyrinth trap for domestic animals such as sheep, dogs, and cats.

Characterizing sediment remobilization in caves

Ainhoa Val[1], Neal Mathes[1], Susan Ivy-Ochs[2], Naki Akçar[3], Marc Luetscher[1]

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Clastic sediments in caves may either result from the ingress of allogenic material or produced in situ by the physical degradation of the host rock by corrosion or mechanical abrasion. Both are intrinsically related to the hydrological regime which, in mountain environments, is controlled by the seasonal melt of the snow cover. Whilst sediment transport through the cave system depends primarily on water flow, alluviation occurs as soon as the shear stress lowers below a critical value that depends on the sediment grain size. In cave passages abandoned by the main water streams, sediment sequences represent a valuable archive for the reconstruction of past hydrological regimes, providing a good understanding of their deposition context. Here, we investigate sediment transport mechanisms in hydrologically active cave streams to better quantify remobilization processes under different flow regimes. In particular, we aim to assess the minimum flow rate required to displace centimeter- to meter-sized boulders and whether this can be achieved under modern climate conditions. Results will help quantifying the sediment residence time in caves, a parameter needed for the interpretation of clastic sediment sequences and their burial ages.

Hydrochemical analysis of an active tufa depositing stream in the Cradle of Humankind: understanding controls on tufa precipitation

Kgotlhelelo Seagiso, Tariye Onyeogu, Zubair Jinnah, Khuliso Masindi

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The Cradle of Humankind, a globally significant paleoanthropological site, hosts not only hominin fossils but also active and inactive tufa deposits. Tufa is a calcium carbonate that precipitates under ambient temperatures in environments such as fluvial environments and lakes when the supersaturation of calcite is triggered by biotic or abiotic CO2 degassing. Tufa is important in paleoclimatic, paleoenvironmental, and landscape evolution studies, and serves as an indicator of good water quality. The Grootvleispruit is significant as it actively precipitates tufa. Analysing the river's hydrochemistry assists in understanding the factors controlling tufa precipitation. Water and rock samples were collected from the Grootvleispruit and its confluence with the Skeerpoort River at Lefika la Noka tufa site. Water samples were collected in summer and winter with field parameters of the water measured onsite. Rock samples were analysed for major elements through XRF and for trace elements through ICP-MS, while water samples underwent isotopic analysis and ICP-OES for constituents. A total of eleven water samples—five in summer and six in winter—along with two active tufa samples were collected. At Nouklip spring (Station 1), summer calcium and magnesium concentrations were 41 mg/L and 24 mg/L, respectively, indicating influence from a dolomitic aquifer. Although calcite is supersaturated from the spring source to the river confluence, tufa only precipitates approximately 100 metres downstream, likely due to increased water turbulence and micro/macrophyte activities. Winter discharge at Nouklip spring was 95 L/s, the lowest recorded, further indicating that turbulence may be necessary to initiate tufa precipitation at this site. Dolomite saturation was highest along the stream, averaging 6.8 in winter. Active tufa samples displayed low MgO concentrations (below 1.4 wt%), suggesting that magnesium remains dissolved. Therefore, tufa precipitation at Lefika la Noka requires supersaturation of calcite and additional factors such as turbulence or microbial activity to trigger tufa precipitation.

Pedogenic carbonates are prior calcite precipitates that affect speleothem records differently than vadose prior calcite precipitates

David Domínguez-Villar[1], Želika Zgorelec[2], Katarina Matan[2], Kristina Krklec[1]
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Pedogenic calcite (PC) occurs frequently in soils above karst, especially in Mediterranean, arid and semiarid climates. The existence of at least some PC (e.g, as small diffuse crystals) is common in most climates. In karst soils, meteorological conditions and soil CO_2 variability dominates the dissolution and precipitation of PC. We have studied a soil with PC over a cave in a temperate and relatively humid Mediterranean climate in Croatia. Based on continuous data of soil CO_2 concentration and meteorological parameters, we modeled the chemistry of the soil solution to simulate the dissolution and precipitation of calcite. The results show that some amount of PC precipitates and dissolves every year. Hydrochemistry of a cave drip was also measured. The simulated soil [Ca^{+2}+Mg^{+2}] concentration represents 66% of the dissolved [Ca^{+2}+Mg^{+2}] measured in drip water, whereas the other 34% is expected to be acquired along the flow path through the vadose zone. The high cave atmosphere CO_2 concentration during summer months prevents the precipitation of calcite in the vadose zone, resulting in high and relatively constant values of dissolved solutes. During the rest of the year, when cave ventilation is enhanced, the total dissolved species decreases as a result of prior calcite precipitation (PCP), increasing the drip water Mg/Ca ratio. Despite the lack of PCP during summer in the vadose zone, the drip water records a PCP trend, because of precipitation of PC in the soil. In the studied case, most of the increase of Mg/Ca ratio in drip waters is related to pedogenic rather than vadose PCP. Occurrence of PC is favored during the dry and warm conditions, so enhancing seasonality in Mediterranean climates, rather than trends towards drier conditions, can result in net accumulation of PC. Thus, PCP recorded in cave waters results of calcite precipitated either in the soil or in the vadose zone. Since the controls of PCP occurred in the soil or the vadose zone differ, the interpretation of Mg/Ca signals in speleothems dominated by PCP are likely more complex in regions that have (or had) PC in the soil above the cave.

Session 7:

High resolution Karst Records of climate variability: millennial to seasonal scale resolution

Speakers:

Yidong Li
Yao Wu
Francisco Cruz
Michael Weber
Nikita Kaushal
Liangcheng Tan
Sophie Warken
Joshua Feinberg
Andrea Columbu
Laura Endres
Angela Ampuero Grandez
Agathe Lise-Pronovost
Jennifer Klose
Camille Marie Afonso
Nicolás Stríkis
Nathalie Melissa M. Medina
Marc Luetscher
Isabel Montanez
Ellen Corrick

Posters:

1. Mathilde Dubois
2. Kang Xie
3. Lilian Pendergrass
4. Yassine Ait Brahim
5. Masha Boekholt
6. Maddalena Passelergue
7. Isabel Montanez
8. Andrea Borsato
9. Juan Luis Bernal Wormull
10. Lvfan Chen
11. Aaron Mielke
12. Francisco Cruz
13. Carlos Pérez-Mejías
14. Nicolò Ardenghi
15. Dildi

16. Natasha Sekhon
17. Anupam Samanta
18. Kimberley Stevens
19. Alfred Skeidsvoll
20. Bethan Lodge
21. Dimitra Skoulikari
22. Monica Geraldes Vega
23. Jeffrey Lang
24. Nathalia Stadler
25. Julio Cauhy
26. Marcela Eduarda Della Libera
27. Nikolai Tkach
28. Aida Zyba
29. Nils Schorndorf
30. Patrick Brett
31. Huiru Tang
32. Yanzhen Li

Reconstructing Climate Variability in the Northern Black Sea Region over the Last 60,000 Years: Insights from Crimean Speleothems

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The understanding of paleoclimate variability in the northern Black Sea region has been limited by the lack of high-resolution terrestrial records. Crimean speleothems hold significant potential to fill this gap by providing insights into past climate conditions in this area.We present a composite dataset of stalagmite records from Crimea, featuring stable isotope and trace element data spanning the last 60,000 years. $\delta^{18}O$ values of Crimean speleothems can serve as a proxy for air temperature on orbital timescales, reflecting the variations in the Northern Hemisphere insolation. The Holocene $\delta^{18}O$ records from Crimean stalagmites are similar to the records from the eastern and southern Black Sea regions, with mean values that are ca. 1‰ more positive. However, records from the eastern and southern Black Sea regions show a significant negative offset (3 to 5 ‰) during the last glacial period compared to stalagmites from Crimea. We tentatively interpret this as a reflection of the north-south displacement of the westerlies during glacial periods. As a result, the eastern and southern Black Sea regions received more precipitation and more-depleted $\delta^{18}O$ values compared to Crimea. During Marine Isotope Stage 3, Crimean stalagmite $\delta^{13}C$ records exhibit more pronounced millennial-scale signal shifts than the $\delta^{18}O$ record. Heinrich events are particularly notable in the $\delta^{13}C$ record, indicating a greater sensitivity of this soil proxy to cold and dry conditions.Meteorological and cave microclimate monitoring data for Crimean sites indicate that, despite high summer precipitation, strong evaporation reduces the summer net infiltration to less than 37%. In contrast, winter precipitation, associated with $\delta^{18}O$-depleted moisture transported by the westerlies from the North Atlantic and Mediterranean regions, contributes over 85% to groundwater recharge. The $\delta^{18}O$ values of winter precipitation (-6 to -10‰ V-SMOW; 2010–2014) closely align with the $\delta^{18}O$ values of drip water (-8 to -13‰ V-SMOW; 2020–2023). This suggests that Crimean speleothems primarily capture a winter precipitation signal.

Variations in regional hydrological environment and human activities inferred from $\delta^{18}O$ and $\delta^{2}H$ of stalagmite fluid inclusions in southwest China

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The interpretation of $\delta^{18}O_C$ and $\delta^{13}C_C$ values of stalagmites within China is still complex, although numerous cave records have been reported in this region. Present challenges include distinguishing between natural and anthropogenic influences on regional hydrological and environmental changes, due to the increasing human activities during the mid-to late Holocene. Here, we report the $\delta^{18}O_{FI}$ and $\delta^{2}H_{FI}$ records of fluids entombed as inclusions during the Holocene (6290 to 690 yr BP) from a stalagmite from southwest China. Based on capillary and Rayleigh fractionation models, our improved inclusions measurement technique enables testing for significant evaporation of samples during preheating. Artefacts in isotope results caused by heating can be effectively identified and mitigated through meticulous petrographic examination and comparative measurements using glass tubes. Our reconstructed southwest China $\delta^{18}O_{FI}$ and $\delta^{2}H_{FI}$ records demonstrate sensitivity to evaporation processes in the epikarst zone and cave environment. The more significant evaporation experienced by fluid inclusions during formation may lead to their isotopic composition exhibiting a greater amplitude of response to external climate and environmental changes in comparison to the isotopic composition of calcite. Our record reveals four drought events during the mid-to late Holocene (1360, 2260, 3450, and 5600 yr BP), related to more persistent El Niño conditions, increased ENSO variability led to a higher frequency of drought events in southwest China. Between 950 and 1150 CE, $\delta^{18}O_{FI}$ values exhibited a dramatic positive shift (magnitude 7‰), revealing environmental degradation in the study area due to the expansion of cropland resulting from population migration. Our study highlights the substantial impact of human activities on the regional environment already prior to the industrial era.

Precipitation Dipole in South America During Heinrich Stadial 1 event from Speleothem Isotope Records and model simulations

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Heinrich Stadials (HS) events significantly affected tropical precipitation in South America through changes in the interhemispheric temperature gradient as a result of abrupt cooling in the North Atlantic. Pioneering work with speleothems in South America revealed an antiphase precipitation pattern with monsoon regions in the Northern Hemisphere characterized by a more humid climate on the continent. In recent years, new studies with higher isotopic resolution and with speleothems dated in greater detail have revealed an internal structure of HS1 over eastern tropical South America that is associated with the widespread increase of monsoon precipitation over the South Atlantic Convergence Zone domain. Based on a suite of new speleothem records from caves located in the western portion of the continent, it is now possible to confirm the occurrence of a zonal dipole in the precipitation in part of the HS1 event that is characterized by dryer conditions in the region climatologically influenced by the Andean Low-Level Jet. Here we used data from the isotope-enabled version of the Community Earth System Model (iCESM) during the deglacial period (20 -11 ky) as simulated by the iTraCE project. We analyzed precipitation, $d^{18}O$ in precipitation, as well as horizontal wind and vertical velocity to investigate changes in the regional Hadley and Walker circulations over South American continent and the adjacent Atlantic and Pacific oceans during Henrich event 1 (HS1). iTraCE data faithfully reproduce the observed spatial footprint of $d^{18}O$ excursions during HS1 and indicate that these isotopic anomalies can be traced back to perturbations in both the meridional and zonal overturning circulations over tropical South America during HS1.

Reoccurring rapid warming events during the fourth glacial cycle in the Mediterranean

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Millennial-scale climate variability during glacial periods is a prominent feature in various climate records and expressed as temperature variability in the high northern latitudes and precipitation variability in the tropics. The last glacial period was characterised by abrupt millennial- to centennial- scale climate oscillations, known as the Dansgaard – Oeschger (D/O) events, and synthetic Greenland ice core data suggest that millennial-scale climate variability also occurred during all glacial phases of the past 800 ka. However, the detection and synchronization of millennial-scale climate oscillations beyond the last glacial cycle remains challenging due to the general lack of precisely dated high resolution climate records beyond the last interglacial.Here we present a new speleothem record from Cueva Victoria (SE Spain), covering MIS (Marine Isotope Stage) 11a and 10. Speleothems from Cueva Victoria have shown to reveal hydrological changes on both millennial and orbital timescales, and numerous D/O events have been identified in their stable isotope records during the last glacial cycle. This demonstrates the strong interconnection between North Atlantic climate patterns and stable isotope signals recorded in Cueva Victoria on the millennial timescale. Our data from MIS 11a shows two distinct cooling events that coincide with the previously described Iberian margin stadials (IMS) 4IMS-6 and 4IMS-7 during the fourth glacial cycle. In addition, the $\delta^{18}O$ record shows a general cooling trend towards fully glacial conditions in MIS 10, interrupted by at least seven rapid warming events. These warming events are characterized by a rapid warming (within ~250 years) followed by gradual cooling and exhibit a similar timing, duration and magnitude as the D/O events from the last glacial cycle. The $\delta^{13}C$ generally mirrors the $\delta^{18}O$ record but reveals longer phases of enhanced soil activity during the warming events, even when temperature is already decreasing. The timing of these climate oscillations agrees with the predicted occurrence of D/O events based on the synthetic Greenland ice core record. These data highlight the potential of Cueva Victoria speleothems to reconstruct the timing and duration of past millennial scale climate variability beyond the last glacial cycle.

Potential for hydroclimate reconstruction using speleothem trace element proxies from the SISALv3 speleothem database

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The PAGES-SISAL Working Group has created the latest version of the speleothem database SISALv3 which includes records of carbon isotopes, Mg/Ca, Sr/Ca, Ba/Ca, and U/Ca. We present initial results on using these data to improve our understanding of the Prior Carbonate Precipitation (PCarbP) process as a mechanism for driving speleothem trace element variability. Our ultimate goal is to increase our confidence in the PCarbP mechanism as a proxy for reconstructing hydroclimate changes. High pCO2 infiltrating water can degas in air cavities in the karst, precipitating CaCO3 before the water reaches the speleothem surface, this process is referred to as PCarbP. During changing hydroclimatic conditions, the extent of this process impacts the trace-element-to-calcium ratios as well as carbon isotopes in measurable ways, thus forming a multi-proxy mechanism of reconstructing hydroclimate variability. We use 58 calcite speleothem records from the SISALv3 database to investigate in what ways the PCarbP process drives trace element variability in speleothems. Our guiding questions are:To what extent do published studies of PcarbP sensitive elements agree with partition coefficient slope-based models?Which proxies are more reliable for identifying PcarbP in speleothem records?Which numerical approaches can best constrain PcarbP in speleothem records?We find that while the majority of published studies attribute PCarbP as a possible driving mechanism of trace element variability in their speleothems, this interpretation can be based on different stable isotope and trace element combinations, and may have none-to-complex models for testing this hypothesis. A priori knowledge of trace elements sources in speleothem studies is often based on previously published regional geological information and field work where possible. However, examining speleothem elemental concentration against stated lithologies in the database suggests that either the cave lithology does not correspond to the one derived from broad regional geological information, or other sources (soil, aerosol) and mechanisms (incongruent carbonate dissolution) are involved in determining the drip water composition. This is relevant since trace element sources control slopes of paired-proxy partition coefficient based models.Our study identifies important research directions for the identification and attribution of what controls trace element variability in speleothems.

Hydroclimate changes in Sri Lanka over the past millennium

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Understanding the decadal variability of hydroclimate in Sri Lanka during historical time is of great significance for disaster prevention, water resource management, and agrarian economy in this area under a global warming scenario. However, the evolution patterns and driving mechanisms of decadal hydroclimate variability in Sri Lanka remain controversial due to lack of long-term and high-resolution records. Here we present the first temporally highly resolved stable isotope and trace element stalagmite records in Sri Lanka, covering the past millennium. Our records agree well with other hydroclimate records over Indian subcontinent and Southeast Asia, showing two notable humid intervals during the early medieval period and the late Little Ice Age, and prolonged droughts from 1200 to 1600 CE. By using this record, we further explore the driving mechanisms of hydroclimate variations in Sri Lanka on centennial to decadal scales and its possible impacts on societal changes.

Discovery of Speleothem sulfur spike from Laacher See Eruption c. 13ka BP synchronizes climate records from Central Europe and Greenland

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Due to their nearly global distribution, the study of precisely dated speleothems can provide important information to complement ice core records from polar regions. There is increasing evidence that volcanic sulfur emissions can not only be traced in ice cores but also in speleothems, thus permitting a direct link between volcanogenic sulfur spikes, climate proxy records, and absolute age. Here we present a near-annually resolved geochemical record of the late Glacial Laacher See eruption (LSE) from Herbstlabyrinth Cave, Central Germany. The LSE is identified by a distinct increase of speleothem sulfur and fluorescent organic matter contents as well as ash-leached trace element abundances. Thus, our record allows to assess the local and regional environmental impact of the LSE, with the speleothem proxies ($\delta^{18}O$ values, annual lamina thickness, and trace element abundances) only suggesting a minor influence on local climate and environment within c. 20 years after the eruption. Most importantly, precise $^{230}Th/U$ dating of the volcanic spike allows to link the LSE, which deposited a key chronostratigraphic marker in European terrestrial archives, to a previously unidentified sulphate spike in the Greenland ice core record. Combining our age with recent age estimates (Reinig et al., 2021) allows to derive an absolute date of the eruption of 13,008 ± 8 BP_{1950} and establish the LSE as a first near-absolute time marker in the ice core chronology for the late Pleistocene-Holocene transition. As a consequence, the event synchronizes radiometric and ice-core calendars back in time, which consistently demonstrate that the eruption pre-dates the onset of both the Younger Dryas (YD) in Europe and Greenland Stadial 1 (GS-1) cooling by about 150 years. Our results underline a direct and dynamic coupling of mid- to high-latitude climate opposed to a time-transgressive spread of the YD/GS-1 cooling from Greenland to central Europe. This study thus demonstrates the fundamental role of precise, accurate, and synchronized chronologies, in particular for inferences on the timing of climatic transitions and sequence of events.

Evidence of a Late Pleistocene Sea-level Highstand from an Iron-rich Layer in a Bahamian Flowstone

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Blue holes are deep sinkholes within carbonate bedrock that are connected to the ocean and have significant stratification in their water chemistry. Dramatic sea level fluctuations associated with glacial-interglacial cycles modify the bedrock around blue holes, forming dissolution cavities decorated with flowstone, stalagmites, and stalactites. These layered carbonates offer clues to the processes that were active at different stages of sea-level oscillations. Here, we characterize the chemical and physical properties of a widespread, submillimeter red layer within a flowstone formed in a Bahamian blue hole whose growth coincides with the first sea level highstand during Marine Isotope Stage 7 (MIS 7.5, ~240 ka). This red material is similar to deposits found on the floor of modern blue holes and has been variably interpreted as an accumulation of windblown Saharan dust, local residuum from the host carbonate (terra rosa), or a flooding surface. Each of these interpretations carries implications for the sedimentary setting represented by the layer. We employed a suite of characterization techniques for this study, including optical and electron microscopy and magnetic approaches such as vibrating sample magnetometry (VSM) and quantum diamond microscopy (QDM). We found that the red layer abruptly truncates columnar calcite and is overlain by fine-grained calcite which gradually transforms back into a columnar fabric. The red layer occurs at an uneven, partially dissolved surface and is composed of iron-oxide framboids, a morphology common to pyrite. Electron microprobe measurements show a general increase in sulfur within the red layer, indicating that sulfides were available at some during framboid formation. Magnetic measurements indicate a mixture of both hematite and magnetite. Our results are consistent with the hypothesis that the red layers found in Bahamian flowstones formed as part of a short-lived flooding process, where flowstone formation was interrupted by rising sea level and dissolved by mixing of fresh and saline waters. Iron-sulfide framboids were precipitated on the surface of the flowstone under euxinic conditions. Finally, when sea level fell, the framboids were oxidized and subsequently covered by newly nucleated calcite.

Dryness at 4.7 ka is more intense than at 4.2 ka in Sardinia (Italy): what is the real structure of the so-called “4.2 event”?

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Among several Holocene climate instabilities, the “4.2 event” holds particular significance. Identified as one of the major cooling/drying abrupt events, it is often referred to as a “megadrought” that even had a role in the decline of ancient civilizations in Eurasia and Africa. Yet, the nature of the event is at times elusive, as it is not recorded in some sites and appears to be out of sequence in others. Therefore, it is still necessary to better investigate the supposed 4.2 ka event possibly with a multiproxy approach and from understudied regions; furthermore, focus should also be addressed on time slices around 4.2 ka in order to improve the understanding of climate triggers and teleconnections. Indeed, other oscillations at times of greater magnitude with respect to the 4.2 event have been somehow underexplored because the “main” 4.2 event often takes all the importance. Here we present novel multiproxy data ($\delta^{18}O$-$\delta^{13}C$, fabric and trace elements) from a stalagmite collected in S’Armidda Cave (Osini, Sardinia, Italy). U-Th based chronology demonstrated that the sample SARM2 deposited from 5.6±0.14 to 3.3±0.14 ka. The aim is thus to characterize the climate variability in this portion of the Western Mediterranean around 4.2 ka, with average $\delta^{18}O$-$\delta^{13}C$ resolution of about 16 years and subannual for trace elements. Preliminarily, $\delta^{18}O$-$\delta^{13}C$ attest that at ca. 4.7 ka there is a centennial long climate deterioration characterized by lower rainfall and vegetation activity. While SARM2 is composed of calcite, during this period there is an evident aragonite layer that further points to dryness. From ca. 4.6 rainfall increases, peaking at ca. 4.35 ka. Progressing toward 4.2 ka there is a drying trend, which appears of minor magnitude with respect to the one at ca. 4.7 ka, as aragonite is not present. Our preliminary findings suggest that the supposed 4.2 event is instead formed by two arid phases interrupted by a wetter period, where dryness at ca. 4.7 ka is even more intense than at ca. 4.2 ka, at least in the Mediterranean context. The resulting crucial climate and cultural implications will be discussed within the talk.

Tracking North Atlantic Climate and Freshening Events Over the Last Glacial Maximum and Termination 1 Using Northwest Iberian Speleothem

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Changes in climate and ocean circulation over the last deglaciation represent a meaningful test case for understanding abrupt climate events, because of multiple cascading feedbacks in the involved earth system components, particularly the ice sheets. Related to uncertainties in dating of marine proxies and plausible ice sheet reconstructions, constraining the timing and order of events within the North Atlantic realm remains challenging. We present here a new independent U-Th chronology from a stalagmite from the proximal North Atlantic spanning LGM and the entire last deglaciation from 24 ka to 12 ka BP, with an average sample resolution of 25 years. Focusing on stable isotope $\delta^{18}O$ and $\delta^{13}C$, the proxies are concurrently showing changes in ocean surface $\delta^{18}O$, indicating the presence of Northern hemisphere meltwater, and changes in surface air temperature. By comparison with ice sheet reconstruction, we confirm the presence of gradual meltwater inflow already during LGM and the early last deglaciation 20.8-18.2 ka, followed then by a set of abrupt increases in meltwater with transition midpoints at 18.1, 16.14 and 15.29 ka BP. Further, coldest temperatures are reached only by 17.1 ka, which suggests that consequences of AMOC weakening might have substantially lagged the first meltwater pulse at 18.1 ka. In contrast, a very short-lived cooling emerges synchronously with the meltwater pulse at 16.14 ka but not at 15.29 ka BP. At our site in NW Iberia, warming is pronounced for the transition into Bølling-Allerød, both in model and our data, and is concurrent with a rapid decrease of the surface meltwater anomaly. This increased downwelling capacity of a re-strenghtened AMOC is a further indicator found for the end of both Heinrich Stadial 1 and 2. Overall, the here presented record gives a proximal, Eastern North Atlantic chronology for a detailed view of the interplay between surface ocean $\delta^{18}O$ and temperature over the last deglaciation.

Tropical Land temperature Evolution over the Last Glacial Termination recorded in a stalagmite from central-eastern Brazil

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The Last Glacial Termination featured a global-scale warming from the temperature minimum of the Last Glacial Maximum (LGM) to the mild climate of the Holocene. This transition was marked by a stark increase in atmospheric CO_2 (80 ppm) and punctuated by cold episodes in the North Atlantic high latitudes (HS1 and YD) and Antarctica (ACR), driving abrupt climate changes worldwide. Although climate patterns and mechanisms that prevailed during these episodes are generally understood, uncertainties remain regarding the temperature evolution in the tropics due to the scarcity of continental surface temperature records. Particularly, large temperature variations as occurred during the last deglacial warming, may be critical for stalagmite oxygen isotopes ($\delta^{18}O$) due to the temperature-dependance of isotope fractionation. Therefore, accurate temperature reconstructions can potentially help to constrain its influence in stalagmite precipitation records, significantly improving its interpretation. Here, we analyze rainfall and land temperature changes from the Last Glacial Maximum to the early Holocene, derived from a well-dated stalagmite in central-eastern Brazil, a region undergoing severe warming since the 1970s and unprecedented over several hundreds of years. Our stable oxygen isotope record confirms the distinct response of rainfall to the millennial-scale cooling episodes in the North Atlantic, recognized during Heinrich Stadial 1 and the Younger Dryas periods. We refine our interpretation by comparing it with the drip water isotopes extracted from fluid inclusions, which support the good preservation of the climatic signal in our records. We obtained a precise and well-dated land temperature time series by applying microthermometry analyses, a physics-based method that does not require empirical calibration. We show that temperature closely follows global atmospheric CO_2 and temperatures in the Southern Hemisphere high latitudes. We also demonstrate that temperature and rainfall are decoupled, as warming across the termination did not lead to a precipitation increase. Instead, warm temperatures can reduce the water balance by favoring evapotranspiration over precipitation.

Environmental magnetism linked with pollen, charcoal and stable isotopes in stalagmites from semi-arid southern Australia

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Whilst considerable progress in speleothem environmental magnetism has been made in recent years, our knowledge of how magnetic proxies respond to Earth-system processes in arid/semi-arid environments is limited. Two 'dirty' calcite stalagmites were collected in the entrance chamber of Webbs Cave on the Nullarbor Plain, southern Australia, an area that receives low precipitation (~250 mm/year). U/Th age estimates indicate the stalagmites cover the last 2400 years. Here we present results from rock magnetic experiments and interpret their environmental significance in relation to pollen, charcoal, and stable isotopes from the speleothems. Magnetic experiments include anhysteretic and isothermal remnant magnetizations, hysteresis loops, and low-temperature magnetometry to inform on the concentration, phases, and grain size of the speleothems' magnetic mineral assemblage. Analysis of detrital particles and speleothem porosity was also undertaken using x-ray microtomography. We find that the magnetic mineralogy of both stalagmites is typical of stalagmites globally in being dominated by partially oxidized magnetite or maghemite with grain size distributions in the superparamagnetic to single-domain range, which occurs alongside goethite and potentially hematite. Both the low and high coercivity fractions co-vary and are consistent with local soils. Comparing these magnetism results with the paleovegetation and stable isotope records from the same stalagmites, we find that magnetic enhancement occurs during drier climates. We infer that magnetic enhancement results from increased detritus entering via drip waters, along with increased deposition of localized cave dust during (dry) periods of slow stalagmite growth. By characterising the magnetic particles and their provenance, this work contributes baseline Late Holocene paleoenvironmental data for an underrepresented Australian semi-arid region. In addition, it reveals exciting potential to derive a paleomagnetic record held by the single domain magnetic particles and recover Earth's magnetic field history at multi-decadal resolution in a previously undocumented region of the globe.

Precisely dated flowstone growth phases as a proxy for particularly warm climate conditions during MIS 3 in Central Europe

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The last glacial period and especially Marine Isotope Stage 3 (MIS 3, ca. 60 – 30 ka) was characterised by rapid climate oscillations and periodic warm phases. While first discovered in Greenland ice cores, these warm Greenland Interstadials (GIs) have been identified in numerous climate records globally with a strong emphasis on the northern hemisphere and especially the North Atlantic region. However, only few speleothem records from Central Europe are available, presumably due to too cold and dry climate conditions leading to unfavourable conditions for speleothem growth. Here, we present a composite record of flowstones from Bleßberg Cave, Germany, showing episodic speleothem deposition during the last glacial period contemporaneous with individual GIs and revealing Central European warm phases during MIS 3.By combining high-resolution solution-based and in-situ laser ablation ^{230}Th/U-dating, we accurately determined the timing and duration of eight particularly warm periods during MIS 3. These favourable climatic conditions for speleothem growth occurred intermittently from around 60 to 32 ka, lasting much longer than previously reported in other speleothem records from Central Europe. The onset of speleothem growth lagged behind that of the GIs, covering approximately 88% of their total duration during the early phase and around 25% during the middle and late phases of MIS 3. These findings indicate a trend of progressive climatic cooling during MIS 3, with the phases of speleothem growth representing persistent warm phases in Central Europe.In addition, the Bleßberg flowstones are highly sensitive to climate change and particularly short-term temperature fluctuations. The longest continuous growth phase of the Bleßberg speleothems coincides with GI 14, the longest GI of MIS 3. We applied a multi-proxy approach (i.e., stable isotopes, trace elements, LOPs, Ca isotopes, fluid inclusions and fluid inclusion-based temperature reconstructions), which revealed two centennial-scale cold events during GI 14. One of them coincides with cold event GI 14b in the Greenland ice core record, which has not been discussed in any other terrestrial climate record from Central Europe yet. Our results document Central European warm phases during MIS 3, indicating rapid regional temperature fluctuations and the absence of continuous permafrost in this region.

Where do tropical land temperatures sit on the bipolar see-saw?

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The last glacial cycle has been characterized by millennial-scale climate oscillations, marked by large and rapid temperature swings in the North Atlantic region accompanied by opposite and smaller temperature variations in the Southern Hemisphere. In the context of these millennial-scale climate fluctuations, we seek to understand the tropical climate behavior, determining whether it followed the Northern Hemisphere pattern or the Southern Hemisphere pattern and atmospheric CO_2.In this study, nucleation-assisted microthermometry (Krüger et al., 2011) was used to determine stalagmite formation temperatures based on fluid inclusion liquid-vapor homogenization. The method was applied to stalagmite SC03, from Secret Chamber in Clearwater Cave, located in the Gunung Mulu National Park, Northern Borneo. SC03 has previously been studied for changes in precipitation (Carolin et al., 2013). Here, we present a reconstructed quantitative land temperature record, covering MIS 5a through MIS 3. Our preliminary findings suggest that tropical temperature did not follow Northern Hemispheric patterns but instead closely correlates with Antarctic temperatures and atmospheric CO_2 levels. Additionally, we confirm a previously reported decoupling between hydroclimate and land temperature changes in Northern Borneo (Løland et al., 2022). Our study contributes to a broader understanding of the interplay between low and high-latitude climate during millennial-scale reorganizations of the global climate system.

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Anthropogenic drought captured in Southern American speleothem record

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The increase in global temperatures and the potential for evapotranspiration driven by climate change significantly impacts the water balance in tropical regions. In this context, reconstructing hydro-climatic parameters beyond instrumental records is essential for understanding the full scope of natural climate variability and assessing the contribution of anthropogenic influences on regional climate. To assess the effects of global warming on the climate of eastern lowland South America, we developed an annually resolved record of oxygen isotopes and trace elements using stalagmites from a well-ventilated cave in a savanna region located in the middle course of the São Francisco Drainage Basin in central-eastern Brazil. The approach used in this study allowed us to analyze the combined effects of local precipitation and potential evaporation on the geochemistry of the speleothems. The cave, known locally as Lapa da Onça, features a wide entrance with numerous actively dripping stalagmites in the entrance chamber. Cave monitoring and isotope records from annually layered speleothems indicate that, on an intra-annual timescale, seasonal variations in cave temperature are a significant driver of oxygen isotope variability. Conversely, at the interannual timescale, fluctuations in evaporative demand emerge as the primary driver of isotope variability. Consequently, the isotope effects linked to periods of reduced rainfall are intensified by the kinetic isotope effects associated with increased evaporation during water dripping. This combined influence leads to a significant increase in the oxygen and carbon isotope of speleothem calcite departing from the 1970s. Similarly, variations in trace elements like Mg/Ca, Sr/Ca and Ba/Ca present a steep increasing trend, suggesting the prior calcite precipitation as the main driver of trace element composition. By extending our record back to the year 1298, we observe that the rise in δ18O, δ13C and trace elements is unprecedented over the past 720 years. These findings strengthen the argument for a severe long-term drought in the tropical regions of the Southern Hemisphere, linked to anthropogenic warming.

Last 20,000 years speleothem multiproxy paleoclimatic reconstruction from Central Brazil

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A growing number of speleothem records from central Brazil have shown the spatial complexity of precipitation within the South American Summer Monsoon (SAMS). The most remarkable feature is the invariant or even absent summer insolation trend in Holocene oxygen isotope records underlying the proximity of South Atlantic Convergence Zone (SACZ) main rainfall accumulation axis. The climate forcing mechanisms and factors driving the observed oxygen isotope variability in this region are still elusive in part due to the lack of alternative lines of evidence such as independent cave hydrologic proxies. To better address this issue, we present a multiproxy approach that includes records such as Sr/Ca ratios, $^{87}Sr/^{86}Sr$ and $\delta^{234}U$ isotopes, gray scale, hyperspectral imaging and XRD mineralogy, together with other XRF-derived elemental data from five stalagmites collected in seasonally flooded chamber in Lagoa Azul Cave eastern Mato Grosso, Brazil. A hitherto unstudied region located between the Araguaia and Rio das Mortes flooding plains, directly under northern SACZ core. As expected, $\delta^{18}O$ show abrupt oscillations between wet-dry-wet conditions during the Bølling-Allerød and Younger Dryas. Whereas over the Holocene, unlike the $\delta^{18}O$ record, Sr/Ca ratios, Sr isotopes and $\delta^{234}U$ show a trend toward wetter conditions (i.e. lower PCP and shorter residence time) following the austral summer insolation. Suggesting oxygen isotopes are rather responding to a source effect than to an amount effect over orbital scales, which is evident in the formation of lakes adjacent to the study cave. Over millennial scales, lower Sr/Ca ratios and depleted $\delta^{18}O$ values coincide with increases in subpolar North Atlantic ice rafted debris also recognized in other speleothem records from the same region. Circa 6.0 ka BP, an extreme precipitation event associated with Bond 4 might have increased the cave phreatic level, as registered by a detrital layer in one speleothem. Additionally, intercalations of primary aragonite and calcite reveal varying geochemical patterns, which are interpreted as changes in water residence times.

Holocene hydroclimatic changes deciphered in Tunisian speleothems, Grotte de la Mine (Djebel Serdj)

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A precise delineation of humid phases in North Africa not only supports our understanding of past human activity but also contributes to a better understanding of aquifer recharge with direct implications for a sustainable management of present-day groundwater resources. Here, we investigate Holocene speleothems from Grotte de la Mine, Djebel Serdj (Tunisia). Reproducible and marked petrographic transitions suggest major and repeated changes in the local hydraulic conditions. Periods of rapid stalagmite growth alternated with times of more regular but slower calcite deposition. Cave monitoring data over that last decade provide important reference points for the interpretation of the speleothem record. Although the surface environment and the cave dynamics have been artificially impacted by human activity (i.e. forestry, mining, caving), we nonetheless identify analogues between the early Holocene record and the modern cave environment. While our observations underline a rather uncommon hydrological regime when compared to the past few millennia, similar conditions already prevailed during the Holocene.

Volatile Climate in Early Holocene California: Hydroclimate Response to the 8.2 ka Event at Sub-Decadal to Sub-Annual Scales

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Climate simulations for the 21st-century California (CA) project an increase in "whiplash climate," characterized by rapid oscillations between wet and dry extremes. These projections underscore the need for research into previous periods of climate volatility in the region. Holocene paleoclimate records suggest that the 8.2 ka event serves as the best and most recent analogue for such hydroclimate instability. A coastal stalagmite record from central CA (WMC1) reveals highly variable infiltration and generally wetter conditions during the 8.2 ka event. Fire biomarkers from this stalagmite indicate a link between extreme rainfall variability and fire activity in Western North America. However, few high-resolution records of the 8.2 ka event exist in other parts of the state.Here, we present a sub-annual resolution, multi-proxy study of the WMC1 stalagmite alongside new data from a southern Sierra Nevada stalagmite (C67-1) from an unexplored cave, Crystal 67. Preliminary $\delta^{18}O$ data from C67-1, combined with monitoring data from 2022 to 2024 bracketing the extreme $\delta^{18}O$ for drip water in the cave, indicate atmospheric river-dominated hydroclimate conditions prior to 8.2 ka BP, followed by a rapid shift to North Pacific storm dominance during the 8.2 ka event. Both $\delta^{13}C$ and trace element time series provide insights into soil and hydrological conditions surrounding each cave, supporting the occurrence of a sharp, saw-tooth “Greenland-like” wet 8.2 ka event in the Southern Sierra (C67-1) and a more “whiplash-like” coastal pattern characterized by alternating droughts and extreme rainfall (WMC1). Additionally, P/Ca ratios for both caves increase before and during the 8.2 ka event, indicating enhanced colloidal influx, which has been associated with increased fire activity at WMC.By analyzing both C67-1 and WMC1 at quinquennial to sub-annual resolution for the early Holocene and comparing the sub-structure of the 8.2 ka event between coastal and inland mountainous regions of CA on a year-to-year basis, we can enhance our understanding of regional coherence during periods of high climate variability and their modern implications.

A multiproxy record of Dansgaard-Oeschger events from 120 to 72 ka based on cave stalagmites from south-eastern France

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Last Glacial Dansgaard-Oeschger (D-O) events are one of the best examples of naturally occurring abrupt climate change. Stalagmite records from Western Europe, where the climate is strongly linked to the North Atlantic, provide an important opportunity to assess the impact of North Atlantic changes on proximal land masses and to precisely constrain the timing of these events. We present a high resolution, multiproxy ($\delta^{18}O$, $\delta^{13}C$, Mg/Ca and Sr/Ca) composite stalagmite record from Saint-Marcel and Orgnac Caves (south-eastern France), providing near continuous coverage from 130 to 71 ka (spanning MIS 5e-a). Proxy variations are well replicated between temporally overlapping sections of the stalagmites. $\delta^{18}O$ and $\delta^{13}C$ record clear changes in precipitation, and soil and vegetation processes interpreted to strongly reflect temperature changes. Mg/Ca and Sr/Ca reflect hydrological and growth rate changes. U-Th dating of each stalagmite is focused on the abrupt transitions and a composite depth-age model is constructed. The record captures the interglacial context and glacial inception, during which the pattern of abrupt events is established. Almost all D-O events from Greenland Stadial 26 to Greenland Interstadial (GI) 19.2 are recorded, demonstrating a strong sensitivity of rainfall and temperature changes at the site to climate changes in the North Atlantic region. In addition, sub-millennial events such as GI 23.2, GI 24.1b and GS 24.2 are recorded, indicating these very short lived and often smaller magnitude events were consistently expressed in this region. This stacked record provides improved understanding of the response to millennial and sub-millennial changes in western Europe, and refined chronological constraints for the timing of abrupt events throughout the early Last Glacial period.

Reconstructing hydroclimate and flood history in New Zealand's Waikato region through environmental magnetism and geochemical analysis of speleothems

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There is an urgency to understand flood history in the context of climate change. This is particularly critical in regions like New Zealand, where the frequency and intensity of extreme weather events, including floods, are projected to rise. For example, Cyclone Gabrielle in 2023, claimed 11 lives and caused widespread damage; these devastating impacts highlight the need to understand past flood events to predict future risks better. Previous cave monitoring and geochemical analyses of Holocene speleothems from Waipuna Cave, in the Waikato region of New Zealand's North Island, have revealed that the cave preserves high-quality paleoclimate records. Millennial- to multi-decadal-scale resolution data are available throughout the Holocene. Our research aims to extend these existing records through to the Last Glacial period, using a novel analytical approach, which combines established speleothem techniques with environmental magnetism. Here, we present results from two cores WP15 (70 cm) and WP23 (90 cm) drilled from a large flowstone adjacent to a stream. We employ stable isotopes of oxygen (δ18O) and carbon (δ13C), trace elements, uranium-thorium (U-Th), and magnetic analyses to reconstruct high-resolution paleo-hydroclimate for the Waikato region. Existing U-Th chronology WP15 presents a basal age of 32 ka, while preliminary age estimate for core WP23, produced through dynamic time warping (DTW) of stable isotopes, suggests that WP23 extends further. Through employing established hydrological speleothem proxies (δ13C, δ18O, trace elements) in conjunction with environmental magnetism analysis, we aim to identify unique magnetic signatures throughout distinct climatic periods- i.e., glacial, interglacial, and transitional - to track the frequency and intensity of flood events in the region.

Storminess and flooding reconstructions from metamorphic cave-grown speleothems on the west coast of Scotland

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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 cave 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 drip waters in the Jura and Islay caves reflect near-synchronous Late Holocene storm events and associated sea flooding on the west coast of Scotland.

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A Multiproxy Hydroclimate Record of East Java During the Late Pleistocene

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The Indonesian maritime continent, located within the Indo-Pacific Warm Pool (IPWP), is a region of significant climatic and geographic diversity. Its modern climate is characterized by highly variable weather patterns, including shifts between droughts, floods, and forest fires, which impact resource availability and ecosystems on both regional and global scales. These weather patterns are heavily influenced by a combination of climate systems and modes, including the Indo-Australian summer monsoon (IASM), the El Niño Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), and the Intertropical Convergence Zone (ITCZ). Because the IPWP plays a critical role in modulating regional- to global-scale climate patterns, it is an important area of study for understanding past hydrological variability and teleconnections with higher latitudes and predicting future climate change impacts in this highly populated region.Here we present a multiproxy hydroclimate reconstruction using stable isotopes (δ18O and δ13C) and trace elements (Mg/Ca and Sr/Ca) measured on a 30 cm-long stalagmite (GG1) collected from Gua Gung Cave in the Pacitan Karst Region, southeast Java, Indonesia. Our record, spanning ~85 – 70 kyrs B.P. based on ~10 U-Th dates, covers the transition from Marine Isotope Stage (MIS) 5 to MIS 4, capturing the shift from a warmer interstadial to a cooler stadial phase. Based on modern precipitation isotope data and prior studies from the region, we interpret the δ18O record to primarily reflect large-scale changes in atmospheric circulation, such that more negative δ18O indicate deeper convection associated with a strengthened IASM and vice versa. The general trend in δ18O from 85-70 ka resembles local summer insolation, similar to other terrestrial and marine records from Indonesia. Comparing this with the GG-1 δ13C and trace element records, which are more reflective of local rainfall variability, show similar patterns, particularly at millennial time scales. Specifically, a series of abrupt δ18O enrichment events coincide with overall higher δ13C, Mg/Ca, and Sr/Ca, suggesting that periods of weaker monsoon convection were linked with lower rainfall in the region.

Holocene Climate Dynamics in the Western Mediterranean, inferred from high-resolution speleothem records in Northern Morocco

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This study presents a Holocene rainfall index derived from three high-resolution and well-dated speleothem records from cave Chaara and Grotte de Piste in Northern Morocco, an area influenced by the westerly winds modulated by the North Atlantic Oscillation (NAO). We analyze centennial to millennial timescales, revealing a correlation between North Atlantic ice-rafting events and negative NAO-like conditions during both the Early and Late Holocene. However, our findings indicate a divergence during the mid-Holocene, where ice-rafting events coincide with positive NAO-like patterns, supported by additional paleo-oceanographic and paleo-atmospheric data. These observations suggest that complex interactions between prolonged north and south shifts of the westerly winds belt—reflecting both positive and negative NAO-like patterns—may play a significant role in triggering or amplifying ice-rafting events and contributing to the slowdown of the Atlantic Meridional Overturning Circulation. This research enhances our understanding of Holocene climate dynamics and the influence of westerly winds on hydrological patterns in the Western Mediterranean.

Submerged speleothems provide insights into palaeohydrological and paleoenvironmental changes in northern Namibia

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In this study, we investigated stalactites from three flooded caves and one cenote in the Otavi Mountains in northern Namibia. Neoproterozoic carbonate rocks are widespread in this region and show a high degree of karstification. Caves are common and include large underwater systems, some of which indicate lower former groundwater levels by the presence of submerged stalactites. In this study, we examined a series of such submerged speleothem samples that were collected by divers in the 1990s and provided to us by G. Brook. Initial studies using radiocarbon dating and U-Th analyses using alpha spectrometry suggested several intervals of lower groundwater levels than today during the past 130 ka, attributed to more arid conditions in northern Namibia (Brook et al., 1997, 1999). We re-examined these samples and carried out petrographic and stable isotope analyses as well as U-Th dating by MC-ICP-MS in order to assess long-term changes in the karst groundwater level in this region.Most specimens are composed of an inner stalactite consisting of dense calcite, overgrown by light brown calcite showing a complex fabric and a generally high porosity. Some samples exhibit hemispheric morphologies consisting of laminated calcite overlain by a black Fe-rich coating. Such porous calcite overgrowths have been described as subaqueous stromatolites from the Wondergat cenote in the North West Province of South Africa (Gomes, 1985) where they are currently forming down to 20 m depth.Preliminary U-Th ages suggest lower groundwater levels in the Namibian caves during the last glacial period, with no evidence of intermittent highstands comparable to today's levels. The oldest layers of stromatolitic calcite indicate that these caves were flooded about 15,000 years ago.

Age constraints on Antarctic ice-sheet meltwater pulses during the Last Interglacial Period

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According to recent IPCC estimations based on the intermediate scenario, global warming will likely result in a 0.8-1.5 m sea-level rise by 2100. Since polar ice sheets are the major potential contributors to sea-level rise, it is crucial to understand their response to past warmer periods for better constraining ice-sheet and climate models used for future predictions. The Last Interglacial (LIG; 129 to 116 ka BP) is a suitable period for this approach since temperatures have been estimated at ~1 °C above pre-industrial temperature, which is likely to be reached by the middle of the century. During the LIG, several Meltwater Pulses (MWPs) occurred, as identified in ocean-sediment cores from both Hemispheres. However, the timing and boundary conditions of Antarctic MWPs remain uncertain due to poorly constrained chronologies. Here we will present preliminary results of a project aimed at reducing the chronological uncertainties of LIG ice-sheet MWPs by linking marine sediment records from the Southern Hemisphere with Australasian speleothems. These paleoclimate archives are datable with high precision and have a proven track record at registering climate perturbations triggered by high-latitude meltwater releases. Atmospheric changes related to MWPs will be identified through a high-resolution multiproxy analysis of the speleothems, and their timing constrained with high-density U-Th dating and Synchrotron-X-ray Fluorescence microscopy lamina counting. Synchronisation of speleothem and ocean-sediment core time-series will allow us to produce a new precise chronology for Southern Hemisphere ocean-sediment records that preserve LIG MWPs. Furthermore, the well-constrained chronologies will be used to resolve the phasing of MWPs from both SH and NH ice sheets, which is crucial information for testing ice-sheet model simulations and for evaluating future responses to global warming.

Multi-phased Response of Western U.S. Hydroclimate to HS 4 archived in a California Stalagmite

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The last glacial period and deglaciation (120 to 11.8 ka) were characterized by millennial-scale climate variability expressed as decadal-scale transitions from cold stadials to century to millenia-scale interstadials. Of the six coldest stadials (i.e., Heinrich Stadials (HS)), HS4 (40–38 ka) is hypothesized as the most pronounced — characterized by severe cooling, massive ice volume release, and the largest CO_2 change. Low- to mid-latitude stalagmite records of HS4 document a multi-phased response to this high-latitude climate variability expressed as changes in precipitation amount in tropical Brazil and shifts in intensity of the East Asian monsoon. Few HS4 records, however, exist from the western U.S. and they lack the temporal resolution to investigate the phasing relationship to other records. Here we present $\delta^{18}O$, $\delta^{13}C$ and trace element time-series across HS4 for stalagmite CC1 collected from California Caverns in the central Sierra Nevada foothills. U-Th dating indicates CC1 grew between 35.6 and 39.9 ka BP and reveals the three distinct phases of HS4 and the transition to Greenland Interstadial 8. Major growth rate shifts in CC1 are synchronous with identified HS4 phases in the Brazilian and Chinese speleothems, with two short-term intervals of rapid growth rates during the terminations of phase 1 (39.5 ka) and phase 3 (38.3-38.0 ka). The transition to GIS 8 is defined in CC1 at an annual resolution, with the rapid growth aligned with isolated peaks in Mg, Sr, Ba, U and P. These observations suggests that CC1 records the decline of the Asian Westerlies, responding to oceanic reorganization, as well as ITCZ fluctuations at sub-centennial resolutions. A statistical coherence test of CC1 time series with other published $\delta^{18}O$ and $\delta^{13}C$ records of HS4 is used to identify their phasing relationships and to investigate the hydroclimate response in this region of the western U.S. to climate anomalies in the North Atlantic region. Paleo-hydroclimate from the western U.S. expands the range of climate regimes in which HS4 phase relationships have been investigated and is key to improving our understanding of the atmospheric and oceanic mechanisms that transmitted the high-latitude climate signal across the hemispheres during Heinrich Stadials.

High-resolution hydroclimate reconstruction from Holocene stalagmites from the Kingdom of Tonga

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There is currently a paucity of palaeoclimate data from the Southern Hemisphere and, therefore, there are conflicting theories about how the Southern regions may have responded during the Holocene climate fluctuations. To address this gap, our ARC-DP funded project investigates Holocene hydroclimate variability across the South Pacific as sourced from speleothem proxy data. Here we present preliminary findings from five stalagmites collected from two distinct caves in the Kingdom of Tonga.Despite their vicinity, Ana Hulu (on Tongatapu island) and Ana Maui (on ‘Eua island) caves exhibit contrasting lithological and microclimatic settings. Ana Hulu is a warm (24.2 °C) and shallow coastal cave, while Ana Maui is a deep and relatively cooler cave opening deep in the forest at 188 m asl. These characteristics result in well-laminated and coloured stalagmites retrieved from Ana Hulu and colourless, faint-laminated stalagmites from Ana Maui.The ensemble of U-series dated stalagmites provides an almost continuous record spanning the entire Holocene up to ca. 11,500 years, with growth rates between 50 and 300 µm/year. This high-resolution chronology offers the potential to obtain annually resolved records of infiltration (rainfall) variability, and record shifts of the South Pacific Convergence Zone (SPCZ), the largest component of tropical circulation on our planet.However, the interpretation of speleothem $\delta^{13}C$ and $\delta^{18}O$ values in terms of SPCZ shifts is challenging, due to the potential enhanced evaporation and degassing effects related to warm temperature and low cave air pCO_2, and only a multi-proxy approach on coeval stalagmites can provide robust hydroclimate information. To overcome these complexities, we utilised stable isotope ratios and LA-ICP-MS trace element data coupled with high-resolution synchrotron XRF and petrographic observations. This integrated strategy, combined with an assessment of crystallization pathways, will enable robust reconstructions of coeval changes in infiltration regimes and hydroclimate dynamics across the South Pacific.

Quantitative temperature reconstruction during the last deglaciation and the Holocene in northern Iberia constrained by speleothem fluid inclusion water isotopes

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In the Northern Hemisphere, the last 16.5 kyr were characterized by abrupt temperature transitions during stadials, interstadials, and the onset of the Holocene. These changes are closely linked to large-scale variations in the extent of continental ice-sheets, greenhouse gas concentrations, and ocean circulation. The regional impact of these rapid climate changes on Southwestern European environments is recorded by various temperature proxies, such as pollen and chironomids preserved in lake sediments. However, a current challenge is to accurately determine the precise chronology and the quantitative magnitude of these abrupt changes, given the scarcity of records directly reflecting paleotemperature variations. To address this issue, speleothems and their fluid inclusions serve as valuable proxies, offering high-resolution chronologies and quantitative records of past temperature changes. These non-biogenic quantitative temperature records are essential to assess whether climate models can accurately simulate regionally divergent climatic trends and for understanding global and regional climate mechanisms in the past. Here, we present a record from five speleothems from two caves on the northeastern Iberian Peninsula (Ostolo and Medukilo caves). Using hydrogen isotopic composition of fluid inclusions, we developed a δ^2H/T transfer function in order to reconstruct regional temperatures over the past 16.5 kyr (Ostolo-Mendukilo Fluid Inclusion Temperature record [OM-FIT]). Our findings reveal an increase of 6.0 ± 1.9 ºC at the onset of Greenland Interstadial 1, relative to the cold conditions of the preceding Greenland Stadial 2.1a. Also, the OM-FIT record shows a temperature decline of approximately 5.3 ± 1.9 ºC during the early phase of Greenland Stadial 1. The end of this cold phase and the onset of the Holocene are marked by a rapid warming of about 3-4 °C and reaching a maximum at 11.66 ± 0.03 kyr BP. The OM-FIT record also exhibit abrupt events during the last deglaciation and the Holocene, which are also reflected in the $\delta^{18}O$ values of the calcite, including Heinrich Event 1, Greenland Interstadial 1d, and the 8.2 kyr event.

A Seasonally Resolved Stalagmite $\delta^{18}O$ Record Indicates the Regional Activity of Tropical Cyclones in Southeast China

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Identifying tropical cyclone (TC) signatures in paleoclimate records enhances our understanding of long-term TC activity trends and the climatic factors influencing TC evolution. Stalagmites are considered promising archives for recording TC activity. However, despite the western North Pacific being the most TC-active ocean basin globally, it lacks stalagmite-based TC reconstructions. Here, we present a seasonally resolved stalagmite $\delta^{18}O$ record from XRY cave in Southeast China, covering the period from 1951 to 2018 CE, to identify annual signals of strong TC activity. We propose that the minimum seasonal XRY $\delta^{18}O$ value of each year can reconstruct regional TC activity, achieving an identification rate of 86% for strong TC years in study area. This demonstrates the feasibility of using stalagmites for TC reconstruction in Southeast China. Moreover, our research shows that inland stalagmites can still capture TC activity signals, which will promote the use of stalagmites in obtaining long-term records of post-landfall TC activity and inland impacts.

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

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To better estimate 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 in 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 ^{230}Th/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 ($\delta^{18}O$ and $\delta^{13}C$ 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 CO_2 exchange, will be essential. The resulting multi-proxy speleothem time series will allow 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.

Northeast Brazil paleoprecipitation variability over the last millennia

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In Northeast Brazilian region (NEB), the north border (N-NEB) precipitation is exclusively originated from the Intertropical Convergence Zone (ITCZ), while the southern portion (S-NEB) is in the margin of the South America Monsoon System (SAMS). Previous studies described the SAMS variability in different time scales, as well as the ITCZ, however the relationship between them has poorly been tested for the last millennia due to a few number ITCZ records described in South America. Our main goal is to comprehend the ITCZ and SAMS dynamics over NEB and how they interact with each other. Stalagmites from Trapiá and Furna Nova Cave (N-NEB) and Gruta do Jerônimo (S-NEB) were dated by U/Th and analyzed for oxygen isotope ratios. N-NEB paleoprecipitation was reconstituted for the last 3,200 yrs in high resolution and the results suggest that the range of seasonal migration/contraction/expansion of the ITCZ was not symmetrical around the Equator and a new zonal ITCZ pattern was detected ranging from N-NEB and eastern Amazon. Previous results from stalagmites of S-NEB describe paleoprecipitation for the last 4,000 yrs. Concomitant events occur in N and S-NEB and can be associated with changes in Atlantic sea surface temperatures. However, most of the S and N-NEB paleoprecipitation records are forced by different mechanisms and timescales. Changes in S-NEB rainfall are modulated by the Pacific Decadal Oscillation while the sea surface temperature gradients in Pacific and Atlantic stretched/weakened the ITCZ-related rainfall meridionally over NEB.

Reconstructing MIS3 climate during Neanderthal extinction in Iberia using speleothems from Spain

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The Iberian Peninsula represents one of the last refuges where Neanderthals survived and likely interbred with Homo sapiens. Current evidence points to a staggered timeline in their disappearance across Iberia: Mousterian industries, attributed to Neanderthals, seem to have ended around 44-45 ka BP in northern Spain and closer to 36-37 ka BP in the south. While various hypotheses —ranging from climate and ecosystem shifts to competitive pressures from Homo sapiens— have been suggested to explain their extinction, the topic remains under active debate.In this study, we present two stalagmite records from eastern Spain, covering the period from 59 to 31 ka BP, encompassing MIS3, the time when Neanderthals are thought to have vanished across Iberia. The stalagmites were collected from semi-arid zones within in two distinct climatic settings: one from the continental Mediterranean region of the Iberian Range, with an average annual precipitation of around 431 mm, and another from the maritime Mediterranean climate of the Balearic Islands, which is slightly more humid. Notably, the $d^{13}C$ profiles in these records mirror sea surface temperatures in the nearby Atlantic, highlighting vegetation and soil responses to Dansgaard-Oeschger (DO) oscillations identified in Greenland ice core records. A significant finding is the variation in isotope profile amplitudes for each DO event, which contrast with the more consistent patterns observed in Greenland, indicating varying sensitivity and intensity in the $d^{13}C$ responses among DO events. Our new proxy data achieves high temporal precision, with age uncertainties around 170 years at the MIS4 to MIS3 transition and less than 100 years between 35 and 31 ka BP, in the more recent portion of MIS3. Notably, our record captures the precise timing of Heinrich Stadial 4 and Heinrich Event 4, as the $d^{18}O$ in one of the stalagmites is particularly sensitive to shifts in the $d^{18}O$ composition of the nearby ocean, reflecting meltwater discharges in the Atlantic. Therefore, the absolute chronology provided for these events offers a framework for reconstructing ecosystem anomalies associated with Heinrich 4 and assessing its potential impacts on hominin populations.

Paleofire, Vegetation, and Climate Records from Holocene Mediterranean Speleothems: A Multi-Proxy Approach

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Project PROMETHEUS aims to reconstruct high-resolution records of paleofire activity, vegetation shifts, and climate variability during the Holocene using speleothem archives from Mediterranean caves in Italy (including the Alps, Apennines, and Sardinia) and the Balkans. Our approach utilizes uranium-thorium (U-Th) dating to establish precise chronological frameworks, at times with propagated 2σ uncertainties lower than 1%, thus obtaining accurate climate-environmental proxy time series. We incorporate a novel hydrocarbon extraction protocol developed from our work on Australian stalagmites[1,2], which facilitates slow acid dissolution in a clean-room environment. This method enhances the yields and detection limits of organic compounds, thus broadening the range of analytes detected. This allows us to integrate of the hydrological information derived from the more traditional stable isotope analysis ($\delta^{18}O$-$\delta^{13}C$) with other paleo-proxies to produce unprecedented high resolution (centennial to sub-decadal) records. In particular, we focus on polycyclic aromatic hydrocarbons (PAHs) as indicators of past fire regimes, and n-alkanes from leaf waxes as indicators of changes in vegetation and terrigenous input as well as a secondary fire marker.We present here the results from an initial round of samples at a millennial- to sub-millennial-resolution, with a focus on establishing broad insights into fire activity and environmental changes over the Holocene. Our study also includes comparisons with existing paleofire sedimentary records from Italian lakes, where shifts in fire regimes have previously been identified, as well as with modern fire occurrence data derived from registries and satellite observations. By integrating these diverse datasets, we aim to elucidate the complex interactions among fire activity, vegetation dynamics, and climate fluctuations in the Mediterranean.This multi-proxy approach is designed to provide foundational insights into the drivers of environmental change across the Holocene, laying the groundwork for future high-resolution analyses that will refine our understanding of Mediterranean ecosystem responses to climatic variability and inform predictions of fire and vegetation dynamics under changing climate conditions.

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2. https://doi.org/10.1016/j.gca.2023.11.033

Natural and Anthropogenic Influences on Stalagmite Geochemistry in Mawmluh Cave, Meghalaya, India

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This study investigates stalagmite samples from Mawmluh Cave in Meghalaya, India, one of the world's wettest regions, to reconstruct environmental changes driven by both natural processes and nearby industrial activities. The cave is today located below an active cement quarry established in 1960 and contains several speleothems that reflect climate variability and potential human impacts. We analysed three stalagmites (Samples A, B, and C), which show a clear transition from calcite at the base to aragonite at the tops. ^{230}Th/U-dating shows that aragonite formation occurred approximately from the mid-19th century to the present in Sample A, and from the mid-20th century to the early 21st century in Samples B and C. Our findings reveal consistently high concentrations of trace elements (Mg, Sr, U, and Ba) prior to the quarry's establishment, which most likely document natural processes. The elevated trace elements are likely due to variations in drip water chemistry, with particularly high Mg/Ca and Sr/Ca ratios indicating conditions supporting aragonite formation associated with strong Prior Calcite Precipitation (PCP) during drier periods. Positive $\delta^{13}C$ values observed across all samples indicate natural vegetation cycles and soil CO_2 fluctuations, with limited ventilation contributing to CO_2 buildup in the cave.Post-1960 CE, the quarry appears to have increased variability in both trace elements and isotopes, highlighting a significant environmental response to industrial activities. These anthropogenic effects overlay natural signals, creating a complex record that captures both monsoon-driven variability and anthropogenic influences. By integrating trace element and stable isotope data, this study elucidates the interplay between natural climate drivers and industrial impacts on speleothem chemistry in Mawmluh Cave, emphasizing the need to differentiate natural baselines from human contributions for improved interpretation of paleoclimate records and contemporary environmental changes.

Discerning hydroclimate conditions in the Indo-Pacific Warm Pool during Heinrich Events

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Episodic iceberg discharge events (Heinrich Events; HE) from the Laurentide ice sheet in the Northern Hemisphere impacted global climate through atmospheric-oceanic teleconnections. The Indian Pacific Warm Pool (IPWP) straddling the equator and often referred to as the heat engine of the globe is the leading driver of heat transport in this region. Speleothem-based geochemical reconstructions suggest low-latitude monsoon region response abruptly during HE. However, this climate expression is not homogenous within the IPWP. Developing high-resolution, multi-proxy speleothem paleoclimate records that track hydroclimate variation are required to fill an outstanding knowledge gap that investigates IPWP's hydroclimate response to HE. The Philippines is ideally located within the IPWP. Here, we will investigate □18O, □13C, and trace elements (Mg/Ca, Ba/Ca, Sr/Ca) in a speleothem sample, BH-1. BH-1 was collected from Hinagdanan Cave and grew between 26-51 kyrs B.P. with an average growth rate of 8.12 µm/yr. Modern climatology suggests that Hinagdanan Cave recharges to summer precipitation. As such, speleothem growth covered Heinrich Events 3-5. Change-point analysis conducted on the □18O record reveals that Heinrich Event 3 in the Philippines experienced drying conditions. The drying is in alignment with □18O trends reflected in Borneo stacked speleothem records. Further investigation of BH-1 trace elements and stable isotopes will disentangle regional (□18O amount effect, moisture source) versus local (prior calcite precipitation) hydroclimate variability. Finally, we will compare our geochemical results with existing climate model simulations (iTRACE) to discern potential climate drivers that modulate IPWP hydroclimate during Heinrich Events.

Calcite – aragonite speleothems record inter-annual climate fluctuations in Botswana during the Late Holocene

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Southern Africa is a crucial location for studying the effects of climate on early human evolution/migration out of Africa. Here, we present speleothem data from Gcwihaba Cave in northern Botswana, which contains mixed calcite and aragonite mineralogy. This adds a layer of complexity to the interpretation of the speleothem proxy data. Therefore, we first focus on the late Holocene, where speleothems show well-preserved fabrics.We analyzed carbon ($d^{13}C$) and oxygen ($d^{18}O$) isotopes as well as trace element concentrations (such as Mg/Ca, Sr/Ca, Ba/Ca and U/Ca). However, calcite and aragonite have different water-to-carbonate carbon and oxygen isotope fractionation factors, as well as trace element partitioning coefficients. Mineralogical and petrographic studies of these speleothems are thus crucial to deciphering the climate signals within them. Preliminary petrographic investigations show alternate and/or mixed aragonite and calcite layers, whose thicknesses range from several micrometers to millimeters. U-Th ages and layer counting indicate they are likely of an annual nature, hinting at a strong seasonal fluctuation in rainfall amounts in the area. This observation is consistent with earlier work from the same cave (Railsback et al., 1999). Modern-day crystal growth experiments conducted during late winter to early summer in the cave documented primary aragonite and calcite precipitation without clear evidence for phase transformation in the current environmental/climate conditions.High-resolution isotope and trace-element data show consistency with petrographic observation, further supporting significant seasonal contrast in rainfall. Influence of the Indian Ocean Dipole and El Niño-Southern Oscillation-like climate phenomena in this region may govern these seasonal and/or interannual fluctuations in climate variability.

The timing and sequence of climate changes during the penultimate deglaciation in a French stalagmite record

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Glacial terminations are the largest magnitude climate changes during the Quaternary Period. Speleothems are important archives for: (1) refining the sequence of climate changes during glacial terminations; and (2) providing accurate and precise chronological constraint to these changes. More records are needed to fully understand the sequence of events during the penultimate deglaciation. Here we present a multiproxy (δ18O, δ13C, Mg/Ca, Sr/Ca) stalagmite record from Orgnac Cave, France, where the climate is strongly influenced by westerly air masses originating over the North Atlantic. The record provides continuous coverage from ~138 ka through to the last glacial inception. Stalagmite δ13C records soil and vegetation changes in response to temperature changes at the site, which are closely correlated with sea-surface temperature changes in the North Atlantic. Three approximately millennial long cooling events are recorded during Heinrich Event 11 that are likely associated with discrete meltwater pulses and AMOC weakening. The δ18O records a strong negative transition during Heinrich Event 11, reflecting a moisture-source effect from a decrease in surface ocean δ18O in the North Atlantic due to the influx of meltwater, the signal of which is carried to the site by the westerly air masses. The largest and most abrupt shift in δ13C marks the main Termination II transition, suggesting strong warming and an increase in soil and vegetation activity at the site, and is preliminarily dated to 130.0 ± 0.8 ka. This multiproxy record provides improved insight to the temperature and hydrological changes in France during the penultimate deglaciation, as well as recording North Atlantic freshening during Heinrich Event 11. Precise chronological constraint enables robust comparison with other Termination II records.

Fluid Inclusion Water Isotope study of a stalagmite from the southern coast of South Africa over the 60 – 90 ka time interval

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The southern coast of South Africa is home to key archeological sites critical for studying the cognitive and cultural evolution of early Homo sapiens. To understand the environmental and climatic influences on human evolution, detailed paleoclimatic reconstructions are essential. During speleothem growth, voids may be formed between crystals and subsequently filled with drip-water. These remnants of drip-water can be released and analyzed for their isotopic composition by crushing chunks of calcite into a dedicated analytical line. Because the oxygen isotopic fractionation between water and calcite is temperature dependent, temperature estimates can be calculated. In a previous study, Fluid Inclusion Water Isotopes (FIWI) were measured on a stalagmite from Bloukrans cave in the De Hoop Nature Reserve, located in South Africa's Western Cape region. These analyses revealed that most FIWI data plotted along the Meteoric Water Line (MWL) and the temperature calculated were consistent with independent Microthermometry measurements. Some data deviated significantly from the MWL and gave unreasonably high temperatures, which were interpreted as in-cave evaporation during drier time intervals. Here we present new FIWI data from a sample collected in Bloukrans cave. The current age model indicates growth from 63 to 90 ka with hiatuses between 64 - 70 ka and 72 - 75 ka.

Rapidly growing stalagmites from Curaçao provide insights into modern climate controls on tropical speleothem geochemistry

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The climate of the Caribbean is primarily governed by the influences of ocean-atmosphere teleconnections, such as interactions between the Atlantic Meridional Overturning Circulation and the intertropical convergence zone, and on shorter timescales the El Niño Southern Oscillation. Paleoclimate records from speleothems and corals have shed light on the evolution of these relationships over the past several thousand years across much of the Caribbean. However, the Southern Caribbean which is notably hotter and drier than the more tropical Northern, Western, and Eastern areas, remains comparably understudied. The island of Curaçao in the Lesser Antilles sits off the coast of Venezuela, currently outside of the Atlantic hurricane belt. Curaçao has multiple limestone reef terraces that are home to caves with actively precipitating speleothems. Here we present trace element (Mg/Ca, Sr/Ca, U/Ca) and stable isotope ($\delta^{18}O$ and $\delta^{13}C$) analyses of four actively growing stalagmites from Hato Cave (HC) in the Pleistocene higher reef terrace on Curaçao in order to investigate modern climate controls on speleothem geochemistry in the Southern Caribbean. Carbonate accumulated on HC drip plates suggests high rates of contemporary stalagmite growth (>100 µm/a), while U-Th analyses reveal high and variable initial Th ratios, making U-Th dating challenging. We explore the potential for regular cyclicity observed in Mg/Ca, Sr/Ca, and U/Ca to provide chronologic constraints on stalagmite age models via layer counting. Analysed $\delta^{18}O$ in multiple stalagmites exhibits distinct negative excursions of up to 4 ‰, suggesting the potential influence of isotopically depleted precipitation from tropical storms on the island, despite Curaçao's southerly location. High resolution, sub-annually resolved stalagmite records can further be compared with records of marine conditions from corals collected off the Curaçao coast. 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.

A detailed climatic context for the growth and decay of Cretan civilizations

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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 ^{230}Th-dated and analyzed using a multi-proxy approach. Coupling stable isotope ($\delta^{18}O$, $\delta^{13}C$, and $\delta^{44}Ca$), trace element, 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 identify climate shifts and extreme climatic events within its cultural history.

Late Pleistocene high resolution speleothem record from the Philippines provides insight into south east Asian monsoon dynamics at varying frequencies

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Hydroclimate variability in the Philippines, whose rainy season spans June-September, is poorly constrained across decadal to orbital timescales. This region of the Maritime Continent lies on the Northern edge of the boreal Intertropical Convergence Zone, implying great hydroclimate sensitivity to small climate shifts. Additionally, the role of the Indo Pacific Warm Pool (IPWP) in relation to the Asian monsoon system and its influence on hydroclimate over the Philippines is also poorly understood. A high-resolution terrestrial record from this important region in the tropics allows us to resolve monsoon dynamics at multiple frequencies and more accurately incorporate the spatial effects of the IPWP on the Asian monsoon into climate models.This work presents a ~24kyr speleothem $\delta^{18}O$ record from a 1.26 m stalagmite that grew between 94,395 ± 964 to 70,563 ± 687 years B.P. in Puerto Princesa Underground River Cave, Palawan, Philippines (10°10′N, 118°55′E). This record shows hydroclimate variability during MIS 5b, 5a, and the onset of glacial MIS4 in the tropics. We established a relationship between modern precipitation influx and cave drip water via monthly samples of this karst-hydrological system over 1.5 years. $\delta^{13}C$ and trace element analysis are considered to constrain cave dynamics influencing calcite deposition, such as prior calcite precipitation and kinetic effects. U-series ages, whose uncertainties have been constrained and add to the literature on tropical detrital The systematics, reveal a fast growth rate of up to ~7 year/mm for some portions of the record, which allows us to explore the effects of millennial to sub-decadal scale climate modes with high resolution drilling, and additional climate forcings on precipitation over the IPWP. This tropical record from the Philippines spatially links previously published low latitude and mid latitude climate records from East and Southeast Asia, filling in important spatial gaps for published paleoclimate records spanning the IPWP, as currently speleothem-derived climate records from the Philippines are limited to one other study. This Philippines hydroclimate record will aid in constraining models capturing hydrological variations over the archipelago, where over 100 million people currently live.

Impacts of seismic shaking on speleothem chemistry: A case study from the Alpine Fault, Aotearoa New Zealand

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Speleoseismology aims to reconstruct earthquake records by dating pre- and post-damage speleothem calcite, where synchronous and spatially distributed damage features (e.g., rockfall, broken stalagmites) may be interpreted as regional shaking events. Current approaches usually require a large sample size of dated damage features to overcome the often ambiguous (i.e., potentially non-seismic) origins of cave damage. However, in regions of high tectonic strain and short earthquake recurrence, the sample size required becomes impractically large, hence the need for alternative approaches. Our study tested a novel speleothem chemical proxy for quantifying ground shaking that is amenable to high-resolution speleothem studies, and potentially more diagnostic of earthquake damage. We evaluated the hypothesis that large earthquakes temporarily elevate Mg/Ca in cave drip waters via incongruent carbonate dissolution following host rock fracturing (ICD_C), leading to corresponding Mg enrichments in speleothem calcite. To do this, we examined a well-dated Holocene stalagmite (GT1) from a cave near the northern Alpine Fault, a major source of seismic hazard for Aotearoa New Zealand, rupturing every ~450 years in a major (M_W >7) to great (M_W >8) earthquake.We present a record of Mg/Ca variability in GT1 since ~5 ka, obtained by laser ablation inductively coupled plasma mass spectrometry, constrained temporally by >40 U-Th dates. Periodic anomalous Mg/Ca enrichments are interpreted as high-intensity shaking events that temporarily elevated drip water Mg/Ca via ICD_C. Moreover, Mg/Ca enrichments are strongly associated with brown-stained laminae, inferred to reflect soil-derived organics. We propose that the high-Mg/high-organics horizons represent earthquakes that fractured the host rock and enhanced the mobilisation of organics from overlying soil. The GT1 record of inferred earthquakes was compared with an independent 1.4-kyr record of well-dated seismically triggered lacustrine turbidites proximal to the study site. Of the four largest (MMI >VIII) shaking events in the lake turbidite record, which correspond to northern Alpine Fault surface-rupturing earthquakes, three overlap in age with a GT1 Mg/Ca anomaly (MMI: Modified Mercalli Intensity). Further, two of the three historic earthquakes that generated severe (MMI ≥VII) shaking at the study site also overlap in age with a Mg/Ca anomaly.

Monsoon precipitation reconstruction from the coast to central Brazil since the Last Glacial Period

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In recent decades, the number of paleoclimatic studies using speleothem isotope records in Brazil has grown substantially and has enabled great progress in the reconstruction of the South American Monsoon System (SAMS). However, such studies are still absent in large geographic areas such as the coastal region of eastern Brazil, where climate is associated with multiple rainfall regimes. Our results, based on the speleothem records from an east-west transect between coastal and more central Brazilian cave sites, indicate a strong control of insolation and the influence of sea surface temperature (SST) on precipitation in response the directly influence by the South Atlantic Convergence Zone (SACZ) since Last Glacial Maximum (LGM). The results are essential for discussing the periods and durations associated with the expansion of vegetation corridors, over one of the best-known centers of endemism in the Atlantic Forest zone. The speleothem record comparison reveals a strong similarity in the climate variability at distinct time-scales, which favor species dispersal between the Atlantic Forest and the Amazon Forest through areas currently covered by the savanna (cerrado) and dry forests (caatinga). The paleoclimatic reconstruction of the regions influenced by the activity of the SACZ is a fundamental part of interdisciplinary projects that aim to understand the impact of climate change on the hydrological regime of Brazil, as well as in biogeographic studies.

Accessing changes in extreme rainfall events over the last 7 kyrs through stalagmite-based cave flood records from Malfazido cave in South-eastern Brazil

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Climate change projections and observational analysis are evidencing an increase in extreme rainfall events (EREs) frequency and intensity worldwide. South and southeastern Brazil, are highly impacted by EREs with severe socioeconomic impacts such as the catastrophic flooding in Rio Grande do Sul state in April and May of 2024, which displaced over 580,000 people and caused profound socioeconomic problems. In this region, EREs are mainly triggered by the interaction of tropical and extratropical systems such as the South Atlantic Convergence Zone and cold fronts respectively. The El Niño Southern Oscillation (ENSO) enhances this mechanism during strong and moderate El Nino years by shifting the Walker circulation, which channels warm, moist air into the region, increasing the intensity and duration of rainfall events, raising the likelihood of EREs. The scarcity of long-term data limits our understanding of ERE frequency and intensity beyond the instrumental period, precluding insights into how larger-scale climate forcings and atmospheric shifts may impact these events over long timescales. This study presents a detailed paleoflood reconstruction from stalagmites in Malfazido Cave, southeastern Brazil, assessing the frequency of EREs over the past 7,500 years to the present. The records are based on detrital layers within the stalagmites deposited during cave floods that submerge these formations. Cave monitoring data and instrumental records show that monthly rainfall exceeding the 99.4th percentile (>340 mm/30 days) marks a flood threshold in the cave, providing a reliable gauge for reconstructing past extreme events. Instrumental and monitoring data shows that EREs occur mainly during strong and moderate El Niño years, indicating ENSO teleconnections as a significant driver of EREs. We identify notable shifts in cave paleoflood frequency over time, with elevated flood rates in the Middle Holocene compared to the Late Holocene. The last millennium, however, displays a distinct heightened flood frequency trend towards the present, with the Little Ice Age (LIA) standing out as a high frequency period.

Holocene climate dynamics in central-eastern Brazil reconstructed from speleothem multiproxy records

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The South American Monsoon System (SAMS) plays an important role for the hydroclimate variability and rainfall patterns across South America. Stemming from its convective core in the southwestern Amazon basin, the South Atlantic Convergence Zone (SACZ) is a southeastward convection band, and a critical component of the SAMS responsible for large-scale moisture transport, particularly over Central Brazil. Previous paleoclimate studies suggest that the SACZ has changed over time, usually associated with changes in the SAMS, and there are ongoing debates regarding the nature of the SACZ, shifts in its position, size, and intensity. This study addresses these debates for the last 11.200 years based on a novel multi-proxy paleorecord ($\delta^{18}O$, $\delta^{13}C$, and Sr isotope ratios ($^{87}Sr/^{86}Sr$)) from a stalagmite collected in São Mateus cave at the northeast limits of the SACZ in central Brazil. The local climate is characterized as tropical semi-humid with a rainy summer season and a dry winter. The inclusion of Sr isotope data enhances our interpretation of past local climate variability since changes in $^{87}Sr/^{86}Sr$ can provide valuable information about water residence in the karst and changes in soil composition. Comparison with other paleoclimate and pollen data from sites under the SACZ regime enable us to access climate and vegetation changes in different locations within this convective band. This is particularly the case for the Holocene, where several sites report SACZ stability, despite of observed vegetational changes. We demonstrate that, even though other records from SACZ region show a common $\delta^{18}O$ signal without significant trends, our record shows an increasing $\delta^{18}O$ trend during the Holocene. This indicates that the air mass subsidence over NE Brazil caused by the intense convective activity over the core monsoon region to the west can also impact eastward progression of the SACZ until the region of São Mateus cave. Additionally, our $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ records show significant environmental changes throughout the Holocene, agreeing with the regional pollen and speleothem data. Our multi-proxy approach, combining traditional stalagmite proxies with Sr isotope analysis, offers a better understanding of past SACZ changes and their implications for Central Brazil's climate and environment.

A speleothem record of precipitation and temperature history in the Russian Plain as evidence for changes in the Volga River discharge

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The central part of the Russian Plain is an area of abrupt climate change during the Quaternary period, with a strong correlation to climate variations in the North Atlantic. The vast majority of the Russian Plain is situated within the Volga River basin. As a result of repeated glacial periods and fluctuations in precipitation, there have been significant changes in the discharge of the Volga and its impact on the Caspian Sea level. Following the last glacial maximum, two distinct periods have been reconstructed. The first, spanning 18-12 ka, is characterized by relatively low temperatures and high runoff of the Volga River (Panin & Matlakhova, 2015). The second, spanning 8.5-5.5 ka, is distinguished by temperatures higher than those of the present day (Kislov & Toropov, 2006) and low Volga runoff (Panin & Matlakhova, 2015). However, it should be noted that the aforementioned reconstructions have a relatively low resolution. The speleothem records from the Volga River basin have the potential to provide insights into precipitation and temperature changes in the region, and consequently, into runoff changes and its impact on Caspian Sea level changes.Three flowstones and two stalagmites were collected from the Samara region. The cave was located within the confines of the upper Permian carbonate rocks. It is not possible to monitor the cave in its current state, as it has been destroyed by quarrying activities.Two samples of stalagmites (PD-1, PD-2) demonstrate two distinct generations of calcite growth. XRF mapping (Bruker M4+ Tornado) and ICP-MS analysis reveal fluctuations in Sr, Mg, and their ratio with Ca. It is expected that δ18O would also show at least two periods, reflecting different precipitation and temperature conditions. U-Th dating will help us to tie these changes to chronology.

Reconstructing hydroclimate patterns in coastal central California using coeval speleothem records from White Moon Cave

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California's Mediterranean climate makes it highly susceptible to "whiplash" events—rapid transitions between wet and dry extremes. Previously analyzed proxy records from a speleothem from White Moon Cave (WMC1) in the Santa Cruz Mountains of coastal Central California reveal oscillations between extreme wetness and aridity and complex hydroclimate patterns in the early Holocene, particularly during the 8.2 ka event and a precursor event at 8,300 years BP. However, high-resolution Holocene paleoclimate records for this region remain limited. Here, we present U-Th ages and trace element (Mg/Ca, Sr/Ca, Ba/Ca, P/Ca) and stable isotope ($\delta^{18}O$ and $\delta^{13}C$) records from speleothem WMC5, which grew from ~8,000 to ~6,100 years BP, overlapping with the original WMC1 record which covered ~8,600 to ~6,900 years BP. We also present an updated record for WMC1 that extends to ~357 years BP. Further, we utilize confocal laser fluorescent microscopy (CLFM) to link variations in WMC5 and WMC1 stable isotope and trace element data with visible changes in speleothem microstructures and fluorescent banding reflecting changes in organic acid concentrations within the speleothem calcite. WMC $\delta^{13}C$ and trace element records show a multi-centennial drying trend starting ~6,400 years BP, consistent with regional records of increasing mid-Holocene aridity. Stable isotopes from WMC5 show positive offsets compared to WMC1 (~+2.16 ‰ mean difference for $\delta^{13}C$, ~+0.83 ‰ mean difference for $\delta^{18}O$) and greater variability, as is true of trace elements. WMC5 was collected from a deeper position in the cave than WMC1, suggesting the offsets may result from differences in flow path hydrology, enhanced PCP, or in-cave disequilibrium effects. These observations align with modern calcite and drip water data from White Moon Cave, where $\delta^{13}C$ values of DIC are more enriched in ^{13}C for deeper drip sites. Both speleothems display high-contrast, alternating light and dark laminae indicating variable influx of soil organics over time. This multi-speleothem, multi-proxy study offers the ability to examine and account for within-cave processes in a dynamic cave environment, providing a more complete view of hydroclimate variability in coastal Central California throughout the Holocene.

A Composite $\delta^{18}O$ Stalagmite Record from Northeastern Yucatán Peninsula, Mexico, Covering the Last 1,400 Years

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Stable oxygen isotopes ($\delta^{18}O$) in stalagmites from the Yucatán Peninsula (YP) in Mexico and the broader Caribbean region are generally interpreted as indicators of local hydroclimatic conditions, such as rainfall amount and convective activity strength. Variability among the few existing stalagmite $\delta^{18}O$ records from the YP likely reflects heterogeneous precipitation distribution across the peninsula and varying inputs from tropical cyclone rainfall, which carries a distinct isotopic signature. However, larger-scale climatic drivers, such as sea surface temperature (SST) variability, which influence rainfall amount and convective activity over longer timescales, are also expected to be recorded in $\delta^{18}O$ records from multiple stalagmite sites across the region.Here, we present a composite $\delta^{18}O$ record from Áaktun Kóopo Cave on the northeastern YP, Mexico, providing a high-resolution qualitative rainfall history for the last 1,400 years. This record was constructed from three individual, overlapping stalagmite records. High uranium content in these stalagmites enabled precise $^{230}Th/U$ dating, and some chronologies were further refined by counting seasonal variations in Sr/Ca ratios through LA-ICP-MS analyses. The consistency among the individual records suggests that carbonate precipitation in the cave likely occurred under equilibrium conditions, thus reflecting changes in local hydroclimate.The record captures prominent centennial-scale hydroclimatic fluctuations consistent with other paleoclimate records from the YP and Central America, indicating a significant influence of large-scale climatic drivers, including tropical Atlantic and Pacific SST variability and shifts in the mean path of the Intertropical Convergence Zone (ITCZ). Preliminary spectral analyses show periodicities consistent with ENSO variability and solar cycles, suggesting that solar forcing may influence regional hydroclimate, though this relationship varies over time. These findings underscore the value of speleothem archives in advancing our understanding of Mesoamerican climate dynamics on local and regional scales, with Áaktun Kóopo Cave showing potential as a sensitive archive of hydroclimatic variability over centennial to millennial timescales. Extending these analyses to a longer, continuous record would further illuminate distinctions between local and regional climate influences within broader climate trends.

Insights into the timing and characteristics of regional climate change during ‘extra’ Termination IIIa inferred from a multiproxy stalagmite record from south-east France

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Glacial terminations represent the largest magnitude climate changes in the recent past and have occurred roughly every 100,000 years over the late Pleistocene. Not all glacial cycles are alike with some 'extra' terminations occurring outside the ~100,000-year recurrence window. Examples of such events are terminations TIIIa, TVIa and TVIIa, all of which are presently poorly studied. It remains unclear to what extent the drivers and regional responses of these 'extra' terminations are comparable to 'main' terminations. To unravel the processes involved in the rapid climate shifts during these terminations we require records of regional climate changes that are accurately and precisely anchored in radiometric time. Here we present a new multi-proxy stalagmite record from Saint-Marcel Cave (France) that exhibits multiple periods of growth through MIS 7-6, during which Termination IIIa occurred. The $\delta^{13}C$ and $\delta^{18}O$ suggest a centennial scale transition to cold, dry conditions immediately preceding the termination. A final shift to warmer, wetter conditions follows and is interpretated as TIIIa at around 230,000 years BP. Mg/Ca and Sr/Ca analyses are drawn on to support the interpretation, and the chronology is constrained by U-Th dating. Our multiproxy record provides new insights into the timing and regional climate responses during TIIIa.

A Clumped isotopes-based reconstruction of temperature changes through the Last Glacial Maximum to the early Holocene in central China

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The development of high-resolution paleo-temperature records is critical to a comprehensive understanding of climate dynamics and a better evaluation of climate models' simulation abilities. The clumped isotopes in carbonate are a newly developed geothermometer, which has been used to more accurately constrain past temperature changes. Here, we give a first clear picture of how temperature in central China changed from the LGM to the early Holocene by using Δ47 data derived from a 40 cm-long stalagmite from Xianglong Cave. The Δ47 values of the stalagmite range between 0.70 and 0.75, showing the ability to detect changes in temperature with a high degree of sensitivity. The annual mean temperature in central China indicated by Δ47 generally shows a warming trend from the LGM to the early Holocene, and part of millennial climate events can be clearly identified in Δ47 record with substantially fluctuated temperature, including Younger Dryas (YD), Bolling-Allerød (BA) and Heinrich 1 and 2 (H1, H2). According to Δ47 record, the annual mean temperature during the LGM period was about 10℃. The reconstructed temperatures further decreased to around 8°C during YD and H2, with a remarkable cooling climate during H1 (~4°C). In contrast, the BA warm period was characterized by increased temperature, reaching a peak of 17.6°C.

Mercury deposition in central China from the Last Glacial Maximum to the early Holocene recorded in an accurately-dated stalagmite

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Characterization of transport pathways and depositional changes in Mercury (Hg) and their connection to climatic and environmental changes on various time scales are crucial for better understanding the anthropogenic impacts on the global Hg cycle in the Anthropocene epoch. In this study, we examined Hg variations recorded in a stalagmite from central China, covering the period from 25.5 to 10.9 thousand years ago. Our data show a marked increase in Hg concentrations during the late Last Glacial Maximum, which coincided with the period of highest dust deposition on the Chinese Loess Plateau. Hg concentrations were lower during Heinrich events 1 and 2 and the Younger Dryas but higher during the Bølling- Allerød and the early Holocene. We suggest that regional dust load, which enhances atmospheric dry deposition of Hg, is the primary factor influencing Hg deposition in central China on glacial-interglacial timescales. On millennial-to-centennial timescales, climate also plays a significant role. Warmer and wetter conditions increase vegetation, litterfall, and soil/rock weathering, which in turn boost mineral dissolution and soil erosion in the vadose zone. These processes collectively result in higher Hg concentrations in the stalagmite.

Session 8:

Karst Records of Climate Variability on Orbital Timescales

Speakers:

Keynote: Nick Scroxton

Mahjoor Ahmad Lone
Yuri Dublansky
Kathleen Wendt
Daniel Sinclair
Dana Riechelmann
Ngozi Ulasi
Timothy Pollard
Christoph Spötl
Daniel Cleary
Hongbin Zhang
Nick Scroxton
Plinio Francisco Jaqueto

Posters:

33. Lucas Vasconcelos
34. Maria Magdalena Steck
35. Madison Wittmer
36. Andrea Columbu
37. Haiwei Zhang
38. Rieneke Weij
39. Juan Pablo Bernal
40. Hao Ding
41. Jeff Munroe
42. Michael Rogerson

The Long Game: Unravelling Orbital Climate Variability Using Speleothems

Nick Scroxton

University College Dublin, Dubin, Ireland

Sheltered cave environments, preserved for hundreds of thousands of years, and the remarkable precision of uranium-series chronologies make speleothems one of the most valuable paleoclimate archives for studying orbital-scale climate change. From seasonal insolation changes in the tropics to the waxing and waning of large icesheets near the poles, speleothems record both near- and far- field changes in climate and the environment driven by variations in Earth's orbital parameters with high-fidelity and unprecedented temporal precision. This keynote will explore the rich history of orbital-scale climate variability research in the speleothem paleoclimatology field and demonstrate how new methodologies are driving innovative research directions and addressing fundamental questions in paleoclimatology. Growth phase frequency studies aggregate speleothem ages and growth periods to reconstruct past liquid water availability. These studies are valuable in marginal environments, where speleothem growth may stop for long periods of time, and in wet regions, where variation in speleothem growth serves as a proxy for rainfall amount. Recent advances using novel statistical techniques account for the natural attrition of speleothems, enabling more accurate comparisons of growth-phase peaks and troughs through time. This methodology can be applied to both new stalagmite databases, such as SISAL, and older collections of speleothem ages, such as those from the UK and Ireland. Meanwhile, high-resolution geochemical records, including stable isotopes and trace elements analyses, serve as proxies for local and regional climate and environmental change over orbital timescales. These long-term proxy records address fundamental questions about climate system processes and mechanisms. Topics include zonal and meridional climate variability in the tropics, the dynamics of leads and lags in the climate system and the influence of seasonal proxy sensitivity, and whether speleothems have already solved the 100-kyr problem. Recent studies combining stable isotope and trace element proxies from the same speleothem are beginning to unravel seasonal variability, raising new questions about the respective roles of summer versus winter monsoons in the tropics.

Tracing Past Rainfall Sources in Northern Sahara: Insights from Speleothem Fluid Inclusion Mapping and Chemistry

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The Sahara, as the largest hot desert and a major atmospheric dust source, modulates global climate. Changes in its extension will have a significant impact on global climate system making it a critical area of study. Earlier records from the region suggest that present day arid/hyperarid desert has previously been vegetated on multiple occasions. While on the southern margin of the desert this variance is associated with changes in the African monsoon, what is happening on the northern margin, what regulates those changes and how the different northern and southern rainfall systems combine to affect the interior of the Saraha are poorly known. Closing this knowledge gap is an urgent priority, because climate models predict an enhanced drying under future global warming, but the IPCC give this forecast only “Medium” confidence, and it contrasts strongly with those paleoclimatic records which indicate a greener Sahara during the warmer times through the Pleistocene. We address this issue by past climate reconstruction using Loess and speleothems from Tunisia in central North Africa and trace the moisture source through speleothem fluid inclusions. Here we present our work on fluid inclusion mapping and isotope analysis. We observe that fluid inclusions are consistent with a Western Mediterranean source for most rainfall, with some derived from the Atlantic. For much of the record, deuterium excess is highest in the samples with the most depleted $d^{18}O$ and $d^{2}H$, which is consistent with some rainfall being derived from Mediterranean-derived high-intensity events, analogous to modern “medicanes”. High deuterium excess is also found during MIS5e, which is the only time the fluid inclusions we report from Tunisia are similar in composition to those we have already published for Libya, indicating an enhanced Eastern Mediterranean source occurred during the Eemian which is not reflected during other times of MIS5. The distribution and size of individual fluid inclusions can significantly impact isotope results, potentially leading to interpretive errors. To understand these effects, we developed a methodology using confocal microscopy to map inclusion size and distribution, allowing for more precise data interpretation.

Formation of cryogenic cave carbonates during permafrost aggradation

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The prevailing genetic model for the formation of cryogenic cave carbonates (CCC) associated with permafrost suggests that CCC are primarily formed during permafrost degradation (thawing). In this model, the rock above the cave needs to be warm enough to allow water infiltration, while residual permafrost still persisted in the deeper parts of the karst massif. Conversely, during permafrost aggradation, CCC formation is considered less likely, as the frozen ground restricts water infiltration into the caves. In most Central European caves, episodes of CCC formation have been dated to glacial–interglacial and stadial–interstadial transitions.Data from Mirichun Cave (East Sayan Highlands, Eastern Siberia) does not align with this established conceptual model. In this cave, CCC formed during periods of permafrost aggradation rather than thawing (MIS 5c–d, late stages of MIS 5e, MIS 7, and MIS 9). Stalagmites, which indicate permafrost-free conditions, formed in this cave during the Holocene, MIS 5e, and MIS 11.A model explaining CCC formation during permafrost aggradation proposes that: (1) relic permafrost remained in the deeper parts of the karst massif, even after peak interglacial conditions; (2) the regional climate was sufficiently wet to produce ample precipitation, enabling infiltration into the karst rock; and (3) the rock's permeability allowed focused infiltration of surface water deep into the massif, toward the relic permafrost zone. Preservation of relic permafrost at karst massif depths during past interglacials is more likely in regions that are currently within discontinuous or sporadic permafrost. The other two conditions facilitate localized permeability for water within near-surface permafrost as it forms in response to climate cooling. Mirichun Cave meets all of these conditions. Located in discontinuous permafrost (mean annual air temperature of -6°C), the modern cave temperature is 0.6°C. Annual precipitation, ranging from 700 to 800 mm (with 500 to 600 mm falling in summer), significantly exceeds evaporation (220 to 260 mm). The cave's structure, with abundant steep fractures and tectonic faults, facilitates focused infiltration of surface waters deep into the karst rock. This common notion that CCC formation exclusively reflects conditions of thawing permafrost may therefore need to be revised.

Orbital-scale climate change in the Great Basin over the last seven glacial-interglacial cycles: the new Devils Hole record

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The drylands of the Great Basin USA underwent drastic hydroclimate changes throughout the Quaternary. We present a 736,000-year $\delta^{18}O$ and $\delta^{13}C$ record from Devils Hole 2 (DH2) cave in southern Nevada, USA. The DH2 chronology is anchored by 114 uranium-series ages, allowing for an independent assessment of the drivers of hydroclimate change in the southern Great Basin over the last seven glacial-interglacial cycles. Water isotope-enabled Earth System Model (iCESM1.3) with moisture tagging suggest that DH2 $\delta^{18}O$ variations represent large-scale changes in surface temperature and evaporative processes in the eastern North Pacific and western USA region. The new DH2 $\delta^{18}O$ record reveals strong statistical links to atmospheric CO_2 on the AICC2023 chronology, with <300 years of variable phasing between the two records. During terminations II-V, the midpoint of the rise in atmospheric CO_2 coincides with the midpoint of the rise in DH2 $\delta^{18}O$ to interglacial values (132.15 ± 1.5 ka [TII], 244.0 ± 1.1 ka [TIII], 341 ± 3 ka [TIV], 430± 6 ka [TV], 529 ± 6 ka [TVI] and 708 ± 8 ka [TVIII]), indicating fast-acting changes in regional surface temperatures and hydroclimate feedbacks associated with increased radiative forcing. The DH2 $\delta^{13}C$ time series is inversely related to DH2 $\delta^{18}O$. Variations in DH2 $\delta^{13}C$ is in-phase with late boreal summer (peak growing season) insolation. Abrupt reversals towards higher DH2 $\delta^{13}C$ values occur at approximately 426 ±9 ka [MIS 11e], 335 ±4 ka [MIS 9e], 240.1 ±1.5 ka [MIS 7e], 125.8 ±0.4 ka [MIS 5e], and 6.2 ±0.6 ka [Holocene]. DH2 $\delta^{13}C$ reversals are interpreted as abrupt shifts towards lower vegetation density and soil productivity in the high-elevation mountains of southern Nevada in response to decreasing water availability and warming temperatures within each interglacial.

The Response of Tropical South Pacific Rainfall to Rapid Glacial Climate Perturbations: Speleothem Records and Palaeoclimate Models

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The South Pacific Convergence Zone (SPCZ) is a band of atmospheric circulation and rainfall that plays a major role in the climate of the Southern Hemisphere. The shape and position of this system is sensitive to global temperature gradients and complex ocean/atmosphere feedbacks. Although evidence suggests that this system can ‘reorganize’ in response to rapid climate perturbations, limited palaeoclimate records and the difficulty of modelling this complex system leaves us uncertain about how the SPCZ might respond to future rapid warming and perturbations.Here, we present findings from a major research project using paired speleothems and climate models to study the response of the tropical South Pacific to rapid climate perturbations during Marine Isotope Stage (MIS) 3. This period of the last Glacial is a ‘natural laboratory’ for studying rapid climate change due to the sudden climate fluctuations that characterized this time (e.g. the Dansgaard-Oeschger (D-O) Events). We have generated speleothem rainfall-proxy records from several locations within the SPCZ and simulated the rainfall response of the Pacific using the CSRIO Mk3L palaeoclimate model. Our speleothem results demonstrate that the tropical South Pacific can be sensitive to rapid climate perturbations like D-O Events, with rainfall changes in the Pacific synchronous with temperature records from Greenland. The response of the SPCZ appears to be complex, however, with some locations experiencing increases in rainfall while others experience a decrease. We have modelled D-O Events and the results support the speleothem reconstructions, indicating that different regions of the SPCZ can respond differently, with rainfall expanding in some places and migrating/contracting in others.

Dansgaard/Oeschger-like events detected in speleothem proxy records from late MIS 11c to mid 11a from Central Europe

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Two stalagmites, DH_Br2 and DH_Kn6, were sampled from excavations in Dechencave, northwestern Germany. Both were precisely dated by the ^{230}Th/U-method using MC-ICP-MS (Mainz University). The stable carbon and oxygen isotope composition were measured using CF-IRMS (Mainz University and Max Planck Institute for Chemistry, Mainz), and trace element concentrations via LA-ICP-MS (Max Planck Institute for Chemistry, Mainz). Both stalagmites show evidence for diagenesis, such as roundish voids and mosaic calcite fabric in their lower parts. These parts were excluded from further analyses due to the alteration of the ^{230}Th/U-ages as well as the proxy records. The discussed section of stalagmite DH_Br2 started to grow at 401 ka BP and stopped at 379 ka BP, which corresponds to late MIS 11c to mid-MIS 11a. Growth of stalagmite DH_Kn6 overlapped with that of DH_Br2 between 394-390 ka BP. Speleothem records from MIS 11 are rare, in particular from central Europe. The $d^{13}C$ and $d^{18}O$ records show different levels for both stalagmites, related to different amounts of prior calcite precipitation (PCP). Stalagmite DH_Br2 shows millennial-scale oscillation during 389-379 ka BP in the $d^{13}C$ and $d^{18}O$ records. In particular, in the longer record of stalagmite DH_Br2, Al and Y are proxies for the detrital contamination, P and U reflect soil and vegetation activity, and Sr and Ba were influenced by changes in stalagmite growth rate as well as soil leaching. The Mg records correlate well with the $d^{13}C$ records indicating PCP. Trace element and $d^{13}C$ records are proxies for past precipitation. As revealed by DH_Br2, drier conditions prevailed between 401-394 ka BP as well as between 388-379 ka BP, whereas wetter conditions existed between 394-388 ka BP, which is probably related to insolation changes. According to $d^{18}O$ values of stalagmite DH_Br2, temperature was slightly lower during 390-379 ka BP, i.e., after the peak warm period of MIS 11. During this period after the peak warming the millennial-scale oscillation occurs, which is most prominent in the $d^{18}O$ record and are probably Dansgaard/Oeschger-like events, not described up to now from speleothems from central Europe during MIS 11.

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 Termination XVII 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 $\delta^{18}O$ 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 $\delta^{18}O$ and $\delta^{13}C$ 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 in the context of prevailing theories of Early Pleistocene ice-age cycles. Our study highlights the important role of speleothems in resolving the timing and forcing of glacial-interglacial cycles.

A composite speleothem record of Glacial Termination V in central Italy and linkages to the North Atlantic

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Glacial Termination V (TV; c.a. 425 kyr BP) represents the highest magnitude climate transition of the Quaternary Period as reflected in the LR04 benthic $\delta^{18}O$ stack[1] and other globally significant records. Despite its prominence, TV occurred at a time of relatively subdued insolation forcing suggesting that climate feedback mechanisms played an especially important role in driving this glacial-interglacial transition. Understanding how these feedback processes unfolded, and their exact sequencing, requires accurate and precise chronological constraints. At present, however, such constraints are largely confined to the beginning of TV in the North Atlantic (e.g. Cheng et al., 2016). While this suitable for assessing orbital hypotheses related to the timing of termination commencement, it does not provide a precise chronology for the progression of changes that occurred throughout the full course of the glacial termination. Here, we address this issue by presenting a composite speleothem record from Corchia Cave, central Italy, covering the complete MIS 12–11 transition. The record is composed of multiple speleothems (stalagmites and a flowstone) dated by the U–Th and U–Pb methods, and incorporates proxies reflecting local and regional climate, including clumped isotope (Δ_{47}) based temperature data derived from an exceptionally slow growing cave pool carbonate. By taking advantage of established links between speleothem proxies at this cave site and marine proxies from the western Mediterranean and North Atlantic, we are able to transfer the speleothem chronology to the marine record. Placing the North Atlantic ocean record on a radiometric chronology provides an opportunity to establish the timing and sequence of regional climatic changes during TV and to accurately compare these changes with those happening further afield.

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Exploring the potential of speleothems as archives of long-term paleoenvironmental change in Namibia

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Namibia is a country climatically stressed by limited rainfall, high temperatures and long dry seasons. The only region that shows somewhat higher rainfall are the Otavi Mountains in the North, but also there the water balance is negative for most of the year. This region is characterized by abundant carbonate rocks which are strongly karstified and show many caves. Some of them intersect the local karst groundwater table and host large underwater lakes.Modern speleothem-based paleoclimate research in the Otavi Mountains is based on four stalagmites from one cave (Dante cave), collected by G. Brook and analyzed by the group of B. Railsback. Building on this pioneering work, we started an initiative to explore the full potential of caves and speleothems as archives of paleoenvironmental change in this part of Namibia. We visited and sampled several caves and also obtained specimens from flooded caves (provided by G. Brook).Using a dual approach, we examine both vadose speleothems (stalagmites, flowstones) and submerged speleothems to obtain proxy records of paleoclimate conditions as well as quantitative information about long-term changes in the elevation of the groundwater table.U-Th dating of vadose speleothems shows evidence of growth primarily during glacial periods. Large flowstone formations yielded evidence of intermittent growth during MIS 3 and 2, and the Late Glacial. However, with few exceptions, growth came to a halt at the beginning of the Holocene. Speleothems from underwater caves in this region yielded evidence of vadose conditions between about 84 ka and the Late Glacial, followed by a rise in the groundwater table at about 15 ka (see also presentation by Boekholt et al. at this conference).Low groundwater levels during times of widespread growth of vadose speleothems in the last glacial period can be reconciled by considering the role of reduced evapotranspiration as a result of lower temperatures (during glacial periods) versus higher precipitation (during interglacials).In view of increasing aridity predicted by models of future climate change in Namibia, speleothem-based proxy studies provide an important backdrop against which climate model scenarios and their hydrological impacts can be evaluated.

Late-Pleistocene glacial-interglacial cycles: an underestimated temperature regime

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Since the Mid-Pleistocene Transition, glacial-interglacial cycles were characterized by a 100 kyr cyclicity associated with insolation and greenhouse gas concentrations. A challenge in quantifying the associated response in surface temperature on orbital timescales is the notable scarcity of terrestrial reconstructions with precise chronologies. Terrestrial temperature projections thus mostly rely on marine sea surface temperature reconstructions. Here we address this issue by applying the speleothem-derived TEX_{86} palaeothermometer to a 450 kyr composite record of stalagmites and flowstone from seven caves located on the Korean peninsula. A strong correlation between cave mean annual temperature and altitude facilitated a lapse rate correction between sites. The resulting temperatures agree well between speleothems and cave sites and are supported through independent verification via fluid inclusion microthermometry and clumped isotope thermometry methodologies. The resulting TEX_{86} temperatures suggest that models are underestimating the thermal amplitudes during peak glacial/interglacial conditions by ~2.5°C (~6°C versus ~8.5°C). Additionally, temperatures suggest that interglacials were less stable as commonly assumed with multiple 5-6° cooling/warming events occurring prior to maximum glacial extent. There is also a high diversity in the timing and duration of these events with respect to each of the past four interglacials, indicating a single mechanism is unrealistic to explain all variation. This record represents one of the longest quantitative and radiometrically dated reconstruction of surface temperature so far and will provide new insights into past and future climate projections.

Orbital and millennial East Asian hydroclimate variability during Marine Isotope Stage 11

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Marine Isotope Stage 11 (MIS 11) has been widely considered the most appropriate analog to the current Holocene interglacial because of their larger similarity in the orbital parameter and characteristic of the relatively long warm interglacial than that of any other interglacial during the last 500 ka. Deciphering the climatic features during MIS11 will help understand how the current interglacial climate may have evolved and investigate the long-term stability of interglacial climates. Here, we present new multi-proxy speleothem records from Haozhu Cave in central China, which extends through 410 to 350 ka BP, covering the MIS11c, MIS11b, and MIS11a substages. We examined both $\delta^{18}O_c$ and trace elements (Mg^{2+}, Sr^{2+}, Ba^{2+}) to help deconvolve large-scale EASM circulation from local hydrology. Generally, our new $d^{18}O$ record follows the northern high-latitude summer insolation changes on the orbital scale and also preserved the six millennial Heinrich-like weak monsoon intervals. Our $d^{13}C$ and trace elements ratios (Sr-Mg-Ba/Ca) are significantly positively correlated with one another, suggesting that prior calcite precipitation (PCP) control, thus faithfully recording the hydroclimate variation. The composited hydroclimate records of HZZ28 clearly revealed the East Asian hydroclimate variability on both the orbital and millennial scales during MIS 11. Significantly, following the termination of the MIS11c interglacial at about 397 ka, the hydroclimate in north China shows an abrupt transition to drier conditions, while a continuous wetting trend is moving forward in central China. We attributed this regional heterogeneous variation to the abrupt weakening of AMOC when the decreased insolation reached a threshold at the end of MIS11c interglacial. At about 375 ka, the hydroclimate in central China shows an abrupt reversal to wetting hydroclimate, off-track the continuously increased summer insolation, synchronized in time with the strengthening of the East Asian winter monsoon in late MIS11. We attribute these large-scale Asian monsoon circulation variations to the largest meltwater discharging from the high latitude, which fundamentally terminated the non-glacial climate at the high northern latitudes and overridden the insolation forcing.

Explaining variation in hydroclimate from the Last Glacial Maximum through the Common Era in southern Madagascar's subarid bioclimatic zone

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Data from seven stalagmites dating from ~26000 years ago to the present have revealed the existence of two periods of stalagmite growth in southwestern Madagascar, the first covering the Last Glacial Maximum and last deglaciation period and the second covering a portion of the Late Holocene, continuing today (from ~3600 years onward). These periods correspond to times of increased austral summer insolation (associated with a more southern position of the Intertropical Convergence Zone, or ITCZ), and have been called "pluvials". The intervening period, including the majority of the Holocene (from 11700 until 3600 years ago), has been presumed to have been very dry in this part of Madagascar. This interpretation is supported not merely by the lack of stalagmite growth during this interval, but also by the distinct periodicity for stalagmite growth and cessation in the subarid region over the past 115,000 years linked to orbital variation in austral summer insolation. The subarid bioclimatic zone is the driest part of Madagascar and "pluvial" conditions here are not necessarily very wet. Bone collagen isotope data from subfossil (Holocene) vertebrates confirm that the habitats of southwestern Madagascar were drier than other parts of the island well into the past. Indeed, the cessation of stalagmite growth has been shown elsewhere to occur only when mean annual rainfall descends below 250 mm. Today, sites along the southwestern coast of Madagascar generally receive ~400 mm of rainfall annually.We document the temporal variation in the stable isotope ($\delta^{18}O$ and $\delta^{13}C$) records from the stalagmites that we collected in southwestern of Madagascar. Within pluvial events, stalagmite stable isotopes show considerable variation in hydroclimate, including prolonged droughts, as well as periods of increased moisture. Considering changes in austral summer solar insolation, temperature, and likely associated evaporative loss of water in the soil, we evaluate two possible explanations for the observed variation in carbon and oxygen isotopes. They involve changes in the intensity of the monsoon system as a whole, and changes in the primary source of moisture from a more distant to a nearer location. It is likely that both factors played a role.

Iron oxides variations during millennial scale events in central South America

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Stalagmites serve as valuable paleoclimate archives, capturing environmental signals in their mineral composition and growth structures. In recent years, the magnetic properties of speleothems have gained recognition as proxies for reconstructing past climate and environmental changes. The iron cycle plays a crucial role in these studies, as variations in iron-bearing minerals can reflect historical shifts in erosion, transport processes, and soil formation (pedogenesis) in karst systems. Climate and vegetation changes influence pedogenesis, which in turn affects the detrital content in karst systems, and thus the magnetic mineral signatures in speleothems. However, interpretation of magnetic signals in speleothems remains challenging, with conflicting correlations reported in the literature. These varying interpretations may arise from different forcings on decadal to millennial scales that impact karst hydrology, as well as the speleothem's position relative to the cave entrance, which may be influenced by dust and ventilation patterns.This study examines two stalagmite samples from central South America, covering the period from the last deglaciation to the Holocene—a time marked by major climatic transitions, with isotopic records indicating a decrease in monsoon activity toward the Holocene, followed by changes in soil thickness and vegetation density. Using rock magnetic analyses, we assessed the magnetic mineral assemblage throughout the speleothems capturing their temporal variation. Initial findings reveal distinct patterns in magnetic properties from the last deglaciation to the Holocene, likely corresponding to shifts in the delivery of detrital iron-bearing minerals linked to environmental changes. The magnetic mineralogy of these stalagmites is dominated by low-coercivity minerals, associated with pedogenic origins. These results highlight the potential of stalagmite magnetism as a tool for reconstructing paleoenvironmental conditions, capturing both regional climate influences and catchment processes.

Paleoprecipitation record over the last glacial period in subtropical Brazil and its interaction with the South Atlantic

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The present work shows new high-resolution speleothem trace element data for the last 116 kyrs of the Botuvera Cave in south Brazil using the LA-ICP-MS technique. The record show a striking in-phase relation between Mg/Ca, Sr/Ca, and $\delta^{18}O$ suggesting that periods of high South America Summer Monsoon intensity results increase local rainfall amount on periods of high summer insolation. With the use of trace elements as a proxy for paleoprecipitation we ponder if insolation is the sole forcing for monsoon activity in orbital timescales during the Last Glacial Period. When compared with marine cores, the colder waters in subtropical western South Atlantic associated with positive continental precipitation anomalies indicate that more intense South America Convergence Zone activity in south Brazil might be enabled by a high land-sea anomaly, and/or the position of the marine-SACZ axis could be near 24ºS promoting locally colder waters due to cloud and moisture concentration. We observe a period between 70 and 10 kyrs where the trace elements ratios curve are not coupled with austral summer insolation indicating that features from the Atlantic Ocean circulation can play a role in the long-term atmospheric circulation. Millennial timescale Heinrich Stadials events are clearly present in on our record with negative trace elements and isotopic anomalies indicating enhanced SASM activity in the route from the Amazon-Andes-S/SE Brazil via low-level jet activity.

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

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Mirichun Cave, discovered in 2019, is located in the central part of the East Sayan Highlands (Eastern Siberia, Russia; 64.07N; 97.62E). The region is characterized by a cold continental climate (MAAT = ca. -6°C) and lies in the discontinuous permafrost zone. The cave is carved in Lower Cambrian limestones and features a prominent Lower Gallery at a depth of ca. 130 m, accessible via a series of shafts and chambers. The temperature at the Lower Gallery is stable at 0.6°C and patches of ice were observed there. This indicates that this part of the cave is presently close to conditions of permafrost. Cryogenic cave carbonates (CCC) were found at two depths, 45 m and 130 m below the surface. CCC occur in patches, ranging from a few to several tens of m^2. CCC exhibit a variety of morphologies and sizes, ranging from sub-mm to several cm. Preliminary U-Th dates indicate that CCC in Mirichun cave formed during late stages of interglacial periods (MIS 9, MIS 7, MIS 5e) and during early stages of glacial periods (MIS 5c-d). The data from Mirichun cave suggest that in areas that are presently in or near the conditions of permafrost, like Eastern Sayan mountains, formation of CCC occurred at a stage of permafrost aggradation, following major thawing associated with interglacial warmings.

A Northwestern Canadian speleothem calcite d18O and TEX86 record from interglacial Marine Isotope Stage 11

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Marine Isotope Stage (MIS) 11 (~424-374 ka) has been identified as a particularly strong interglacial at northern high latitudes, indicated by permafrost thaw, reduced Arctic sea ice, and a smaller Greenland ice sheet extent. Still, it remains unclear if such widespread melting was due to MIS 11 being longer, rather than warmer, than subsequent interglacials MIS 9 and MIS 5e. We present U-Th-dated speleothems collected from a permafrozen cave in the northwest territories of Canada which act as indicators of thawed conditions at that cave during MIS 11. Our speleothem ages provide an upper bound on the amount of time needed for permafrost thaw since the inception of MIS 11, as well as the minimum amount of time thawed conditions were present before permafrost redevelopment at the end of MIS 11. We also track environmental changes in our cave during the thawed period using the d18O of speleothem calcite paired with TEX86 temperatures. Considering the dynamic airflow in the modern cave, we interpret d18O and TEX86 as summer values and consider their relative intensity across MIS 11. To further put MIS 11 d18O values into context, we compare them to d18O from the same deposits formed during MIS 9 and MIS 5e.

Why did the Neanderthals go extinct? The role of speleothems in answering this hot question

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The Neanderthals, our closest relatives, died out around 40 thousands years ago (ka) after expanding for 350000 years across a wide region from Western Europe to Southern Siberia. Despite decades of research into cultural, demographic, and environmental factors, there is no leading theory about the triggers of the most important biocultural transition in human history. This is likely because the available data comes from a limited number of sites, mostly in Western and Central Europe, which were on the periphery of the Neanderthals' range. To accurately reconstruct the processes that led to Neanderthal's extinction, the scientific community needs new extensive data, ideally from the core regions where the last Neanderthals lived. The LAST NEANDERTHAL project has been financed in 2024 by the Erc-Synergy call, with the ambitious aim to definitely and comprehensively answer the question: why did the Neanderthals go extinct? Three PIs from Bologna, Siena and Haifa Universities will lead this gigantic project involving the multidisciplinary investigation of more than 50 study sites in the western-to-east transect from Italy to Kirghizstan. Reconstructing environmental and climate variations in the 60-20 ka period, and their integration with the novel archeological and cultural data, is key for the success of the project. Together with lake sediments, speleothems were selected as multi-proxy paleo-archives. Pisa University (Italy) is indeed a partner institution for the LAST NEANDERTHAL project, leading the speleothem-based paleoclimate research unit. Several samples from Italy, Greece and Georgia are currently under investigation. Future Analyses will target samples available from Croatia, Macedonia, Hungary and Kurdistan. However, new cave sampling is scheduled in Czech Republic, Slovenia, Romania, Montenegro, Albania, Azerbaijan, Uzbekistan, Tajikistan and Kirghizstan. This poster will present the 6-years long action plan of the speleothem unit, with special focus on: 1) preliminary results on speleothems covering the 60-20 ka period; 2) future cave sampling campaign; 3) job opportunities; 4) potential collaborations.

Orbital-scale variability of East Asian summer monsoon inferred from speleothems in southeastern China

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Significant progress has been made in using Chinese speleothem records to study orbital-scale variations in the East Asian summer monsoon (EASM). However, these records are primarily concentrated in central and southwestern China, while those from southeastern China, covering most time intervals since the last interglacial period, remain sparse. This gap has greatly hindered a comprehensive analysis of the spatiotemporal evolution and the underlying climate mechanisms of orbital-scale EASM precipitation. After years of effort, we have obtained valuable speleothem samples from Shennong Cave in Shangrao, Jiangxi Province, southeastern China. Uranium-series dating indicates that they cover most of the period since the last interglacial.On orbital timescales, the oxygen isotope ($\delta^{18}O$) record of the Shennong cave speleothems shows no long-term variation consistent with changes in Northern Hemisphere summer insolation (NHSI), markedly diverging from the $\delta^{18}O$ patterns observed in other regions of the Asian monsoon. Previous research has also shown that Holocene $\delta^{18}O$ records from Shennong speleothems do not align with NHSI, contrasting with other Holocene $\delta^{18}O$ records across the Asian monsoon region. A comparison with other archives including lake deposits, loess, and marine sediments alongside with climate model simulations reveals that increases in NHSI result in increased EASM intensity and an earlier northward shift of the monsoon rain belt, prolonging its presence over northern China and subsequently reducing precipitation in South China. Simultaneously, the Western Pacific Subtropical High pressure system intensifies and extends westward, bringing Pacific moisture with higher $\delta^{18}O$ values to eastern China. The combined effect of moisture transport and rainfall amount changes leads to distinctive orbital-scale variations in speleothem $\delta^{18}O$ records in southeastern China, contrasting with the more consistent patterns observed in other East Asian monsoon regions, which primarily follow NHSI changes.

Quantifying temperature and rainfall patterns in South Africa over the last 3 Ma to understand their impact on early human evolution

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South Africa hosts some of the oldest hominin fossil remains, centred in the UNESCO Cradle of Humankind World Heritage site, known locally as the Cradle. Climatic and environmental change played a pivotal role in the adaptation and diversification of our early pre-human relatives. Previous work[1] has provided robust chronology for the Cradle, however, little climatic proxy research has been carried out here. As such, the past climatic conditions in the Cradle remain poorly understood, especially during the Late Pliocene-Early Pleistocene when some of our early pre-human relatives evolved. Here we address this gap to test and expand on Pickering et al. (2019). We present the first quantitative multi-proxy study of 30 speleothems using analyses of fluid inclusions stable isotopes (δ^2H and $\delta^{18}O$) and biological proxies (TEX86) of U-Th- and U-Pb-dated flowstones from the Cradle. We reconstruct changes in rainfall and mean annual temperatures at the Cradle and show that, in this region, the Indian Ocean remained the primary moisture source over the last 3 Ma. We identify a gradual increase in speleothem and fluid inclusion $\delta^{18}O$, suggesting a gradual increase in aridity. This is consistent with the geology of the cave fills themselves, with less and less speleothem forming since a peak between 2.2 and 2.0 Ma. These new data provide interesting food for thought as to how past climate variability influenced human evolution in South Africa and places the 3.0 to 1.0 Ma Cradle record in an environmental context wetter than what this region experiences today. These data also suggest that conditions were relatively stable during this time, with the change to more arid overall conditions being slow, on the scale of 100,000 years and gradual, meaning that there is now little evidence in South Africa of rapidly changing climate conditions driving evolutionary change.

1. Pickering, R., Herries, A. I., Woodhead, J. D., Hellstrom, J. C., Green, H. E., Paul, B., Ritzman, T., Strait, D. S., Schoville, B. J. & Hancox, P. J. (2019). U–Pb-dated flowstones restrict South African early hominin record to dry climate phases. Nature, 565(7738), 226-229.

The Hoyo Negro-1 (HN-1) record, a dive into the Eemian and Termination 2 in southern Mexico

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Studying previous interglacial periods enables us to elucidate the responses of hydrological patterns during distinct periods warmer than the Holocene. Glacial terminations provide insights into the impacts of abrupt shifts in the global heat budget (2ºC - 3ºC) linked to rapid increases in atmospheric CO_2, enhancing our understanding of precipitation pattern adjustments in response to altered atmospheric circulation. Here, we present results from a stalagmite from Outland Cave, a submerged tunnel system in the Yucatán Peninsula and preserved within a limestone capsule. Results from U/Th dating show that this unique continuous record grew from 200,000 to 100,000 years ago, covering the entire Eemian interglacial and its associated glacial transition. High-resolution Isotope ($d^{18}O$ and $d^{13}C$) and trace element analyses were conducted to strengthen the interpretation of hydroclimate reconstruction, along with preliminary fluid-inclusion analysis. The results will contribute to evaluating the potential impacts of temperature changes on the hydroclimate of southeastern Mexico under natural climate boundary conditions, providing a critical context for current global warming trends.

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.

Orbital Pacing of Speleothem Growth In Caves of the Uinta Mountains, Utah, USA

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Whiterocks and Chepeta Caves are developed in Carboniferous limestone in the Uinta Mountains of Utah, USA. Whiterocks has a mapped length of 800 m and a vertical extent of 20 m, with an entrance at 2600 m asl. The smaller Chepeta Cave is developed in the same rock unit at a similar elevation ~4.5 km to the west. MAT in both caves is ~5 °C, and vegetation above them is a sparse coniferous forest. Small cores were drilled from speleothems in both caves and dated by U-Th at the Massachusetts Institute of Technology. This screening approach identified speleothems suitable for dating with this technique. These specimens were removed with permission from the US Forest Service, cut, and inspected. Nearly all contained several visible unconformities. Subsequent age determinations focused on bracketing these growth hiatuses to determine whether they were synchronous between the different samples. A total of 94 U-Th ages are now available for 14 speleothems from the two caves, spanning from ~80 ka to the limit of U-Th dating (~600 ka). Seven stalagmites were active during MIS 5, six during MIS 7, seven during MIS 9, six during MIS 11, eight during MIS 13, and three have ages with broad uncertainties consistent with growth during MIS 15. Notably, only four ages fall within glacial intervals (no overlap with interglacials); however, two of these align with MIS 9a, a major interstadial at ~280 ka. The overall pattern strongly indicates that conditions suitable for speleothem growth in multiple locations in both caves were rarely attained during the past 600,000 years, and only during full interglacial conditions. Given the elevations of the caves, nearby geomorphic evidence for extensive alpine glaciation, and patterned ground at higher elevations, our interpretation is that permafrost blocked water infiltration to these caves for most of the past 600,000 years. Only under full interglacial conditions did vegetation and soil develop above the caves, and permafrost disappear, allowing water infiltration to restart speleothem formation. This dataset illustrates a strong orbital forcing of speleothem growth in these high-elevation cave systems, making them highly sensitive archives for long-term climate change.

Spatio-temporal dynamics of speleothem growth and glaciation in the British Isles

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Reconstructing the spatio-temporal dynamics of glaciations and permafrost largely relies on surface deposits, and is therefore a challenge for every glacial older than the last due to erosion. Consequently, glaciations and permafrost remain poorly constrained worldwide before c. 30 ka. Since speleothems (carbonate cave deposits) form from drip water and generally indicate the absence of an ice sheet and permafrost, we evaluate how speleothem growth phases defined by U-series dates align with past glacial-interglacial cycles. Further, we make the first systematic comparison of the spatial distribution of speleothem dates with independent reconstructions of the history of the British-Irish Ice Sheet (BIIS) to test how well geomorphologic ice reconstructions are replicated in the cave record.The frequency distribution of 1,020 U-series dates based on three different dating methods between 300 and 5 ka shows statistically significant periods of speleothem growth during the last interglacial and several interstadials during the last glacial. A pronounced decline in speleothem growth coincides with the Last Glacial Maximum, before broad reactivation during deglaciation and into the Holocene.Spatio-temporal patterns in speleothem growth between 31 and 15 ka agree well with the surface-deposit-based reconstruction of the last BIIS. In data-rich regions, such as northern England, ice dynamics are well-replicated in the cave record, which provide additional evidence about the spatio-temporal distribution of permafrost dynamics. Beyond the Last Glacial Maximum, the distribution of speleothem dates across the British Isles offers the opportunity to improve chronological constraints on past ice sheet variability, with evidence for a highly dynamic Scottish ice sheet during the last glacial. Whilst undersampling is currently the main limitation for speleothem-based ice and permafrost reconstruction even in relatively well-sampled parts of the British Isles, we show that speleothem dates obtained using modern mass spectrometry techniques reveal a higher spatio-temporal resolution of glacial-interglacial cycles and glacial extent than previously possible. Further study of leads and lags in speleothem growth compared to surface deposition may provide new insights into landscape-scale dynamics during ice sheet growth and retreat.