PhD project

Hydroclimatic variability and water management in the northwestern Mediterranean (Provence, SE France) : reconstructions from environmental and archaeological carbonate archives from the Quaternary to the present day.

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In Mediterranean regions, freshwater availability is a critical and vulnerable resource increasingly affected by climate change and human activity. This PhD project investigates long-term hydroclimatic variability in southeastern France by combining natural and archaeological carbonate archives (speleothems, tufas, Roman aqueduct concretions). Through high-resolution geochemical, isotopic and chronological analyses, it aims to reconstruct environmental changes from the Holocene to modern times, with a focus on Roman-era water management strategies. This interdisciplinary approach will improve our understanding of past climate-society interactions and inform responses to current and future water-related challenges in the Mediterranean.

1) Scientific Background and State of the Art

In Mediterranean regions, access to potable water is a crucial limiting factor, subject to multiple natural and anthropogenic constraints. These pressures, exacerbated by global warming, have significant environmental, socio-economic, and public health impacts. In Provence (SE France), rainfall patterns have changed markedly over recent decades: decreased cumulative precipitation, increased flood intensity, and prolonged summer droughts.

In light of these contemporary challenges, investigating the past responses of Mediterranean societies to hydo-climatic variability through natural and cultural archives provides valuable insights. Speleothems and fluvial tufas are powerful proxies for exploring hydroclimatic dynamics throughout the Holocene. The study of carbonate deposits formed in ancient hydraulic structures—especially Roman—offers a unique perspective on water management strategies under climatic constraints.

The “Provence Verte” region, particularly the upper Argens catchment, serves as an exceptional natural laboratory for such research. This territory encompasses both karstic and fluvial environments, along with a rich archaeological heritage (oppida, aqueducts, canals, mills). Laminated carbonate deposits—speleothems, tufas, and aqueduct concretions—record both environmental conditions (precipitation, temperature) and anthropogenic usage.

The speleothems from the Sainte-Baume massif, located near the study area, provide an undisturbed climatic reference archive. Isotopic ($\delta^{18}O$, $\delta^{13}C$) and elemental (Mg/Ca, Sr/Ca) analyses allow for the identification of fine-scale climatic variations and extreme events. The tufas of the upper Argens, still active today despite the regional decline in carbonate deposition since ~4000 BP (Vaudour 1994 ; Dabkowski 2020), represent rare and valuable archives for reconstructing past hydrological dynamics.

In antiquity, the Roman Empire implemented ambitious water access policies through the construction of extensive hydraulic infrastructure. Studying these structures, combined with the analysis of carbonate deposits (often annually laminated), enables the reconstruction of paleoenvironmental parameters (Bobée et al., 2010 ; Sürmelihindi et al., 2013, 2023). These deposits are sensitive to both climatic variability and human water use. More recent historical periods (Middle Ages, Early Modern period) will also be explored using historical and environmental data, in order to assess continuities or disruptions in hydroclimatic and societal dynamics.

2) Scientific Objectives and Expected Outcomes

- Date carbonate deposits (speleothems, tufas, aqueduct concretions) using U-Th dating.
- Characterize current karst dynamics through monitoring of modern speleothem formation.
- Reconstruct the frequency and seasonality of laminae through manual and automated thickness measurements.
- Develop time series of isotopic and geochemical tracers.
- Reconstruct past environmental conditions (precipitation, droughts, temperature, floods) across multiple timescales.
- Compare proxy records with dendrochronological series and regional archives (France, Spain, Italy).
- Assess ancient socio-technical responses to hydroclimatic constraints. Analyze the climatic impact on ancient hydraulic infrastructure management.
- Produce a high-resolution reconstruction of regional hydroclimatic variability.
- Integrate these reconstructions within an interdisciplinary climate–society framework.

3) Material Studied

- Speleothems from the Argens basin
- Tufas from the upper Argens
- Carbonate concretions from ancient structures (aqueducts of Aix-en-Provence, Fréjus ; mills, canals)
- Waters from present-day karstic springs
- Percolation waters from the studied karst massifs

4) Methodology

Fieldwork

The fieldwork will aim to characterize the geomorphological context of the Upper Argens region (geometry of alluvial terraces and travertine barriers, subterranean environment exploration, speleology) to optimize the sampling of reference materials (tufas, speleothems, etc.). This work requires strong field engagement.

Laboratory

This phase involves morphological and petrographic characterization of samples using binocular microscopy, optical and digital microscopy, epifluorescence, and high-resolution imaging. Lamination analysis will be refined using micro-XRF and computed tomography. Laminae counting and thickness measurements will be modeled.

High-precision micro-drilling (Micromill) of carbonates will allow targeted sampling of individual laminae. U/Th dating will be performed by MC-ICPMS. Major and trace elements will be analyzed using ICP-OES, ICP-MS, and LA-MC-ICPMS. Stable isotopes ($\delta^{18}O$, $\delta^{13}C$) will be measured via mass spectrometry in carbonates. Analysis of modern waters (electrophoresis, isotope ratios using laser spectrometry) will help elucidate the hydrogeochemical system. Recent climate data (discharge, rainfall, tree rings) will serve as reference for calibrating carbonate signals.

5) Candidate Profile

Master's degree (MSc or M2) in Geosciences, Geochemistry, Chemistry, or Physical Geography. Skills in fieldwork, laboratory analysis, and environmental statistics. Strong interest in interdisciplinary climate–society approaches.

6) Supervision and Research Environment

The PhD will be hosted at CEREGE (Aix-Marseille University – OSU Pytheas), under the supervision of C. Claude (HDR), O. Sivan (Inrap/LAMPEA), H. Bruneton, and C. Honiat, in collaboration with a team specialised in geochemistry, hydrology, climatology, sedimentology and spectroscopy. The analytical work will be performed on the different plateforms of CEREGE. It will also be conducted in partnership with the "Saint-Maximin la Sainte-Baume" PCR project (A. Flambeaux, C. Landuré, and O. Sivan – Inrap/LAMPEA/SRA PACA).