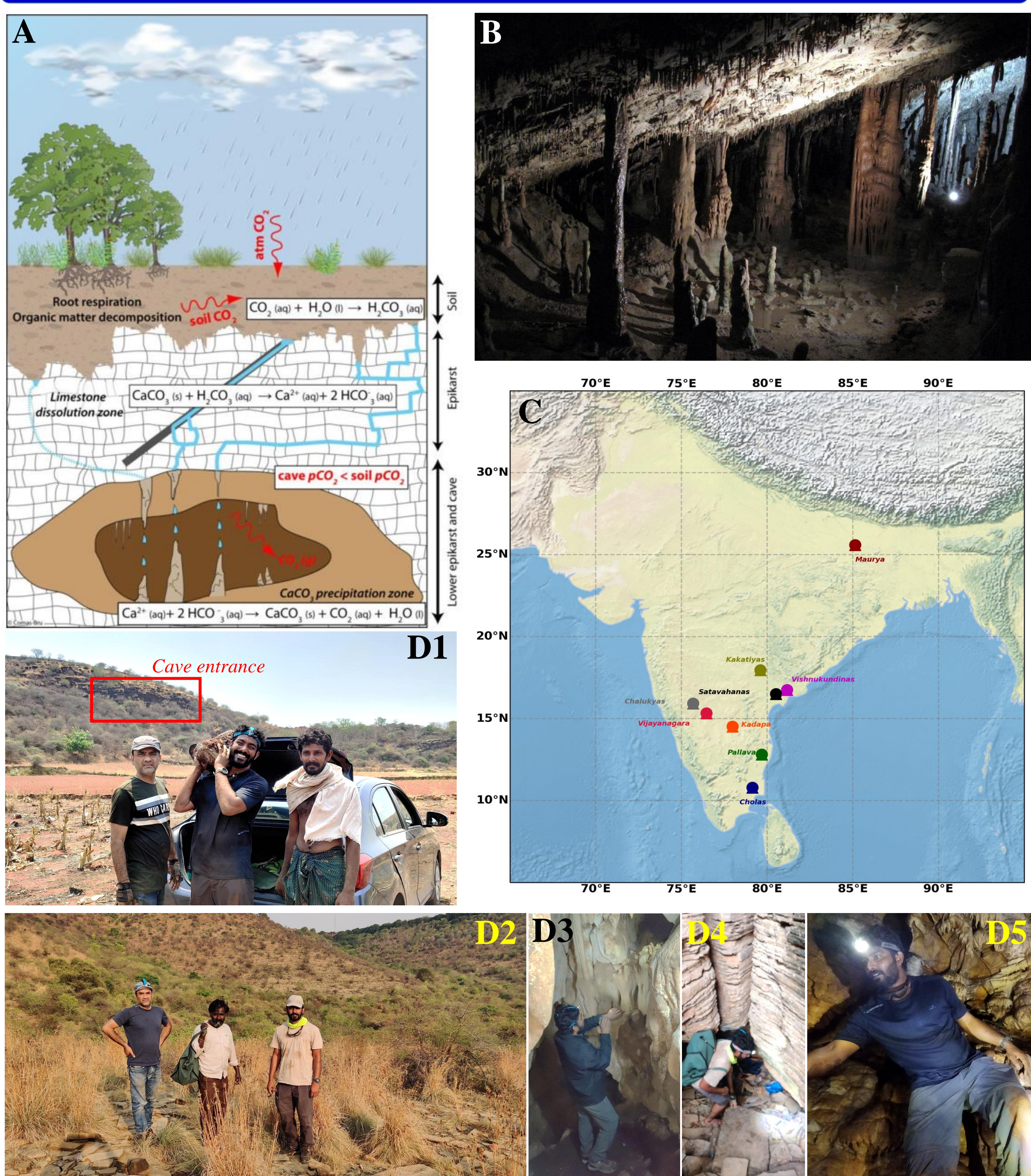


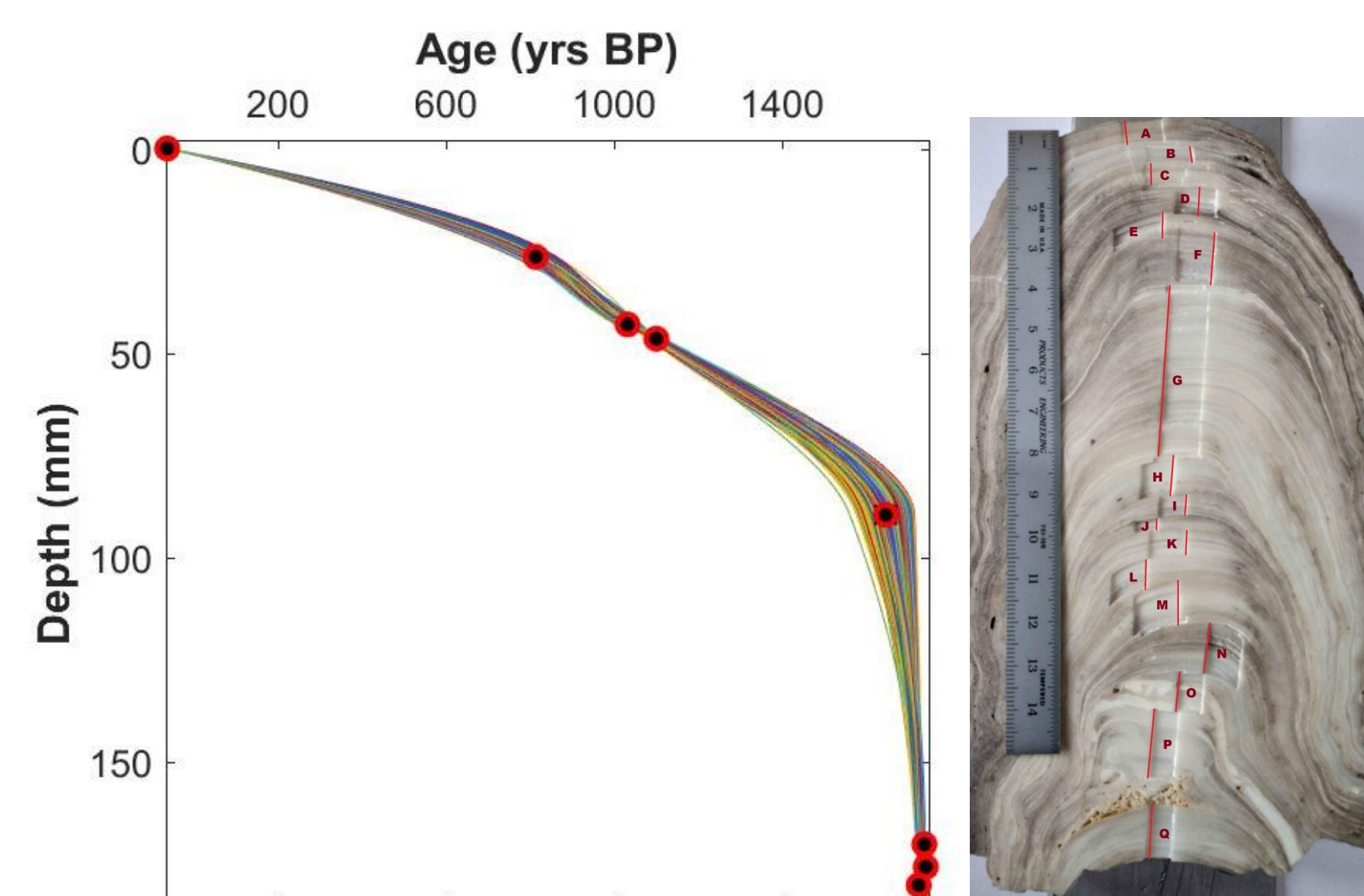
## Introduction

- Indian sub-continent largely depends on summer monsoon rainfall (ISMR), primary for agriculture and livelihood.
- ISMR shows large spatial and temporal heterogeneity, causes to floods and droughts, which impacts the rise and demise of several Indian civilization/kingdoms in the past.
- This study compares ISMR variability for the last three millennia with existing evidence of ancient water harvesting techniques during different Kingdoms/dynasties of Deccan India.

## Cave Deposits: An Archive for Past Monsoon Reconstruction

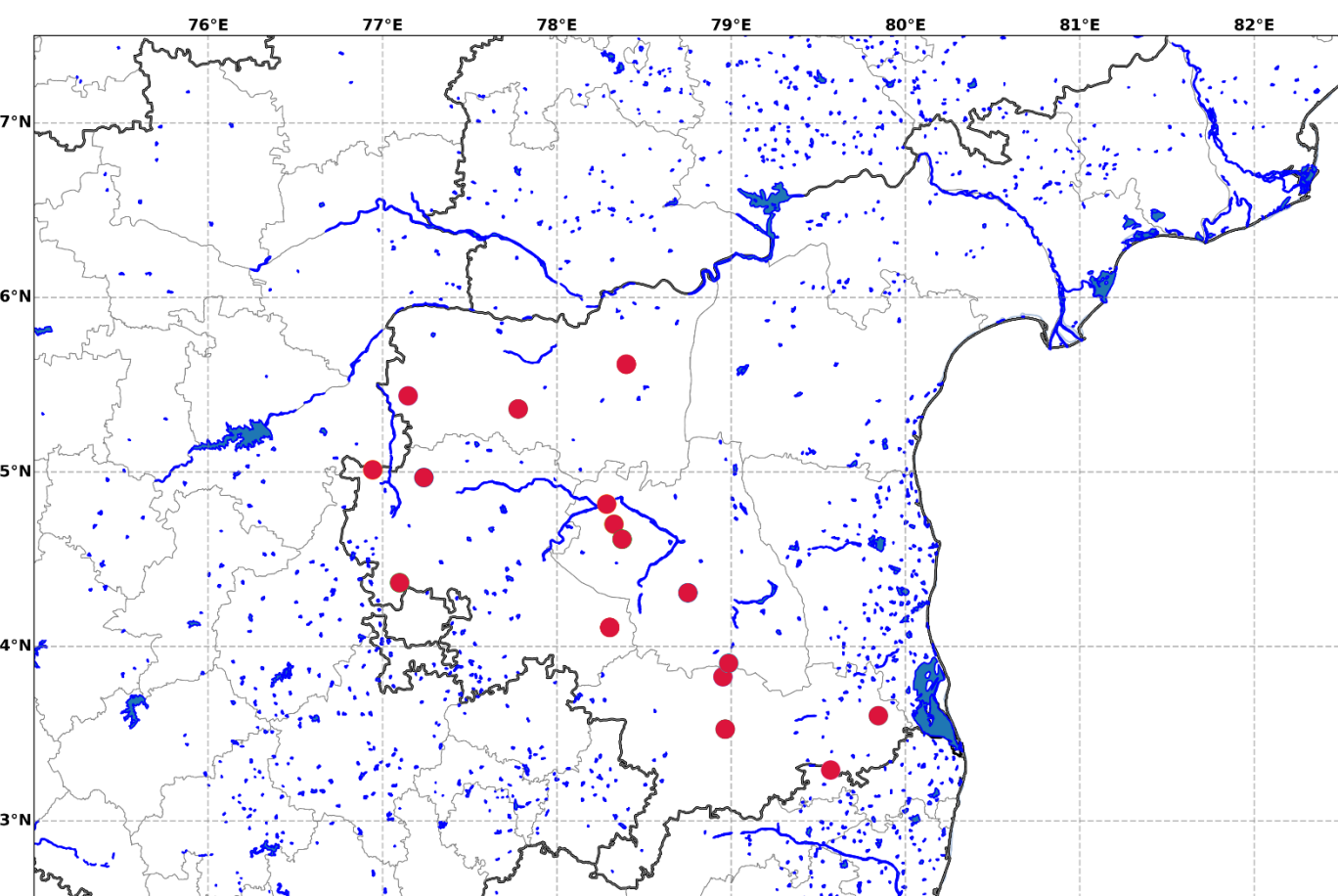


**Fig. 1.** (A) Schematic diagram showing karst system and speleothem formation. (B) Photographs showing underground cave system with different types of cave deposits. (C) Location map showing Kadapa cave (orange) and various kingdoms (capital city) that ruled the Deccan India during the last three millennia. (D1-D5) Field photographs of speleothem sample collection from the Deccan India.



**Fig. 2.** (A) Chronological (age) model for the Deccan India (Kadapa cave) speleothem based on U-Th dating. (B) Photographs showing cross-sectional view of a speleothem samples collected from the Kadapa cave systems, Deccan India. Alternate, dark and light colour bandings indicate different growth events.

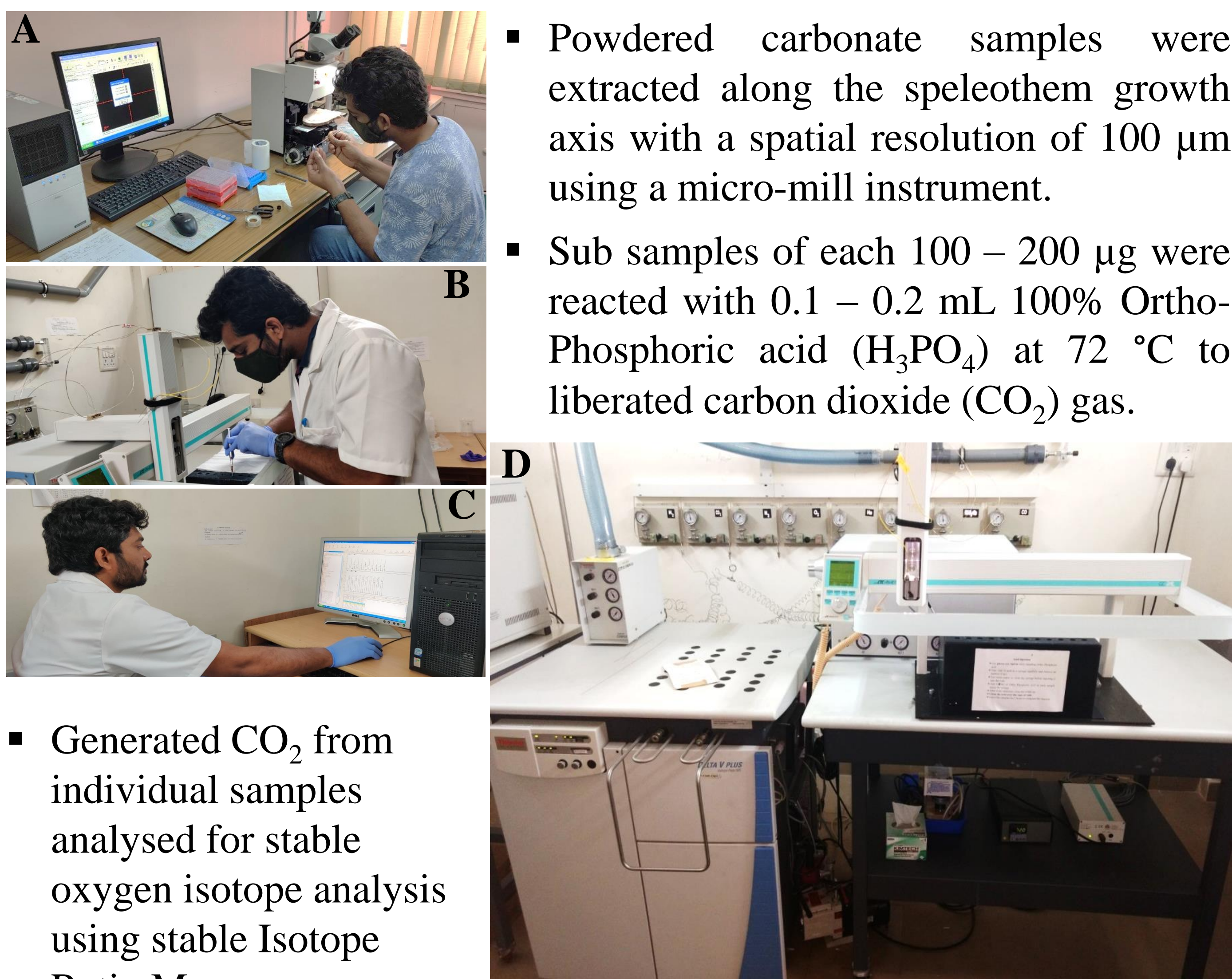
## Historic Cultural Sites and Human Settlements at Deccan India



**Fig. 3.** Map showing ancient human settlements and cultural site (red circles) around Rayalaseema region, near Kadapa cave. Blue colours are indicating water-bodies and rivers.

- Rayalaseema has many sites of Pre-historic and Proto historic, and most of them have found scattered on the river valleys of Penneru, Chitravati, Papagni, Kunderu, Cheyyuru, Krishna and several water bodies.
- Cultural extinction and enrichment are synchronous with weakening and strengthening of ISMR, respectively.

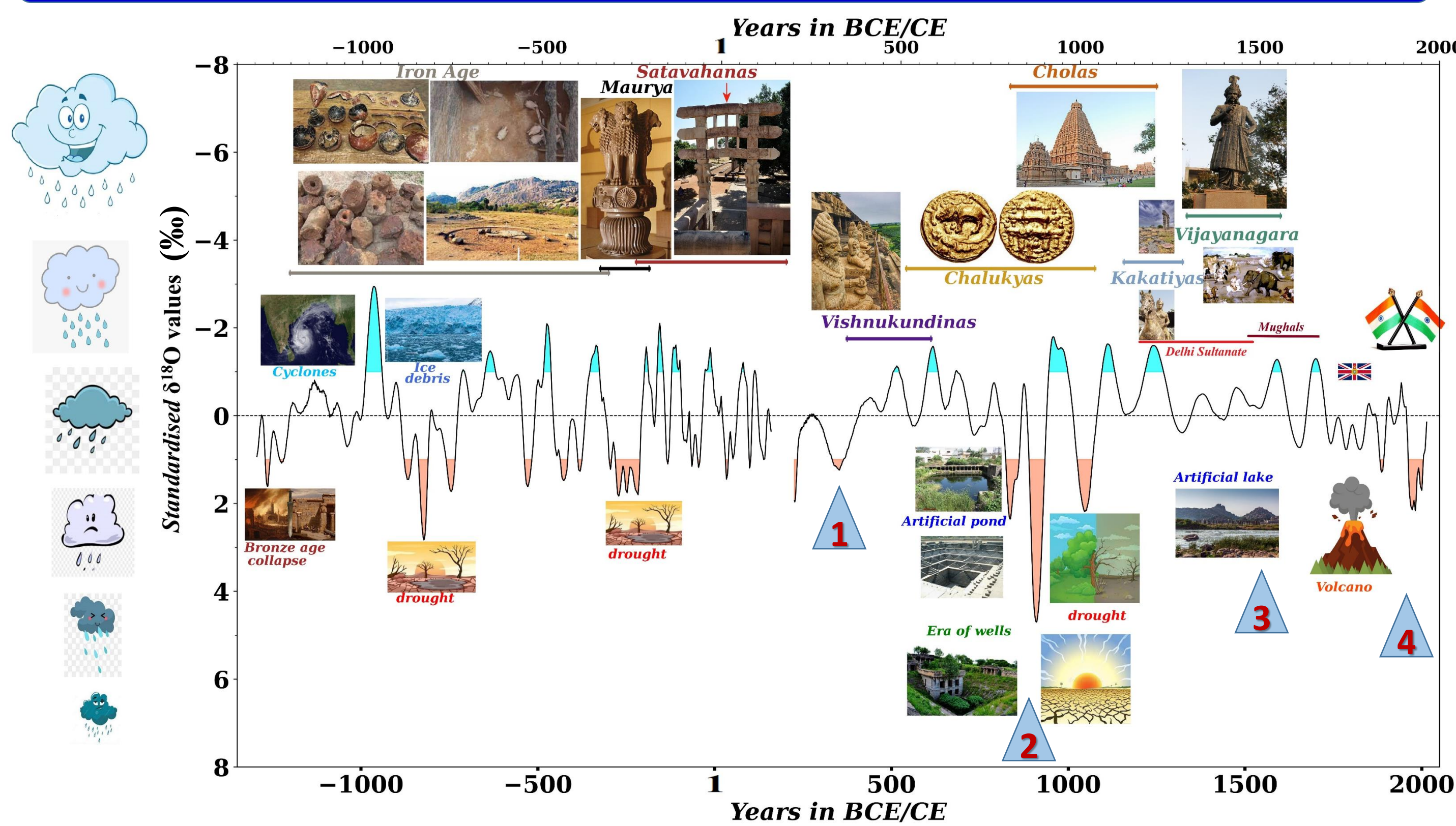
## Analytical Methods



**Fig. 4.** (A-C) Various photographs showing different steps of sample processing and isotopic analysis techniques. (D) IITM Pune stable isotopic analysis (IRMS) facility.

- Powdered carbonate samples were extracted along the speleothem growth axis with a spatial resolution of 100  $\mu\text{m}$  using a micro-mill instrument.
- Sub samples of each 100 – 200  $\mu\text{g}$  were reacted with 0.1 – 0.2 mL 100% Ortho-Phosphoric acid ( $\text{H}_3\text{PO}_4$ ) at 72  $^\circ\text{C}$  to liberated carbon dioxide ( $\text{CO}_2$ ) gas.
- Generated  $\text{CO}_2$  from individual samples analysed for stable oxygen isotope analysis using stable Isotope Ratio Mass Spectrometer (IRMS) at CCRL-IITM Pune.

## Past Variability of Indian Summer Monsoon



**Fig. 5.** Oxygen isotopic ( $\delta^{18}\text{O}$ ) signatures of two speleothem records from Deccan India, Kadapa cave, showing Indian monsoon variability for last three millennia. Drought (flood) events are marked with orange (cyan) color. For reference synchronous climatic and geological events along with different kingdoms/dynasties ruling periods are also marked. Figures also showing the remnants of ancient Indian civilization, such as, gold coins, architectures, irrigation systems and water harvesting techniques. Markings from 1 to 4 in triangles are showing four pulses of advancement in irrigational techniques.

## Conclusion

- $\delta^{18}\text{O}$  record of two stalagmites shows ISMR variability for the last 3200 years. Our result revealed the existence of several prolonged droughts and flood events during the last three millennia, which impacted several major empires/kingdoms to thrive and perish.
- During the 3<sup>rd</sup> century BCE drought conditions, Mauryans started the first hydraulic civilization in India.
- Sātavāhanas used the water wheels for irrigation, suggests the progress of lift irrigation technology to mitigate the widespread droughts.
- During 937-1336 CE (also Kakatiyas period) was the golden age of tanks in Deccan India with response to highly variable monsoonal rainfall.
- Tank based irrigation practice from the Vijayanagara times e.g., the Porumamilla irrigation tank, still in use since last 500 years.
- Four pulses of artificial irrigation advancement during the past two millennia were coinciding with the extreme monsoon climate.

**References:** [1] Sinha et al., 2018. *The Holocene* 28 (11), 1720-1730. [2] Reddy et al., 2021. *Quaternary International*. [3] Reddy et al., 2022. *Climate Dynamics*. [4] Reddy and Gandhi, 2022. *Holocene Climate Change and Environment*, 339-368, Elsevier.

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