PALAEOSCIENCE TODAY

TRACING TIME, TELLING STORIES

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Birbal Sahni Institute of Palaeosciences

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Birbal Sahni Institute of Palaeosciences

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Cover Page: Khari bedrock gorge, located in the central mainland region of Kachchh, western India
Back Page: Confluence of the Indus and Zanskar Rivers

From the Chief Editor's Desk

WHEN A BEDROCK GORGE BECOMES A CLOCK

MEASURING EARTH'S PAST THROUGH MATHEMATICS

IN the editorial of this issue of *Palaeoscience Today*, I wish to introduce to you a fascinating story decoded by me and fellow scientists - a story that transforms a seemingly simple landform, the **Khari River bedrock gorge**, into a powerful narrative of Earth's dynamic past. A gorge is often seen as a spectacular natural feature - steep rock walls, a narrow passage, and a dramatic cut through the landscape.

But for a palaeoscientist, a gorge is far more than a scenic landform. It is a geological archive: a record of how Earth's internal forces and surface processes have shaped the land over thousands of years. One such extraordinary feature is the **Khari bedrock gorge**, located in the central mainland region of **Kachchh, western India** *(See the cover page of this issue)*.

Unlike ordinary river valleys, this gorge appears as a deep, narrow crack in solid rock, carved into sandstone bedrock in a region that is dry for most of the year. Its unusual geometry immediately raises a fundamental scientific question:

WHEN DID THIS GORGE OPEN, AND WHAT FORCES CREATED IT?

In conventional geological studies, landforms are often dated using sediments, fossils, or organic material preserved in river deposits. But bedrock gorges pose a major challenge. They are carved directly into hard rock, and usually contain little or no datable sediment. The Khari gorge is one such case. Yet, understanding its age is essential because it can provide insights into the history of tectonic movements, climate fluctuations, and landscape evolution in one of India's most seismically active regions.

The study titled *"Time assessment of tectonic and climatic forcing on the formation of Khari bedrock gorge, Kachchh: A mathematical approach"* addresses this challenge through an innovative method, **using mathematics as a tool to measure geological time**.

A LANDSCAPE SHAPED BY TWO POWERFUL FORCES

The Khari gorge is about 220 metres long and reaches a depth of nearly 27 metres. Its walls are steep and narrow, resembling a fracture rather than a typical river-cut valley. This observation suggests that the gorge did not form only by slow erosion over time. Instead, we propose that the gorge began as a **tectonic crack**, a fracture produced when the Earth's crust was pulled apart under stress. However, tectonics alone cannot fully explain its present-day size. In a dry region like Kachchh, rivers flow only seasonally, and the landscape experiences long periods of aridity. Therefore, the gorge must also have been influenced by periods of stronger water flow in the past.

The study concludes that the gorge evolved due to the combined action of two major processes:

1. **Tectonic deformation**, which initiated the crack and caused uplift and displacement.
2. **Climatic forcing**, which supplied large volumes of water during wetter phases, widening and deepening the crack.

In simple terms, tectonics created the opening, and climate-driven water acted as the sculptor.

CONFIRMING TECTONIC ACTIVITY USING SATELLITES

To strengthen the tectonic interpretation, we used a satellite-based technique called **InSAR (Interferometric Synthetic Aperture Radar)**. InSAR compares radar images of the Earth taken at different times and detects extremely small changes in ground elevation, sometimes even millimetre-scale deformation. The InSAR analysis of the Bhuj–Khari region revealed patterns of uplift and subsidence around major faults, such as the Katrol Hill Fault system. Importantly, deformation was also detected around the Khari gorge itself. This confirmed that the region is not geologically dormant; it is still undergoing crustal movements.

Thus, the gorge is situated in an active tectonic zone, where fractures can form and evolve over long periods.

THE MATHEMATICAL BREAKTHROUGH: TREATING THE GORGE AS A CRACK

The most unique part of this study lies in its mathematical approach. We treated the gorge not simply as a valley but as a **fracture (crack) formed in brittle rock**, governed by physical laws of crack growth. In fracture mechanics, cracks are classified into modes depending on how they open. The Khari gorge was interpreted as a **Mode-I crack**, meaning it opened due to tensile stress, rock being pulled apart. Once a crack forms, its growth depends on the stress acting on the rock and on the mechanical strength of the host material.

To calculate how such a crack can open and widen, the study used equations involving rock properties, such as:

- **Young's modulus** (a measure of rock stiffness)
- **Poisson's ratio** (how rock behaves when stretched or compressed)
- **Tensile strength** (the stress required to break the rock)

Using these parameters, we calculated the opening displacement of the crack under tectonic stress. Their estimates suggest that the initial opening displacement of the gorge could have been around **0.6–0.8 millimetres**, with widening continuing gradually through time. At first glance, less than a millimetre may seem insignificant. But in geology, even tiny annual changes can create massive landforms if they persist over thousands of years.

WATER FLOW AS A KEY FACTOR: THE "CUBIC LAW"

Tectonic stress alone creates cracks, but water plays a powerful role in enlarging them. We modelled the movement of water through the fracture using a well-known principle called the **cubic law of fluid flow**.

This law states that: The amount of water that flows through a fracture is proportional to the cube of the fracture's aperture (opening). This has an important implication: a small increase in crack width causes a very large increase in water flow. Once water begins to flow through the fracture, it increases erosion and accelerates widening.

Thus, the gorge becomes a product of feedback:

- tectonics opens the crack,
- water enters and flows through it,

- water pressure and erosion widen the crack further,
- wider crack allows even more water flow.

The study calculated that in the early stage, water discharge was extremely high (represented as about **22 Qc**, a relative volumetric flow value used in the model). This suggests that the gorge was strongly modified during wetter climatic conditions, likely when monsoon rainfall was stronger than today. Later, discharge reduced gradually to around **3 Qc**, indicating climatic weakening and reduced water availability.

SO, HOW WAS THE AGE ESTIMATED?

The age estimate was derived by linking three measurable components:

- **The present geometry of the gorge** (length, depth, width, displacement patterns)
- **The calculated rate of fracture opening and widening**
- **The changing influence of water discharge through time**

By applying the fracture-growth equations and fluid-flow models to the measured gorge dimensions, we reconstructed a time-dependent evolution curve. In other words, they treated the gorge as a physical system whose growth rate can be mathematically traced backward in time.

The results suggest that:

- The **initial opening of the gorge began around 125,000 years ago (125 ka)**, during the late Pleistocene.
- Major widening and modification continued until about **8,000 years ago (8 ka)**, during the Early Holocene.
- After 8 ka, climatic influence declined, and the gorge's modification became dominated mainly by slow tectonic deformation rather than strong water flow.

This is a significant achievement because it provides an approximate "birth date" for a landform that cannot be dated easily by traditional methods.

WHY THIS STUDY MATTERS BEYOND GEOLOGY

The Khari gorge is not only a geological curiosity. It is also a key to understanding broader Earth processes in western India. Kachchh is known for major earthquakes and active faults. By studying how fractures develop and evolve, scientists can better understand how landscapes respond to tectonic stress over time. Moreover, this research highlights how climate history is written into the land. Even though Kachchh is arid today, the gorge preserves evidence of wetter climatic phases in the past – the periods when large flows of water were capable of carving and widening deep bedrock fractures.

CONCLUSION: READING TIME IN STONE

The Khari bedrock gorge is a rare example where the Earth's history can be decoded not only through field observations, but also through physics and mathematics. It demonstrates that landscapes are shaped through the combined action of tectonics, climate, rock strength, and time. Most importantly, the study shows that even without sediments or fossils, Earth still offers a way to measure deep time - through the geometry of fractures and the mathematics of natural processes. The next time you see a rocky gorge or a deep crack in the Earth, pause for a moment. It is not just a feature, it is a story written over tens of thousands of years, shaped by forces both deep within the Earth and far above it in the skies.

At *Palaeoscience Today*, our goal is to bring such advanced scientific work to a wider audience. Because every crack in the Earth, every gorge, and every rock surface is more than scenery - it is a chapter of Earth's long story, waiting to be understood.

Warm regards,

Prof. Mahesh G. Thakkar
Chief Editor

Editorial

BRIDGING DISCIPLINES: WHERE PALAEOSCIENCE MEETS ARCHAEOLOGY AND ECOLOGY

IN an era defined by accelerating climate change, biodiversity loss, and cultural transformation, understanding the past has never been more urgent. The Earth's archives, such as lake sediments, peat deposits, tree rings, speleothems, and marine cores, store invaluable records of environmental change. Yet these records speak most clearly when interpreted beyond disciplinary silos. It is at the intersection of palaeoscience, archaeology, and ecology that the most compelling narratives of human–environment interaction emerge.

Palaeoscience reconstructs past climates, vegetation histories, fire regimes, and hydrological shifts across millennia. Archaeology uncovers the material footprints of human societies, their settlements, technologies, trade networks, and adaptive strategies. Ecology provides the conceptual and analytical framework to understand ecosystem dynamics, resilience, thresholds, and feedbacks. When these three domains converge, they illuminate not only what happened in the past, but why, and with what consequences. Consider the case of the Indus Valley Civilization. Archaeological excavations reveal sophisticated urban planning, drainage systems, and extensive trade networks. Yet the story of their transformation cannot be fully understood without palaeoclimatic reconstructions suggesting shifts in monsoonal intensity and river dynamics. Pollen records, isotopic signatures, and sedimentological data provide evidence for hydroclimatic variability that likely influenced agricultural productivity and settlement patterns. Ecology then helps frame the broader implications: how ecosystems responded to climatic stress, how human land use altered vegetation mosaics, and whether societal resilience was exceeded by environmental thresholds. Such interdisciplinary collaboration challenges simplistic narratives of "climate collapse." Environmental change alone rarely determines societal fate. Instead, it interacts with governance systems, economic structures, technological flexibility, and ecological resilience. Integrating palaeoscientific datasets with archaeological chronologies allows researchers to test hypotheses about causality rather than rely on temporal coincidence. Ecology further contributes by modeling feedback mechanisms: between vegetation cover and monsoon dynamics, for instance, revealing complex bidirectional relationships.

Beyond ancient civilizations, this convergence offers insights into long-term human impacts on ecosystems. Fire histories reconstructed from charcoal particles in sediment cores often align with phases of intensified human activity identified archaeologically. These records demonstrate that anthropogenic landscape modification is not merely a modern phenomenon; rather, it is deeply embedded in human history. However, the scale, speed, and global interconnectedness of present-day change are unprecedented, an understanding sharpened by millennial-scale comparisons. Interdisciplinary research also refines our perception of resilience. Ecological theory introduces concepts, such as tipping points and regime shifts. When paired with archaeological evidence of settlement relocation or subsistence diversification, these ideas help identify adaptive strategies that sustained societies during climatic perturbations. Conversely, they reveal vulnerabilities when environmental stress intersected with social rigidity. The methodological toolkit of this integrated approach is expanding rapidly. Advances in high-resolution dating, ancient DNA analysis, remote sensing, and computational modeling now allow for finer temporal alignment between environmental proxies and archaeological records. Geographic Information Systems (GIS) synthesize spatial data across disciplines, enabling landscape-scale reconstructions that bridge natural and cultural archives.

Yet interdisciplinary collaboration is not without challenges. Differences in terminology, scale, and epistemological assumptions can hinder dialogue. Archaeologists often prioritize cultural context and agency, palaeoscientists emphasize proxy interpretation and uncertainty quantification, and ecologists focus on systems theory and predictive modeling. Bridging these perspectives requires not only technical integration, but also intellectual humility and mutual respect. Importantly, this integration carries contemporary relevance. As societies grapple with monsoon variability, water scarcity, and ecological degradation, long-term records contextualize present trends within a broader climatic spectrum. They caution against deterministic thinking while underscoring the importance of adaptive capacity. Lessons drawn from past human–environment interactions can inform sustainable land management, biodiversity conservation, and climate adaptation strategies.

In essence, the meeting point of palaeoscience, archaeology, and ecology transforms fragmented records into holistic narratives. It replaces disciplinary boundaries with collaborative inquiry. The past, when viewed through this integrative lens, becomes more than a chronicle of change, it becomes a laboratory for understanding resilience, vulnerability, and the enduring interplay between humans and the natural world. Bridging disciplines is not merely an academic exercise; it is an intellectual imperative. Only by weaving together environmental archives, material culture, and ecological theory, we can construct a comprehensive understanding of our shared planetary history, and, perhaps, chart a more informed course for the future.

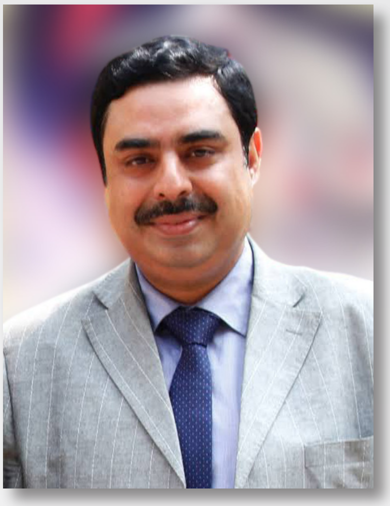
Thank you!

Best wishes…..

Dr. Md. Firoze Quamar
Editor

From the Coordinating Editor's Desk

ARTIFICIAL INTELLIGENCE AND THE FUTURE OF SCIENCE: FROM DATA TO DISCOVERY



IN the last decade, few technological developments have promised an impact on scientific discovery as profound as Artificial Intelligence (AI). What began as a computational aid for pattern recognition has rapidly evolved into a transformative framework, one capable of accelerating research, revealing hidden relationships in complex datasets, and translating scientific knowledge into tangible societal benefits. This transformation was vividly showcased during the India AI Impact Summit 2026, held from February 16–20, 2026, at Bharat Mandapam, New Delhi.

With more than 700 sessions spanning scientific discoveries, innovation ecosystems, governance, and real-world applications, the summit emerged as a global platform reflecting how AI is reshaping the very architecture of research. For India's scientific community, the discussions offered not only inspiration, but also a strategic roadmap for the future.

While the summit addressed a wide range of disciplines, its central message was clear: AI is rapidly becoming an essential engine of modern science. For data-intensive fields, such as palaeoscience—where incomplete records, deep-time scales, and complex environmental interactions are the norm—AI is poised to become a powerful catalyst for discovery.

AI as an Accelerator of Scientific Discovery

One of the summit's intellectual anchors was the Research Symposium held on February 18, 2026, which brought together leading scientists and technologists to reflect on the future of AI-driven research. Distinguished speakers included Dr Sara Hooker of Adaption Labs, Dr Pushmeet Kohli of Google DeepMind, and Prof Stuart J Russell from the University of California, Berkeley.

Discussions underscored how frontier AI methodologies are transforming the research process itself, from hypothesis generation and experimental design to data interpretation and predictive modelling. Traditional scientific inquiry, often constrained by long cycles of observation and validation, is increasingly being complemented by AI systems capable of rapidly analysing massive datasets, detecting subtle patterns, and guiding the next steps in experimentation.

In earth and environmental sciences, where datasets span geological timescales and integrate multiple proxies, AI-based approaches offer unprecedented analytical power. Machine learning algorithms can now synthesize climate records, sedimentological data, fossil assemblages, and geochemical signatures to reconstruct ancient environments with far greater resolution.

Equally significant was the emphasis on open, reproducible AI. Ensuring equitable access to data, algorithms, and computational resources was widely recognised as essential for democratising scientific progress, particularly for researchers in the Global South.

Major AI Tools Transforming Scientific Research

Across the summit, it became evident that AI's impact on science is not confined to a single technique, but spans an expanding ecosystem of tools reshaping the entire research pipeline.

Machine learning and deep learning frameworks now underpin classification, clustering, and predictive analysis across disciplines—from climate modelling and genomics to materials science and earth history. In palaeosciences, these tools enable automated fossil identification, stratigraphic correlation, and large-scale comparative analysis that would otherwise demand years of manual effort.

Computer vision and image-based AI have revolutionised scientific imaging. Convolutional neural networks are widely applied to CT scans, satellite imagery, seismic sections, and thin-section microscopy. In palaeontology, such tools allow precise fossil segmentation, morphometric analysis, and three-dimensional reconstruction of specimens from fragmentary remains, dramatically reducing analysis time and observer bias.

A major focus of the summit was physics-informed and hybrid AI models, which embed physical laws within data-driven architectures. These approaches are especially valuable in data-scarce domains, such as deep oceans, the subsurface, and deep-time Earth systems. For palaeoclimate reconstruction and basin evolution studies, physics-informed AI offers more reliable insights than purely statistical models.

Generative AI and simulation tools, including diffusion models, are increasingly used to address missing or incomplete data. In palaeoscience, where the fossil record is inherently fragmentary, these models enable scientists to explore multiple evolutionary or environmental scenarios and test hypotheses against plausible reconstructions of the past.

Natural language processing (NLP) is also transforming scientific workflows. AI-driven literature mining, semantic search, and automated summarisation now allow researchers to navigate decades of publications, expedition reports, and legacy datasets—unlocking valuable insights buried in textual archives.

Underlying all these tools is the rapid expansion of high-performance computing and sovereign AI infrastructure. India's GPU capacity, now scaling beyond 58,000 units, represents a critical enabler for training large models, running complex simulations, and developing indigenous AI solutions aligned with national research priorities.

Building a Global Ecosystem for AI in Science

The summit highlighted the growing importance of collaborative scientific ecosystems. A notable outcome was the launch of the Network of AI for Science Institutions, bringing together organisations from nineteen countries to promote equitable participation in frontier research.

Another key forum, the Science Working Group, co-chaired by Prof Abhay Karandikar, Secretary, Department of Science and Technology, Government of India, examined AI's role in addressing global challenges, such as climate change, public health, and environmental sustainability.

Participants stressed the importance of ethical governance, safety norms, and interdisciplinary collaboration. Developing high-visibility platforms for nurturing Indian scientific talent and strengthening global thought leadership in inclusive AI emerged as shared priorities. Together, these discussions reinforced a crucial insight: AI is not merely a tool, but a new research paradigm demanding new institutional frameworks and policies.

From Lab to Land: Bridging the Innovation Gap

A recurring theme throughout the summit was the persistent gap between laboratory research and societal impact. Despite robust scientific output, many innovations falter at the stage of scaling and deployment.

Sessions, such as *From Lab to Lives: Turning Innovation into Impact* explored practical pathways to bridge this divide. Moderated by Meghna Bal of the Esya Centre, the panel featured experts including Dr Anurag Agrawal of Ashoka University and Hemendra Mathur of the Bharat Innovation Fund.

The discussions highlighted trust, sector-specific design, and Digital Public Infrastructure as critical enablers for translating research into scalable solutions. The AI Impact Expo further showcased real-world deployments, from multilingual assistive technologies to AI platforms for agriculture, healthcare, and energy, reinforcing the summit's lab-to-land ethos.

AI in Earth System Science: Lessons from the Oceans

The relevance of AI to earth system science was particularly evident in a special panel organised by the Ministry of Earth Sciences, Government of India, entitled *AI for Our Oceans of Tomorrow: Data, Models and Governance*.

In his keynote address, Dr M. Mohapatra, Director General of the India Meteorological Department, highlighted the success of hybrid AI–physical models in cyclone prediction, significantly improving accuracy and early-warning capabilities.

Panel discussions emphasised open, interoperable digital systems and physics-informed AI for data-scarce oceanic domains—recommendations equally relevant to palaeosciences and geological research.

AI and the Emerging Frontier of Palaeosciences

Globally, AI is already transforming palaeontology. Deep learning algorithms are used for automated fossil classification, CT scan analysis, and three-dimensional reconstruction of specimens. Neural networks aid in identifying evolutionary patterns, while generative models address the challenge of incomplete fossil datasets.

Advanced AI tools have enabled rapid processing of high-resolution scans of Triassic reptiles and reconstruction of extinct dinosaur skulls, such as *Protoceratops*, demonstrating how AI can unlock new insights from existing collections.

Opportunities for India's Palaeoscience Community

India's palaeontological wealth, from the vertebrate fossils of the Siwalik Hills to plant assemblages of the Gondwana Basin, offers immense potential for AI-enabled research. Yet much of this archive remains underexplored through modern computational approaches.

Open data sharing, collaborative networks, and physics-informed AI models, as advocated at the summit, provide a clear pathway forward—enabling large-scale fossil analysis, stratigraphic modelling, and palaeoclimate reconstruction.

AI and Science: A Simple Way to Understand the Change

Artificial Intelligence can be understood as a powerful set of computer tools that help scientists see patterns faster, ask better questions, and test ideas more efficiently. Instead of replacing scientists, AI works like a smart assistant—sorting vast amounts of data, highlighting hidden links, and allowing researchers to focus on interpretation and creativity.

Whether it is reading millions of years of climate signals from rocks, identifying fossils from images, or simulating ancient environments, AI helps scientists do in days what once took years. Events, such as the India AI Impact Summit 2026 clearly showed that AI is no longer limited to laboratories or computer science departments—it is becoming a common language across all branches of science.

For students interested in palaeoscience, geology, or earth studies, this shift means new opportunities. Learning basic data skills, understanding how computers analyse images or patterns, and appreciating how science and technology work together will be as important as fieldwork and fossils themselves. The story of Earth's deep past is still written in rocks and fossils, but today, AI is helping us read that story with sharper eyes and deeper insights.

Looking Ahead

Scientific revolutions are often defined by new tools that allow us to revisit old questions. Just as the telescope transformed astronomy and the microscope reshaped biology, Artificial Intelligence is poised to redefine earth science.

AI offers an unprecedented opportunity to decode Earth's deep past—reconstructing ancient ecosystems, tracking long-term climate dynamics, and refining our understanding of life's evolution.

As the India AI Impact Summit 2026 made clear, the future of science lies at the intersection of data, computation, and collaboration. For India's palaeoscience community, the question is no longer whether AI will shape the field, but how prepared we are to harness its full potential.

Warm regards

Dr Nimish Kapoor
Coordinating Editor

Contents

Whispers in Stone: What the Marwar Supergroup Reveals About Life's First Steps

Shamim Ahmad

LIFE on the Earth underwent one of its most essential changes more than 500 million years ago before the existence of dinosaurs, forests and fish. Simple organisms were beginning to experiment with new ways of living, growing larger, becoming more complex, and interacting with their environment in ways that would eventually lead to the rise of metazoans. Some of the clearest evidence of this ancient transition is preserved today in the rocks of western Rajasthan, within a remarkable geological succession known as the **Marwar Supergroup**. These rocks, exposed across the western Rajasthan, may look barren at first glance. Yet they hold subtle fossil clues that are helping us to understand how early life evolved and how the foundations of modern ecosystems were laid.

A GEOLOGICAL ARCHIVE FROM DEEP TIME

The Marwar Supergroup consists of a substantial sedimentary rock formation that contains sandstones, limestones, and shales throughout western Rajasthan (Figure 1). The rocks formed between 600 million years ago and ~520 million years ago when the area existed as a shallow sea coastline. The seafloor accumulated sand and mud and lime over millions of years which created an extensive record of past environmental conditions. The Marwar Supergroup contains three primary geological divisions. The **Jodhpur Group** forms the lower part and consists mainly of sandstones deposited in coastal and nearshore settings. The **Bilara Group**, which appears above the Jodhpur Group, contains limestones that developed in shallow marine environments. The sequence is capped by the **Nagaur Group**, made up of sandstones and shales deposited in tidal flats and shallow seas. The geological layers of this region extend from the late Precambrian Period to the early Cambrian Period, which represents a time when Earth experienced significant biological changes.

LIFE BEFORE SKELETONS

The Marwar Supergroup originated during a time when organisms developed soft body structures which differ from younger rocks that maintain their original shell and bone and tooth materials. The fossil record from this period contains limited evidence because soft tissues decay rapidly and only a few instances result in fossilization. Scientists discover organism remains through their finding of physical impressions which display surface patterns and markings that living creatures left behind. Researchers at Jodhpur Group have discovered circular and disc-shaped impressions which they found on sandstone surfaces. These fossils show similarities to Ediacaran forms which represent the time when Earth first developed large complex life forms. The organisms are challenging to identify because they demonstrate early life forms that attempted to develop larger and more organized body structures. The impressions connect to fossilized microbial mats which consist of thin bacterial layers that used to exist on the seafloor. The mats established perfect conditions to protect fragile impressions because they built surface stability through their sediment trapping. Microbial mats functioned as the first ecosystem engineers on Earth because they modified natural habitats before metazoans assumed this responsibility.

Figure 1. Field photographs illustrating representative horizons of the Marwar Supergroup. (A) Sursagar Sandstone mine, Ediacaran in age, yielding abundant Ediacaran fossil assemblages. (B) Bilara Group exposures showing limestone intercalated with thin chert bands. (C) Dulmera sandstone quarry representing the younger Cambrian horizon of the Marwar Supergroup.

THE FIRST FOOTSTEPS OF LIFE

The most significant finding from the Marwar Supergroup originates from trace fossils which show preserved evidence of movement and activity. The Nagaur Group's more recent rock formations contain evidence of multiple metazoan pathways, which includes their burrows and resting locations. The trace evidence conveys a stunning narrative. The data shows that metazoans moved across the seafloor while they dug through sediment and searched for food. The traces show two types of movement, which include simple horizontal movement and complex behaviors that involve multiple burrowing sessions and extended resting periods. The fossils show that ancient metazoans possessed both muscle development and body coordination abilities, which allowed them to perceive their surroundings. The upward movement through the rock sequence leads to an increase in trace evidence which shows more complex patterns of metazoan behavior. The gradual increase shows a major biological change because it demonstrates that metazoans developed greater physical activity, which allowed them to create more environmental changes.

A SILENT REVOLUTION ON THE SEAFLOOR

The seafloor remained stable because microbial mats controlled its stability until metazoans developed their burrowing skills. The development of digging ability in metazoans allowed them to create disturbances, which broke up these mats and disturbed deep soil layers. The scientists named this fundamental environmental transformation the Cambrian substrate revolution. The Marwar Supergroup preserves this transformation in striking detail. The older layers of the site display smooth surfaces, which cover microbial mat material, but the younger layers show increasing disturbance through metazoan activities. The alteration brought about extensive effects throughout various aspects of life. The process of burrowing created pathways, which enabled oxygen to reach deeper sediment layers, while the process also transformed nutrient flow patterns and established new ecological habitats. The Cambrian Period metazoan diversity explosion developed because these changes created the conditions, which enabled this expansion. The Marwar rocks hold quiet trails and burrows which have preserved evidence of one major scientific discovery that changed the course of life on the Earth.

WHY THE MARWAR FOSSILS MATTER

The fossils of the Marwar Supergroup are significant not only for India but for understanding life on a global scale. Similar fossils and sedimentary features are found in rocks of comparable age in China, Australia, and other parts of the world. This shows that the evolutionary changes recorded in Rajasthan were part of a planet-wide transformation, not an isolated event. Importantly, the Marwar Supergroup provides a crucial record from the ancient southern continents, offering a Gondwanan perspective that complements better-known fossil sites elsewhere. Each new discovery from these rocks helps scientists refine timelines, test evolutionary ideas, and better understand how early life responded to environmental change.

STORIES WRITTEN IN STONE

The fossils of the Marwar Supergroup remind us that evolution is not always recorded in dramatic skeletons or giant creatures. Sometimes, it is preserved in faint impressions, subtle textures, and winding trails on ancient rock surfaces. These quiet signatures reveal how life slowly became more complex, more mobile, and more interactive. As research continues, the rocks of western Rajasthan will undoubtedly yield new insights into Earth's earliest ecosystems. Hidden within the desert landscape is a record of the time when life first learned to move, to modify its environment, and to set the foundations for the living world we know today.

CONCLUSION: LISTENING TO THE OLDEST VOICES OF LIFE

The fossils of the Marwar Supergroup may not look spectacular at first glance. There are no towering skeletons or glittering shells to catch the eye. Instead, there are faint impressions, shallow grooves, and gently wrinkled rock surfaces easy to miss, yet profound in meaning. These are the earliest records of life learning to move, to explore, and to reshape its world. In these rocks, we see a planet in transition. Microbial mats once ruled the seafloor, holding sediments together in quiet stability. Then, slowly, metazoans began to crawl, burrow, and disturb that calm surface.

With every trail and burrow, they changed how oxygen flowed through sediments, how nutrients were recycled, and how ecosystems functioned. These small actions triggered changes that would ultimately allow complex marine communities and eventually life on land to evolve. The Marwar Supergroup reminds us that Earth's greatest revolutions did not always arrive with noise or drama. Some unfolded silently, beneath shallow seas, recorded only as delicate marks in sand and stone. Yet these marks capture the moment when life crossed a critical threshold when it began to engineer its environment rather than simply adapt to it. The deserts of Rajasthan are revealing themselves as one of the world's important archives of early life i.e. Late Ediacaran to Early Cambrian.

The stones speak softly, but their message is clear: ***the story of evolution is written not only in bones, but in behavior, interaction, and the subtle traces left behind by life taking its first steps into complexity.***

About author

Dr Shamim Ahmad is a CSIR Pool Scientist at the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow, specializing in biosphere–environment interactions across the Ediacaran–Cambrian transition. Integrating palaeobiology, sedimentology, and geochemistry, his research explores the evolution of early life. His work provides insights into the origin and diversification of eukaryotes, multicellular organisms, and early animals, as well as their environmental settings and geobiological impacts.

Evidence of billion-years old trail-like features from the Vindhyan Basin, India, rewrites the origin of early motile life

Adrita Choudhuri

WHEN did life first start moving on the Earth? For decades, scientists and curious readers alike have asked deceptively this simple question. Traditional views place the emergence of complex life and its ability to bioturbate during the Ediacaran Period (635-538 million years ago) (Liu & McIlroy, 2015). Before that, the biosphere is often pictured as an essentially static microbial world: biologically active, yet behaviourally static and simple- e.g. stromatolites (microbiota induced carbonate sedimentation) (Figure 1 a, b) (Choudhuri et al., 2016) and microbial mat induced sedimentary structures (MISS) in the siliciclastic sedimentary system (indirect evidence of microbial life) (Figure 1 c, d) (Sarkar et al., 2016).

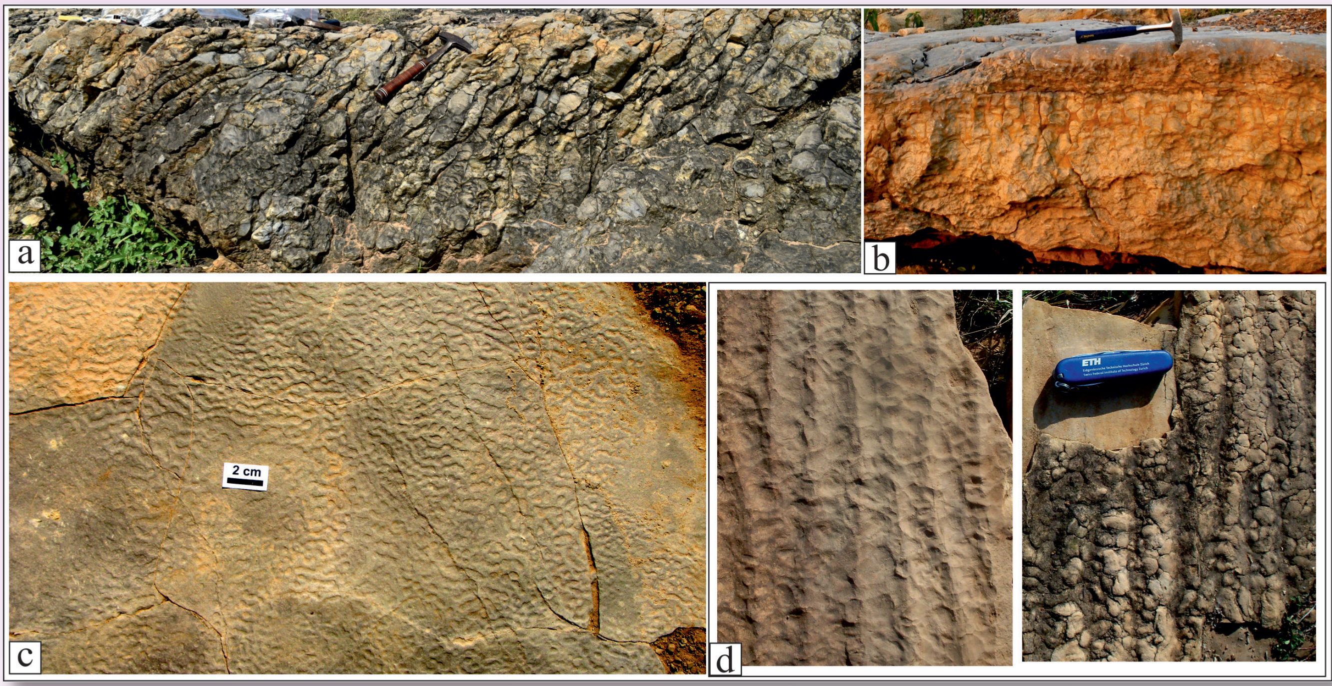


Figure 1: Field photos of stromatolites (microbiota induced carbonate sedimentation)- **a**. inclined and tightly packed stomatolites and **b**. laterally detached columns of stromatolites from the Bhander Limestone Member, Upper Vindhyan Group. Field photos of microbial mat induced sedimentary structures (MISS)- **c.** wrinkle structures preserved on the bedding plane and **d**. load balls (to the right) and their casts (to the left), preserved on the rippled sandstone bed surface within the silicilastic Chorhat Sandstone Member, Lower Vindhyan/Semri Group. (Hammer length 35 cm; Knife length 8.5 cm)

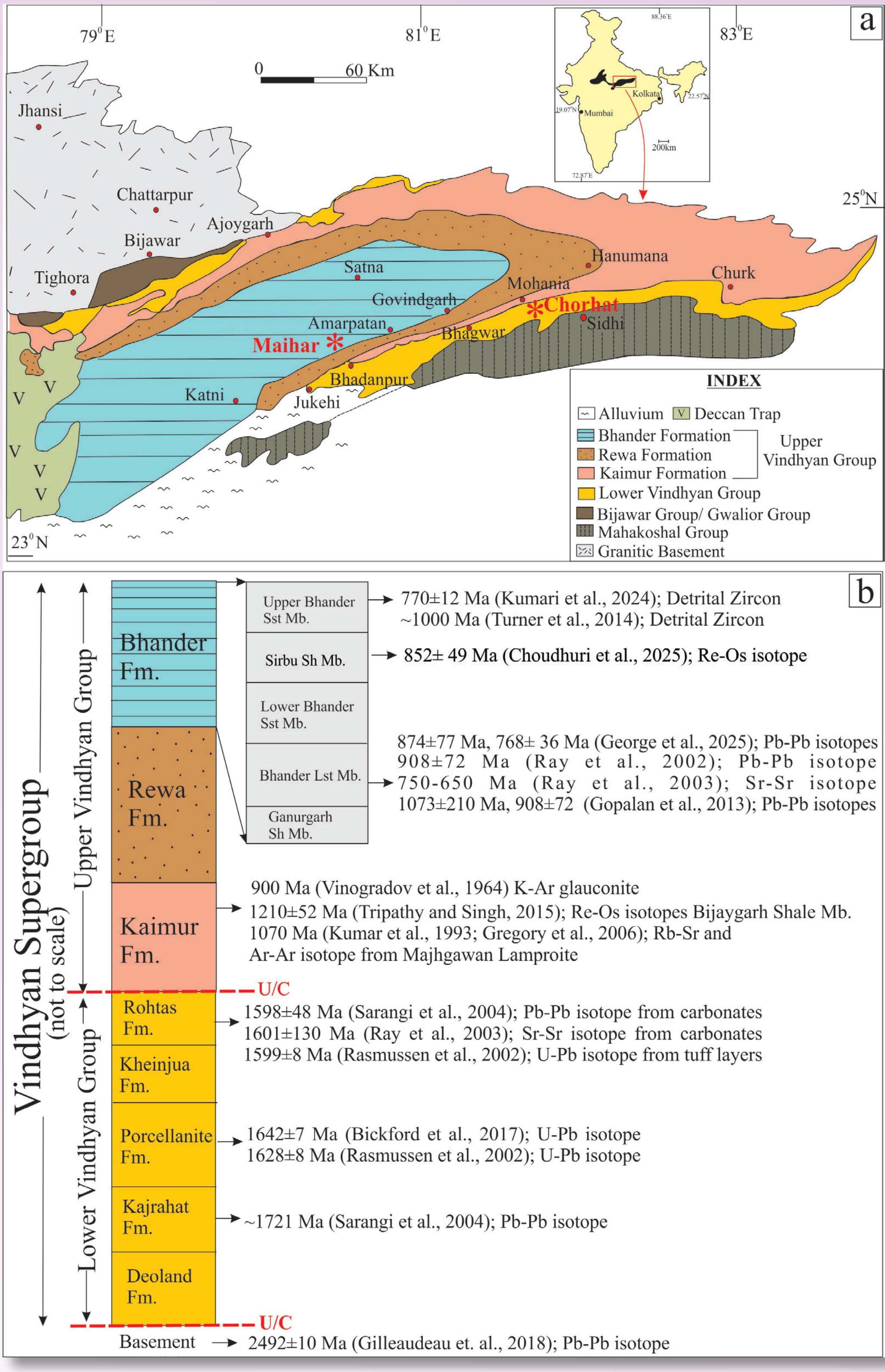


Figure 2: a. Geological map of the Vindhyan Basin in the Son Valley, central India. Biotic traces described in the present study were found within the outcrops near Maihar and Chorhat town (red asterisks). b. Lithostratigraphy of the Vindhyan Supergroup and geochronological age data determined using different radiometric techniques.

However, discoveries from the Proterozoic Vindhyan Basin in central India (Figure 2a) are steadily eroding this narrative, revealing a far older and more gradual story of life learning to interact dynamically with its environment, as ancient sea floors were covered by microbial mats (Choudhuri et al., 2023, 2025). By combining evidence from two different geological intervals: the 1.6-billion-year-old Chorhat Sandstone and the ~852-million-year-old Sirbu Shale, scientists now propose that early organisms may have experimented with mobility some 270 million years before, the generally accepted date for the appearance of metazoan life (Figure 2b; Choudhuri et al., 2023; 2025). Rather than a sudden evolutionary leap, these new research findings reveal a gradual, billion-year-long prelude to complex life.

CLUES FROM THE "BORING BILLION": 1.6 BILLION-YEARS OLD UNUSUAL FEATURES FROM THE CHORHAT SANDSTONE

The older of the two discoveries comes from the Mesoproterozoic (1.6 to 1 billion years ago) Chorhat Sandstone (Figure 2b; Choudhuri et al., 2023), deposited during a period often referred to as Earth's "Boring Billion" (Figure 3). This interval, spanning roughly 1.8 to 0.8 billion years ago, has long been characterised as a time of environmental stability and limited evolutionary innovation. Yet on ripple-marked surfaces of the Chorhat Sandstone, researchers identified an array of unusual ridge–groove structures (Figure 4a) that challenge this assumption. Preserved with remarkable clarity, these features form delicate, looping, and braid-like patterns that wind across bedding planes with consistent widths and abrupt changes in direction (Figure 4b). Such a geometry is difficult to reconcile with purely physical processes. Gas escape, sediment collapse, or current scouring typically produces irregular, diffuse, or directionally consistent features– not the sinuous, repetitive, and sharply defined ridges observed here. Equally striking is their close association with microbial mat structures, which once blanketed these shallow-marine tidal flats. These mats would have formed cohesive, sticky surfaces capable of preserving even fleeting interactions with the sediment (Choudhuri et al., 2023).

The most compelling explanation is that these ridges record movement across or within a living microbial substrate. They may have been produced by microorganisms or simple multicellular bodies gliding across the mat surface, periodically pressing into the sediment as they moved. If so, they represent some of the earliest physical evidence for surficial motility on Earth, occurring nearly 1.6 billion years ago. This interpretation fundamentally challenges the idea that the Mesoproterozoic was a time of biological stagnation. Instead, it hints at a biosphere that was already experimenting with movement, albeit in subtle and cryptic ways (Choudhuri et al., 2023).

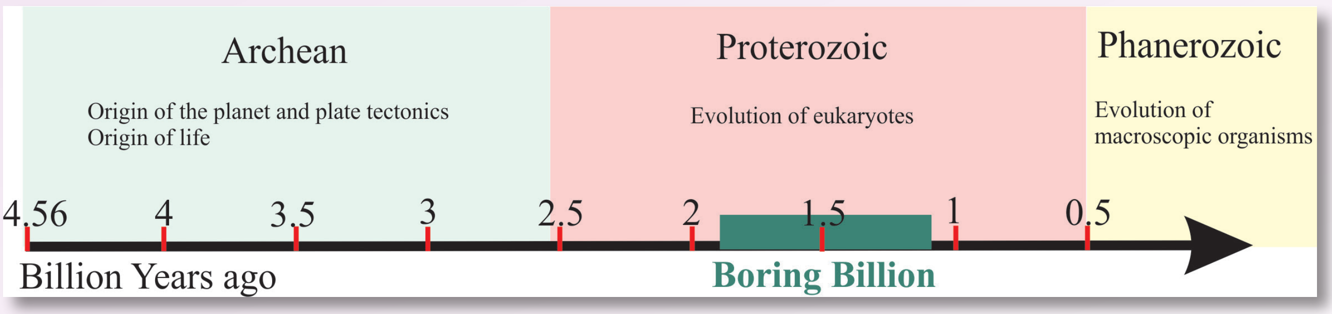


Figure 3: Simplified geological time scale showing different era and "Boring Billion" period (1.8 to 0.8 Billion Years ago) (modified after Mukherjee et al., 2025).

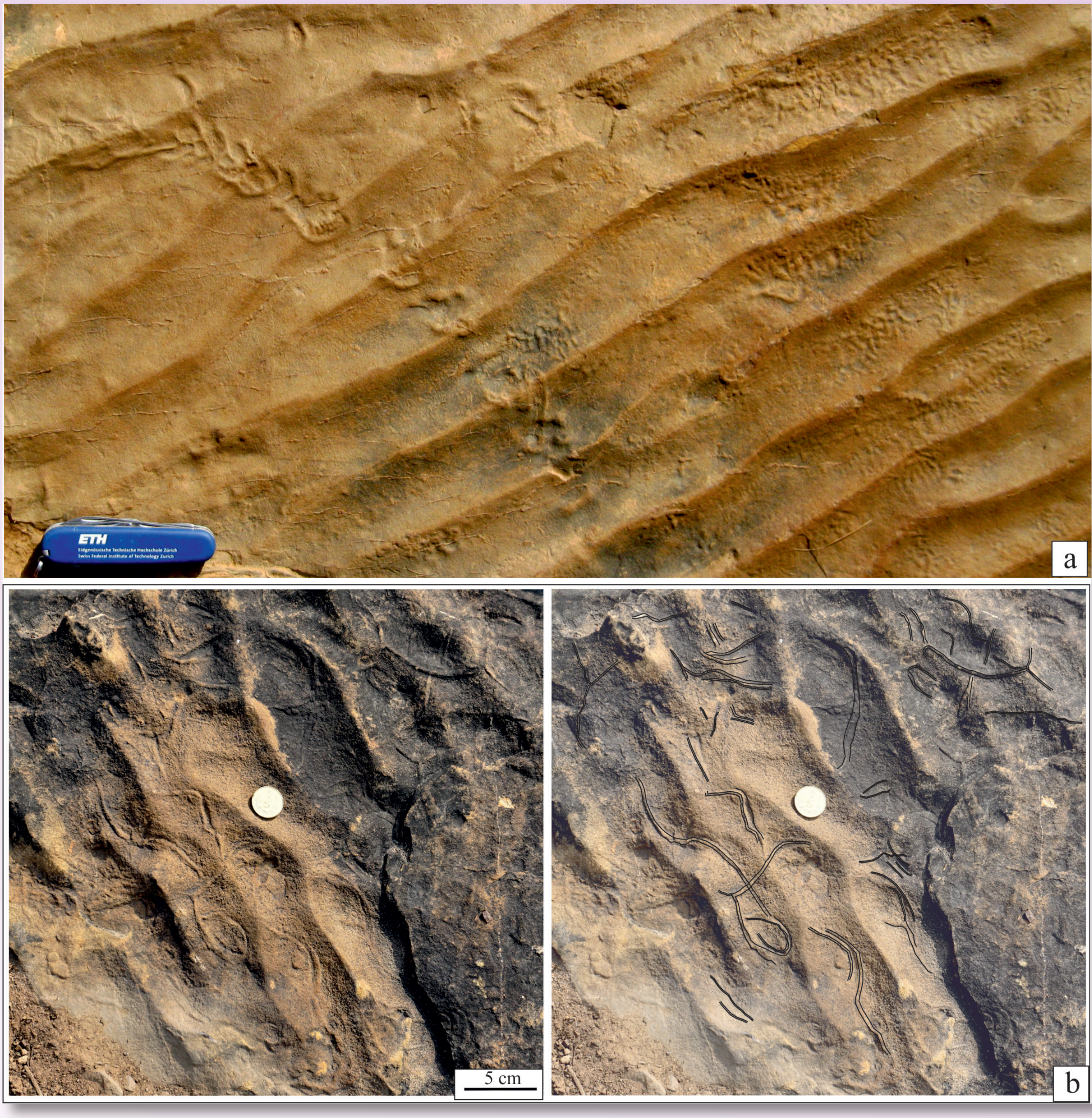


Figure 4: a. Field photo of unusual ridge-groove structures forming a curvilinear row perpendicularly crossing the wave-rippled bed surface of the Chorhat Sandstone Member. b. Field photo of a meandering groove like structure on the rippled bed surface and its hand sketch for better illustration on the right hand side. (Knife length = 8.5 cm)

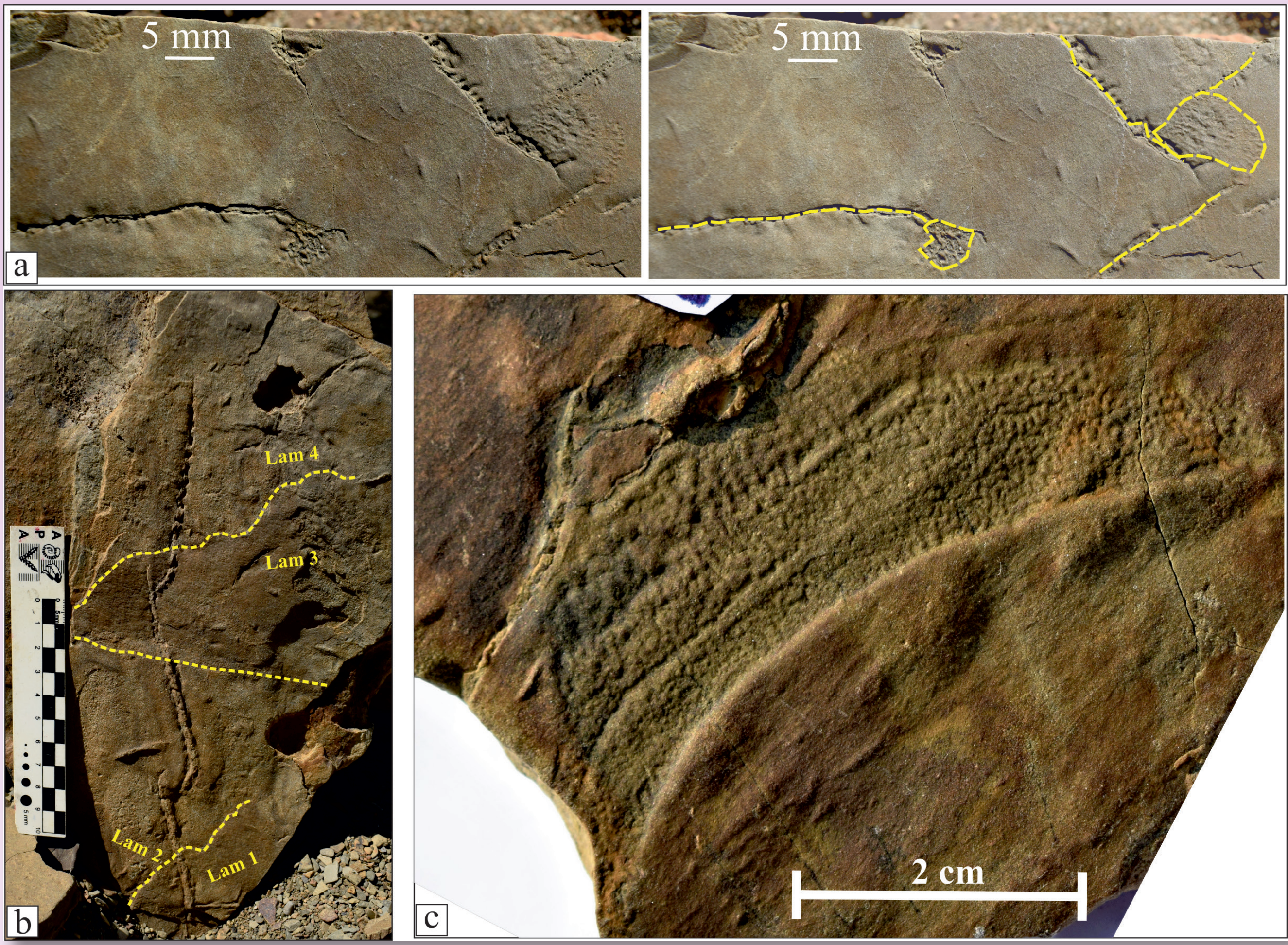


Figure 5: a. Sole of the fine siltstone bed of the Sirbu Shale Member displaying randomly oriented ridges with prominent wrinkle structure at one end of the ridge. b. Cast of spiralled, tubular ridge within the Sirbu Shale Member shows branching pattern and penetrates four sedimentary laminae. c. Arc-shaped feature, comparable to Bunyerichnus, shows numerous transverse ridges on both sides of a sub-median groove.

TONIAN TRAILS: SIGNS OF MOTILITY 270 MILLION YEARS BEFORE THE EDIACARAN

The second discovery, from the Sirbu Shale of the Upper Vindhyan Group (Figure 2b), strengthens this emerging picture and pushes it forward in time to the Tonian Period (1000-720 Ma) of the early Neoproterozoic (Choudhuri et al., 2025). Here, the evidence for early motility is even more striking. Preserved on the undersides of thin sandstone beds are a variety of trail-like and undermat structures that strongly resemble biological traces (Figure 5a). Some consists of elongate ridges with central furrows, others show regularly spaced dimples arranged symmetrically on either side, or a few display patterns suggestive of bilateral organization (Figure 5b). Several morphologies closely resemble known Proterozoic trace fossils, including forms comparable to *Bunyerichnus* (Figure 5c).

To test whether these structures were truly biogenic, researchers applied a suite of high-resolution analytical techniques. Transmitted-light microscopy and SEM-EDS revealed microbial laminae consistent with organism–substrate interaction. Micro-CT imaging allowed the internal geometry of the structures to be visualized in three dimensions, distinguishing different morphotypes and ruling out simple sedimentary artefacts. Together, these lines of evidence strongly support a biological origin, implying purposeful movement, repeated substrate contact, and rudimentary behavioural complexity (Choudhuri et al., 2025).

HOW DO WE CONFIRM THE AGE OF THESE BIOGENIC TRAIL-LIKE FEATURES?

Once scientists confirm that unusual features/ trace fossils from the Precambrian actually record ancient life, the next question is: how old are the rocks that contain them? Fossils alone can mislead, so radiometric dating provides clarity. Fortunately, volcanic ash layers (called tuffs) within sedimentary rocks can be used like a natural clock. Minerals, such as zircon in these layers can be dated very precisely, giving a reliable age for the surrounding rocks. For example, the Chorhat Sandstone has been dated to between 1628 ± 8 million years and 1599 ± 8 million years, based on tuff layers present in the overlying and underlying formations (Figure 2b) (Rasmussen et al., 2002; Bickford et al., 2017).

Scientists have tried several approaches, such as Pb-Pb, Sr-isotope, K-Ar dating of glauconite, and U-Pb dating of detrital zircon, to pin down its age (Ray et al., 2003; Gopalan et al., 2013; Kumari et al., 2024). These studies suggest the Upper Vindhyan rocks formed during the late Tonian period. Yet, other researchers looking at the fossil evidence have proposed a much younger age, placing these rocks in the Ediacaran Period (<548 Ma) (De, 2006; Kumar and Pandey, 2008; Pandey et al., 2023).

The Sirbu Shale study helps resolve this debate. Using a technique called rhenium–osmium (Re–Os) dating, applied to these rocks for the first time, the sediments were dated to about 852 million years old (Figure 2b; Choudhuri et al., 2025). This means the trail-like structures preserved in the rocks formed during the mid-Tonian period, pushing back evidence for animal-like movement by roughly 270 million years compared to previously known Ediacaran traces. These results help bridge the gap between estimates from molecular clocks and the actual fossil record, supporting the idea that complex behaviours arose much earlier than once thought. The study also attempts to resolve the long-due issue of closure age of the Vindhyan Basin, showing that sedimentation continued beyond one billion years ago, but ended long before the Ediacaran Period.

A NEW PICTURE OF EARLY EVOLUTION OF MOTILE LIFE

Taken together, the Chorhat and Sirbu discoveries suggest that the evolution of motility was not a late, abrupt event, but part of a prolonged evolutionary continuum. Long before the primitive organisms evolved to recognizable body plans, they were already interacting dynamically with their surroundings– gliding across microbial mats, probing the sediment, and possibly exploiting new ecological niches. These behaviours may have emerged first in structurally simple organisms, leaving behind only subtle traces/ trails, rather than obvious body fossils (Choudhuri et al., 2023, 2025).

Microbial mats appear to have played a central role in this story. Both the aforementioned formations preserve abundant mat-related sedimentary structures, indicating that these living surfaces dominated shallow-marine environments for much of the Proterozoic (2500-538 Ma). Microbial mats not only stabilized sediments and enhanced fossil preservation, but also created complex microenvironments rich in nutrients and, at times, oxygen (Choudhuri et al., 2023). In the case of the Sirbu Shale, geochemical evidence points to deposition within an isolated, oxygenated intracratonic basin (Ansari et al., 2023). Such localized oxygenated settings challenge the notion that early motility evolved only within rare, short-lived oxic "oases" in an otherwise anoxic global ocean (Choudhuri et al., 2025). Instead, they suggest that stable, habitable niches capable of supporting early eukaryotic life may have been more common than previously assumed.

A BILLION-YEAR CONTINUUM OF LIFE ON THE MOVE

The broader significance of these findings extends well beyond the Vindhyan Basin. During the Tonian, this basin formed part of the Rodinia supercontinent, and its record of early motile life finds intriguing parallels in other intracratonic basins, such as the Amadeus Basin of central Australia, where macrofossils of comparable age have been reported. Together, these geographically distant, but environmentally similar records fuel an ongoing debate in evolutionary biology: did complex life emerge suddenly in response to global environmental triggers, or did it evolve slowly and episodically, with innovations accumulating over hundreds of millions of years?

The evidence from India increasingly favours the latter view. Rather than a sharp boundary separating a static microbial world from an active animal-dominated one, the Proterozoic appears to have hosted a long transitional phase, during which life experimented with movement, behaviour, and interaction long before these traits became widespread or conspicuous. The finding also contributes to the growing awareness that tiny crawlers very likely arrived before Ediacaran time. Specific time-assignments of the host sediments, based on such biogenic features, may give some wrong message, if not validated by radiometric age data, as the time-brackets of ~index fossils change.

About authors

Dr Adrita Choudhuri is presently working as a Scientist C at the BSIP, Lucknow, with the expertise in Sedimentology, Sequence Stratigraphy, and Precambrian Geobiology. Her current research also expands to paleoenvironment, palaeogeography and paleoclimate interpretation of the Late Cretaceous sedimentary formations of NE and South India.

The Hidden Architecture of Healing Plants: Exploring Their Microscopic Identity Through Pollen

Anjali Trivedi, Anupam Nag, Saurav Gaikwad and M.G. Thakkar

HAVE you ever wondered how scientists identify medicinal plants that look almost identical to the naked eye? In forests and grasslands across north-western Maharashtra, many healing plants grow side by side. Their leaves may resemble each other, their flowers may bloom at the same time, and yet their medicinal properties can be very different. A small mistake in identification can lead to incorrect usage in traditional medicine. So, how do scientists ensure accuracy?

The answer lies in something incredibly small pollen grains.

NATURE'S MICROSCOPIC IDENTITY CARDS

Pollen grains are tiny structures produced by flowers for reproduction. But, beyond their biological function, they carry something remarkable: unique surface patterns and shapes that act like a plant's fingerprint (Figure 1).

Under powerful microscopes, pollen grains reveal intricate designs, such as spines, ridges, pores, grooves, and sculptured walls. These microscopic features are often so distinct that they help scientists identify plant species with precision.

In our study, we examined six medicinally important plant species: *Mesosphaerum suaveolens* (Vilaiti Tulsi), *Hygrophila auriculata* (Bhankari, Gokshur), *Pulicaria wightiana* (Sonela), *Barleria prionitis* (Jhinti), *Exacum pedunculatum* (Dodda chiraayatha), *Canscora diffusa* (Bhuin Neem).

These plants are widely valued in traditional medicinal systems, yet detailed pollen-based identification studies for many of them are limited in India.

LOOKING THROUGH TWO WORLDS OF MICROSCOPY

To understand their pollen features, we used two types of microscopes: **Light Microscopy (LM)** – to observe general shape and size and **Scanning Electron Microscopy (SEM)** – to see ultra-fine surface details

SEM allowed us to view pollen grains in extraordinary detail revealing surface patterns that are invisible under ordinary microscopes.

A HIDDEN WORLD OF DIVERSITY

Although these plants may appear similar in the field, their pollen grains were strikingly different. Some pollen grains were spherical, others slightly elongated. Some had three grooves, while others had multiple openings. Their outer walls showed varied sculpturing patterns from smooth textures to spiny and reticulate designs. For example, *Barleria prionitis* showed the largest pollen size among the studied species while *Pulicaria wightiana* had the smallest pollen grains. These differences are not random, they are genetically controlled and taxonomically meaningful.

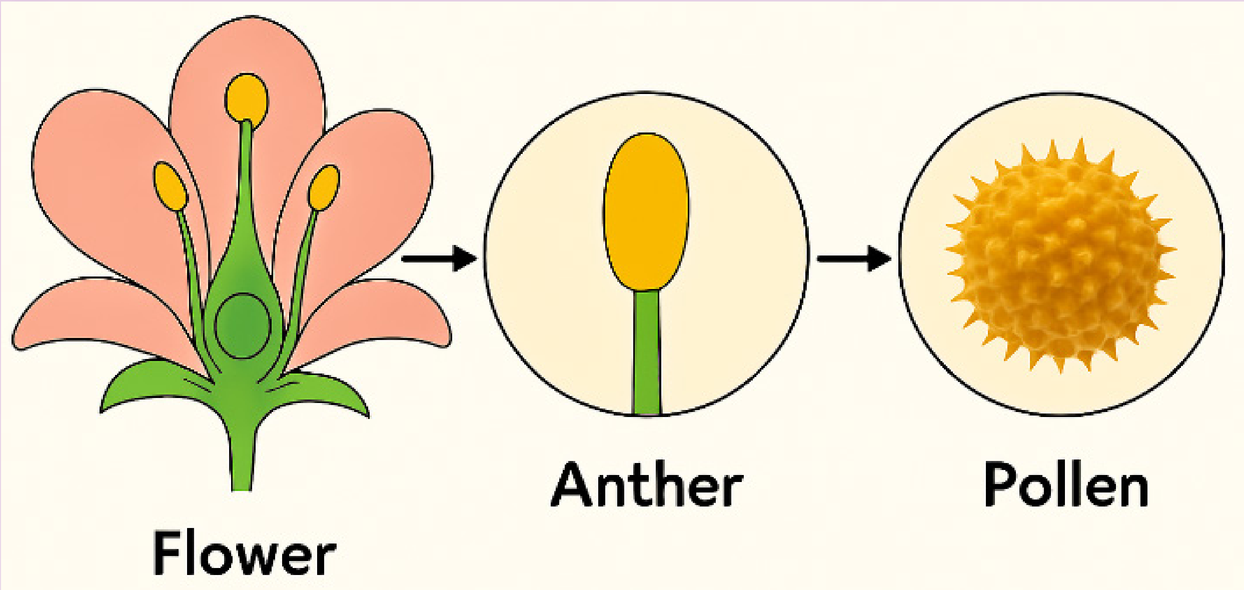


Figure 1: Sequential schematic diagram showing pollen's origin and structure—from flower to anther to magnified grains. Each pollen grain carries a unique surface pattern, acting as a botanical fingerprint and playing a vital role in reproduction and ecological identity.

WHY DOES THIS MATTER?

Accurate identification of medicinal plants is crucial for 1) Ensuring safe use in traditional medicine, (2) Preventing substitution or adulteration, (3) Conserving biodiversity, (4) Supporting pharmacological research.

In a country like India, where traditional plant-based medicine plays a major role in healthcare, scientific documentation becomes essential. Pollen morphology provides an additional, highly reliable tool for plant identification.

Moreover, such studies strengthen the scientific foundation of ethnobotanical knowledge and help bridge traditional wisdom with modern research.

BEYOND THE MICROSCOPE

At first glance, pollen grains may seem insignificant. But under magnification, they tell stories of evolution, adaptation, and identity. Each grain carries structural clues that help scientists classify plants more accurately and understand their relationships within plant families.

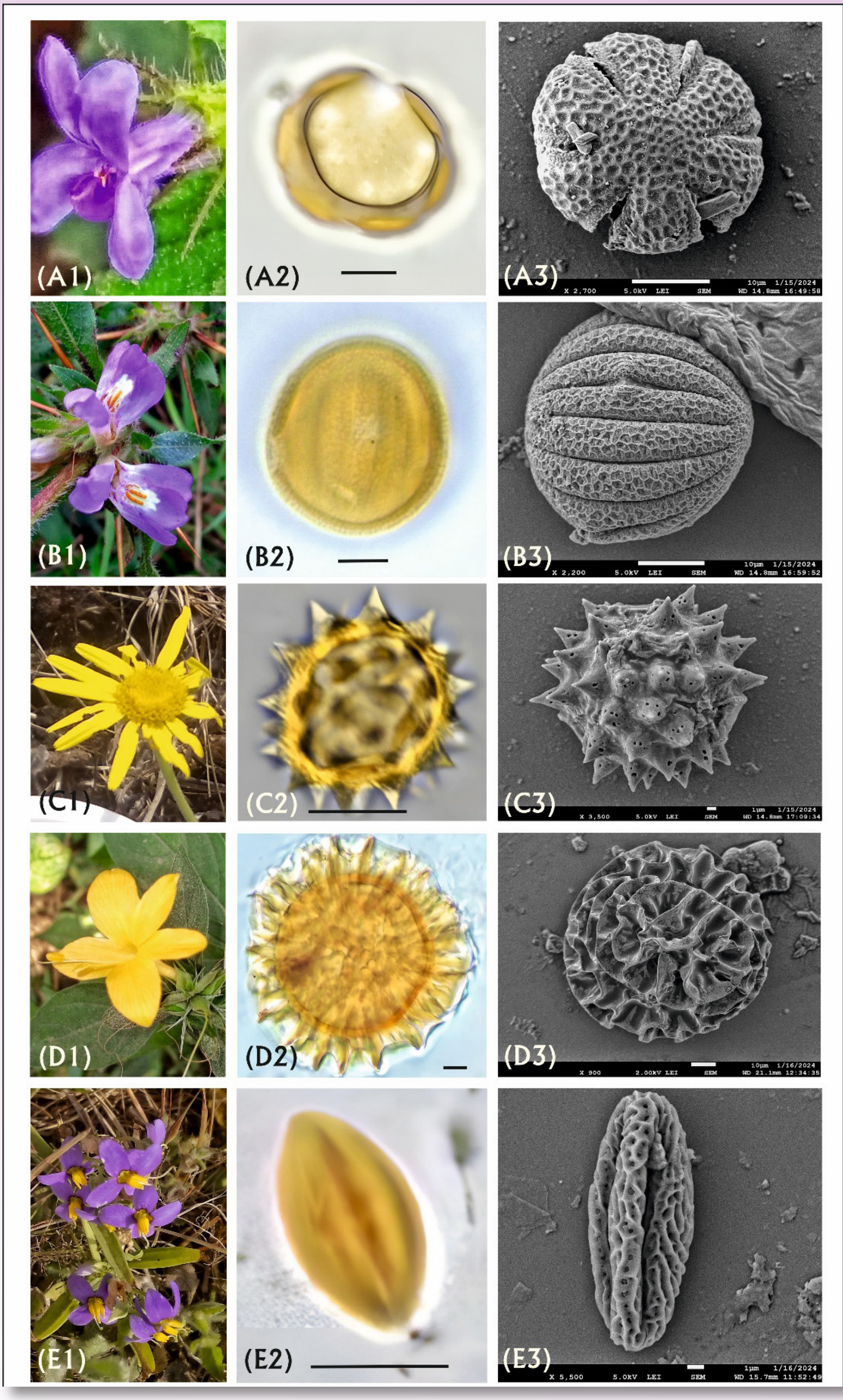
By documenting the pollen characteristics of regionally important medicinal plants, this study contributes to a growing database that supports taxonomy, conservation, and sustainable use of plant resources in India.

In the end, these microscopic grains remind us of something profound: sometimes the smallest structures hold the biggest answers.

SEEING IS BELIEVING

The true diversity of pollen becomes fully apparent when we move from the field studies to the microscope. After documenting the flowering plants in their natural habitat, their pollen grains were examined under Light Microscopy (LM) and Scanning Electron Microscopy (SEM), revealing remarkable differences in shape, size, and surface patterns.

The following plate (Plate 1) represents the flowers and corresponding pollen grains of the six medicinally important species studied. Together, these images illustrate how seemingly similar medicinal plants possess distinctly unique microscopic identities.


(A1)
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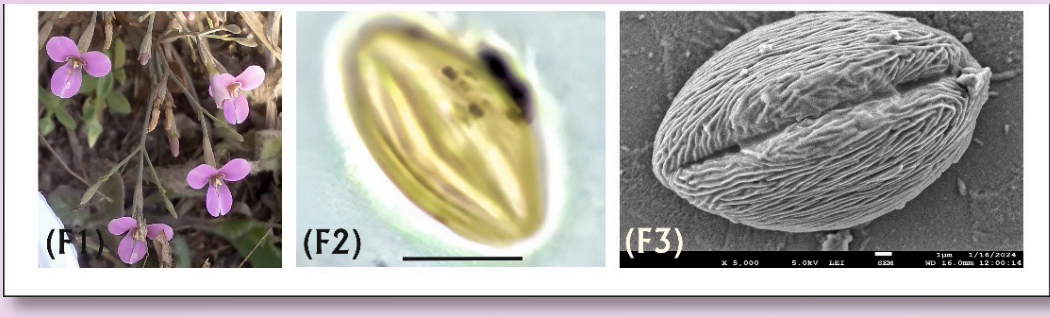

Plate 1. Comparative images of six medicinally important plant species showing flowers (1) and corresponding pollen grains under Light Microscopy (2) and Scanning Electron Microscopy (3): A1–A3, *Mesosphaerum suaveolens*; B1–B3, *Hygrophila auriculata*; C1–C3, *Pulicaria wightiana*; D1–D3, *Barleria prionitis*; E1–E3, *Exacum pedunculatum*; and F1–F3, *Canscora diffusa*.

Reference

Trivedi, A., Gaikwad, S., Nag, A., & Thakkar, M. G. (2026). Palynological characterization of traditional medicinal plant species from the northern Western Ghats, India. Palynology. https://doi.org/10.1080/01916122.2026.2619447

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Signature of the '8.2 ka event' from the Core Monsoon Zone, India

Nagendra Prasad and Mohammad Firoze Quamar

THE Indian Summer Monsoon (ISM) is one of the most influential climatic systems of the Indian subcontinent, controlling vegetation patterns, hydrological processes, and the development of human societies since prehistoric times. Variations in monsoon strength have repeatedly altered ecosystem structure, water availability, and agricultural productivity, particularly during the Holocene. Understanding the long-term behavior of the ISM is, therefore, essential for evaluating both natural climate variability and human–environment interactions.

Although several palaeoclimatic records exist from the Himalayan regions, peninsular India, and the Arabian Sea, high-resolution terrestrial records from the Core Monsoon Zone (CMZ), India remain limited. This is particularly true for abrupt Holocene climatic events, such as the 8.2 ka event, which is an interval of rapid cooling and drying well documented in North Atlantic archives but poorly constrained in central India. Given its sensitivity to monsoon rainfall, the CMZ represents a key region for detecting past phases of weakened and intensified monsoon activity. In this context, pollen records preserved in lake sediments provide valuable insights into past vegetation dynamics and associated climate change. The present study (Figure 1) contributes palaeoenvironmental data from Tuman Lake (TL), located in CMZ, India, and examines vegetation responses to ISM variability during the Middle–Late Holocene, with particular emphasis on the possible imprint of the 8.2 ka event.

The sampling region experiences a tropical monsoonal climate, with the majority of annual rainfall delivered during the summer monsoon season. Mean annual precipitation is strongly dependent on ISM intensity, making the area highly sensitive to monsoon fluctuations. The contemporary vegetation of the region is dominated by tropical deciduous forests, primarily composed of *Shorea robusta* (sal), *Tectona grandis* (teak), *Madhuca indica* (mahua tree), and associated tree and shrub taxa. The landscape is shaped by active fluvial geomorphic processes, including seasonal flooding and sediment redistribution, which favour the preservation of fine-grained lacustrine sediments. These conditions make TL a suitable archive for reconstructing past vegetation and climate variability.

A 1.2-m-long sediment profile was collected from the dried basin of the Tuman Lake. The core provides a continuous sedimentary record spanning approximately the last 8200 calibrated years. Chronological control was established using AMS radiocarbon dating, and an age–depth model was developed using Bayesian statistical methods (in R software using rBacon and IntCal20). Pollen extraction was followed by standard maceration protocols as suggested by Erdtman (1952). Pollen and spore counts were conducted using a transmitted Light Microscope (Olympus BX50 with an attached DP-26 camera for photography) at 40X magnification in the Quaternary Palynology Laboratory of the BSIP, Lucknow, India. Published references aided in pollen identification. Pollen assemblages (Figure 2) were used to infer changes in regional vegetation composition, moisture availability, and monsoon intensity. The presence of cereal-type pollen and other anthropogenic indicators was also examined to assess past agricultural practices and human activities in the region.

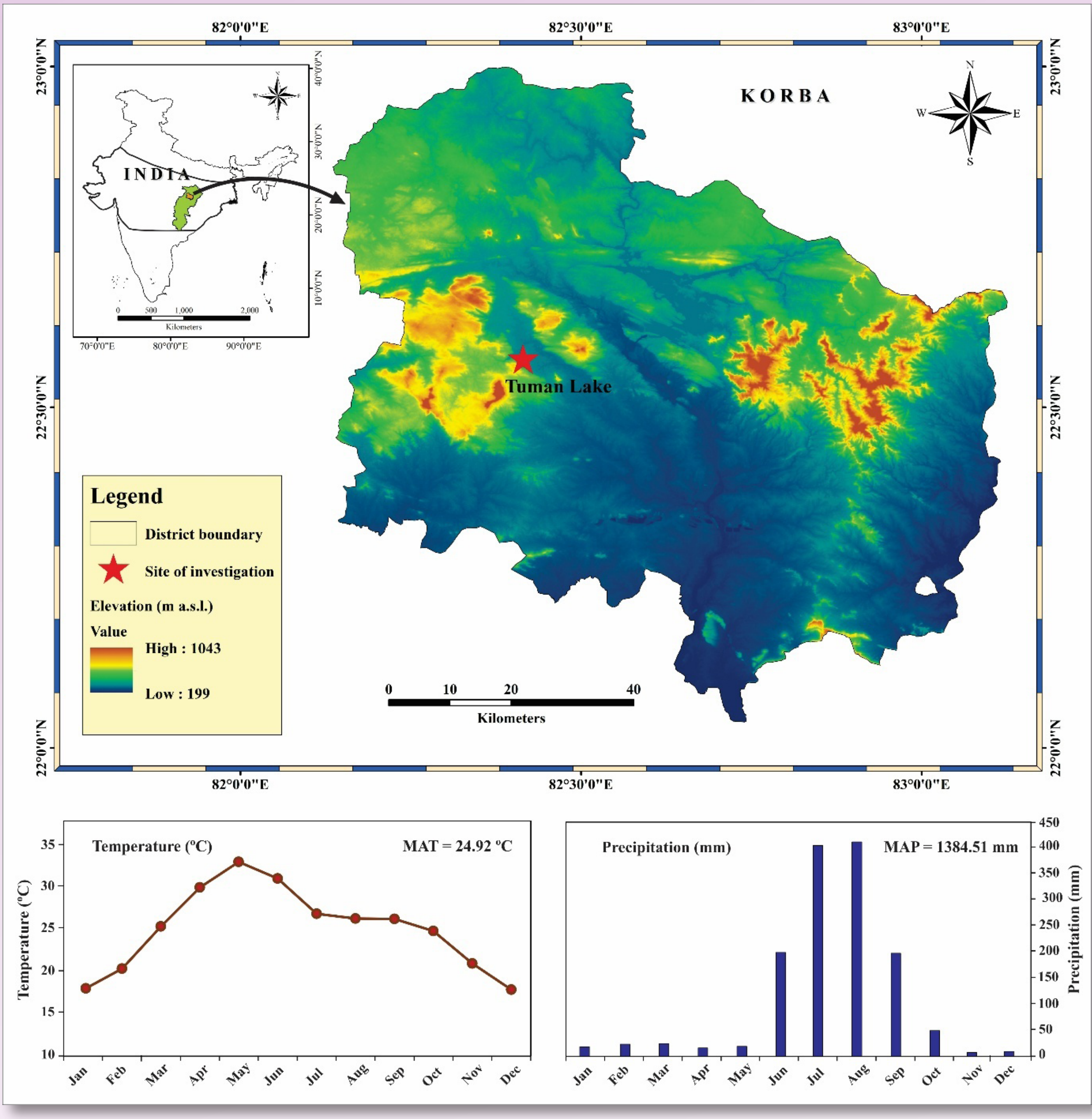

Figure 1. Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) of Korba District, Chhattisgarh, central India, showing the study site (red star), with inset maps depicting the district within India and the Core Monsoon Zone (CMZ, bold outline), and CRU TS 4.07 climate data (1901–2022) illustrating mean monthly precipitation and temperature; MAP = Mean Annual Precipitation, MAT = Mean Annual Temperature. Figure prepared using ArcGIS 10.8.2.

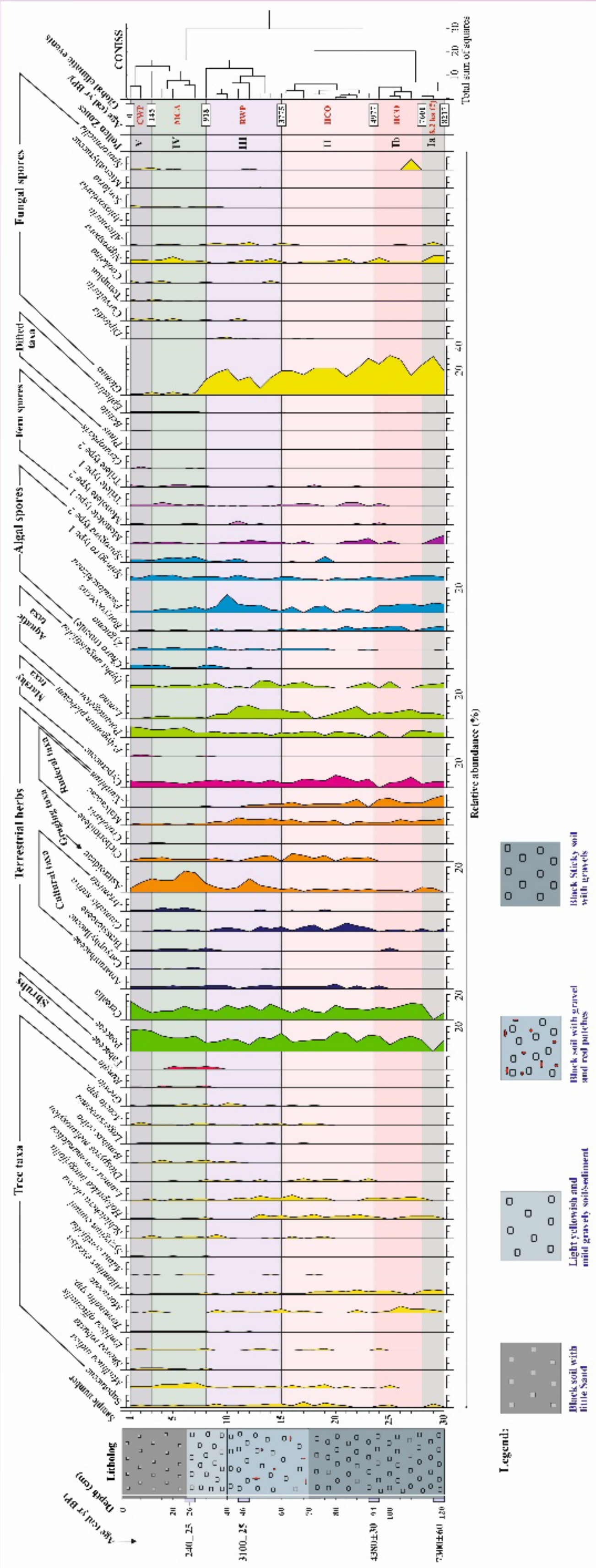

Figure 2. Pollen diagram of Tuman Lake (TL) sedimentary profile from the Korba District (Chhattisgarh), CMZ, India, showing the lithology, pollen zones, and vegetation distribution since the last 8.2 ka.

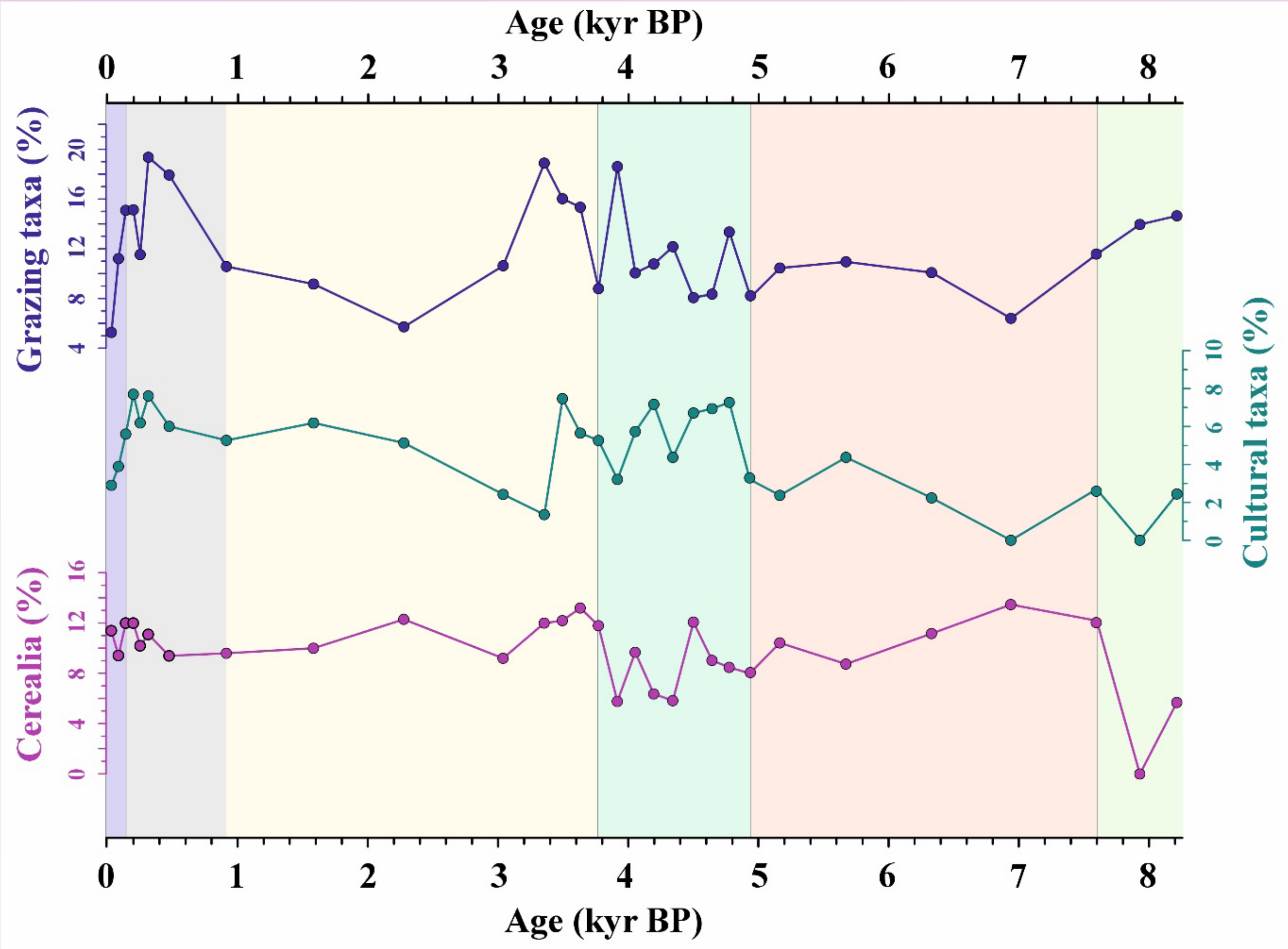

Figure 3. Representation of Cerealia, Cultural and Grazing pollen taxa, since the last 8.2 years, reveals evidence of agricultural practices and other human activities in the area.

VEGETATION DYNAMICS AND ISM VARIABILITY

The pollen record from Tuman Lake reveals distinct phases of vegetation dynamics and climate change during the Middle–Late Holocene, reflecting variations in ISM strength.

- Between ca. 8220 and 7600 cal yr BP, pollen assemblages are dominated by grasses and herbaceous taxa, indicating savannah vegetation under a relatively cool-dry climate, suggesting a weakened monsoon regime.
- From ca. 7600 to 4980 cal yr BP, an increase in arboreal pollen indicates the development of open forest vegetation under a warm and relatively less humid climate, corresponding to moderately enhanced monsoon rainfall. This period broadly overlaps with the Holocene Climatic Optimum (HCO), when monsoon intensity was generally stronger across much of the Indian subcontinent.
- The interval between ca. 4980 and 3775 cal yr BP is characterized by open mixed tropical deciduous forest, reflecting warm and relatively more humid conditions and further

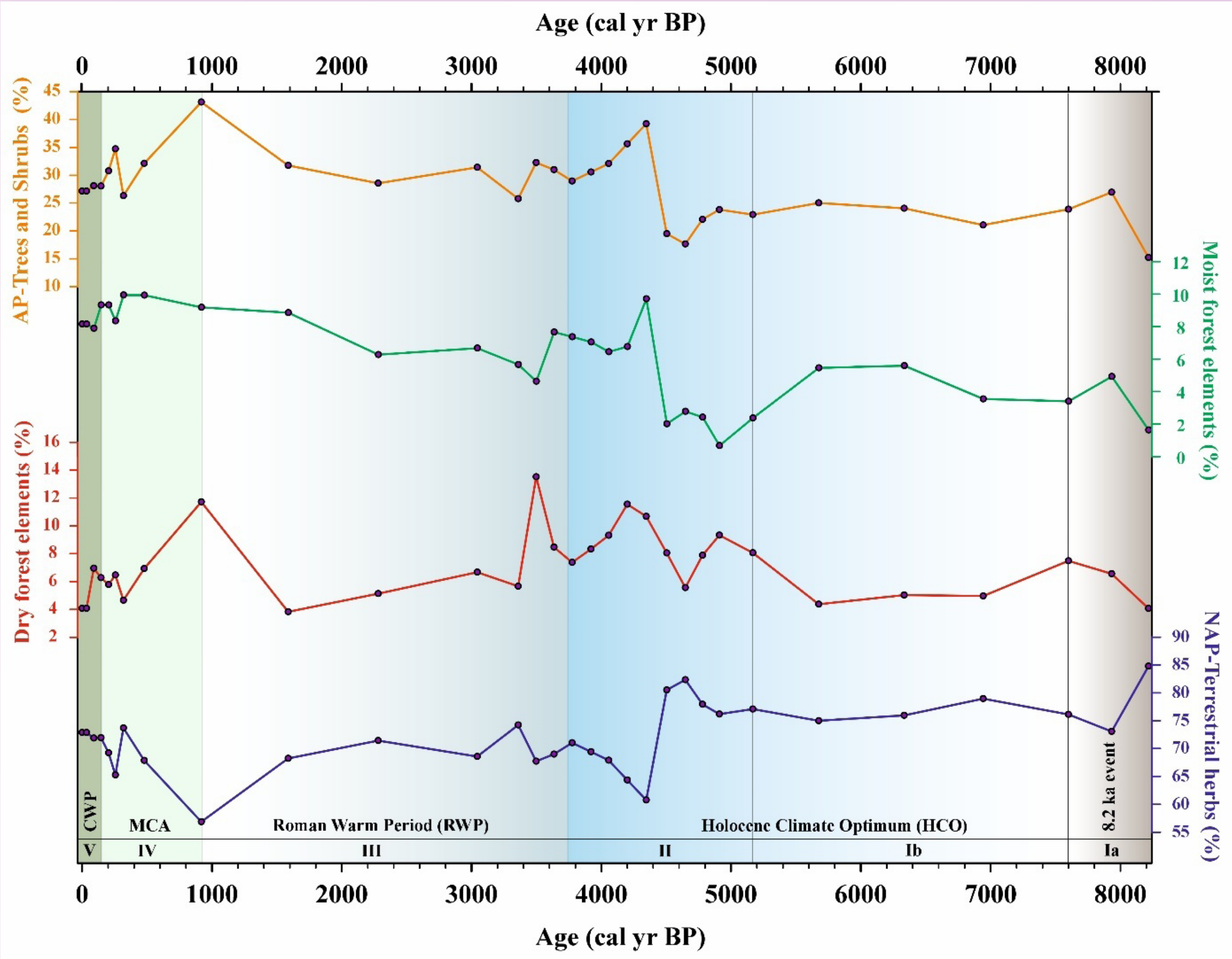

Figure 4. Representation of Arboreal Pollen (AP) taxa, comprising tropical moist deciduous forest vegetation (green) and tropical dry deciduous forest vegetation (red), as well as Non-Arboreal Pollen (NAP) taxa, since the last 8.2 years, encompassing weak monsoon at the 8.2 ka cool event, as well as the strong ISM during the HCO, RWP, MCA and the CWP.

strengthening of the ISM. Subsequently, from ca. 3775 to 920 cal yr BP, forest cover expands further, suggesting sustained monsoon rainfall during the Late Holocene.

- The recent phases (~920 to 145 cal yr BP, and 145 cal yr BP to the present) show variations in forest composition, with evidence for relatively less humidity in the recent part of the record, possibly linked to relatively weakening monsoon conditions and increasing human influence on the landscape.

EVIDENCE OF HUMAN ACTIVITIES

Cerealia pollen grains and other cultural indicators occur sporadically throughout the record (Figures 2 and 3), particularly during the Middle and Late Holocene. Their presence suggests the initiation

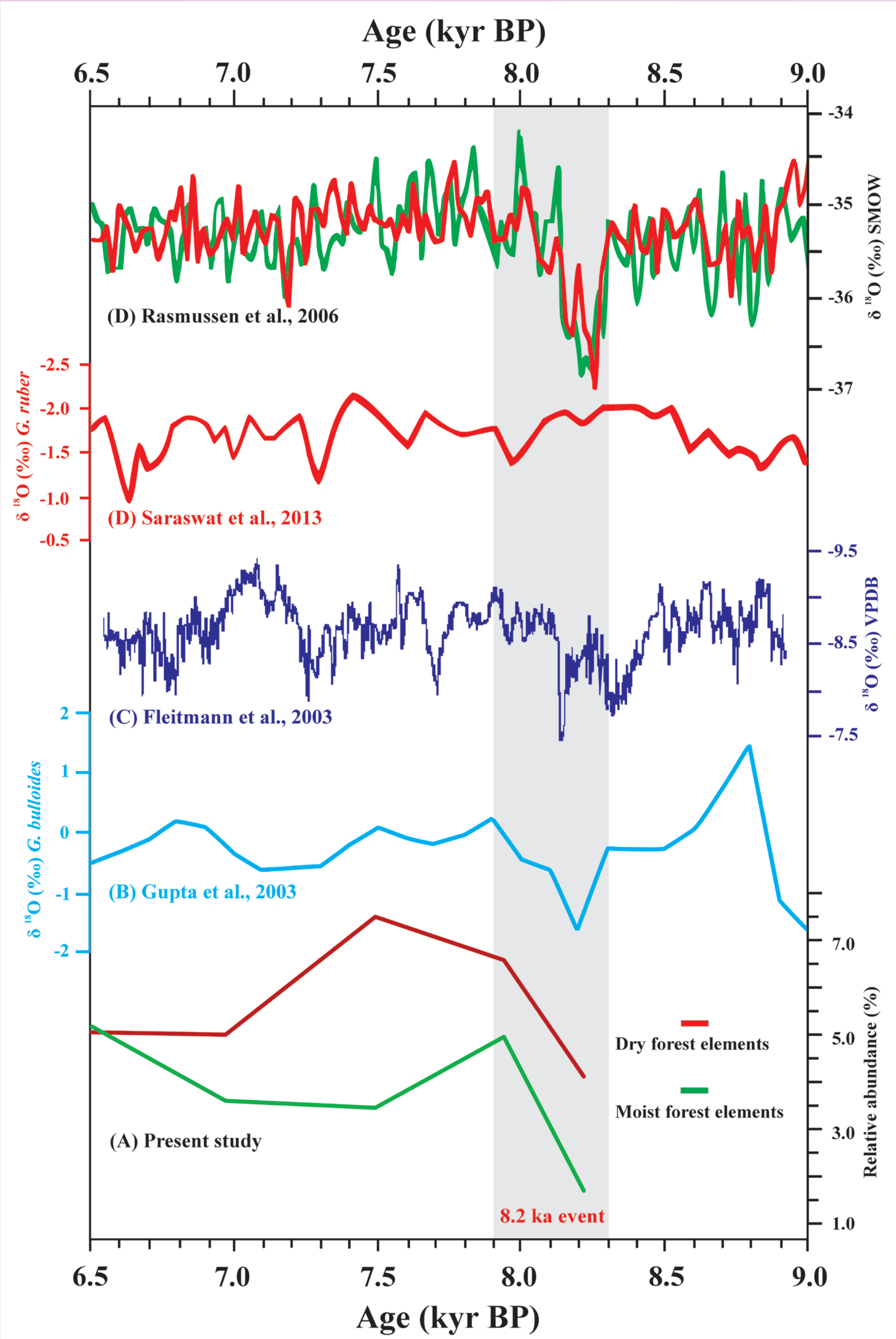

Figure 5. The weakening of the monsoon at 8.2 kyr BP and its correlation with the present study. (A). Present study, and correlation with other studies. (B) Abundance changes in *G. bulloides* from the Arabian Sea (Gupta et al., 2003). (C). $\delta^{18}O$ of Qunf Cave speleothem in South Oman (Fleitmann et al., 2003). (D). ***G.*** *ruber* $\delta^{18}O$ records from the off the Malabar Coast in the eastern Arabian Sea (Saraswat et al., 2013). (E). NGRIP (green) and GRIP (red) $\delta^{18}O$ ice (VSMOW) (Rasmussen et al., 2006).

and continuation of cereal-based agricultural practices in the region.

SIGNAL OF THE 8.2 KA EVENT

The earliest part of the record corresponds broadly with the timing of the global 8.2 ka event (Figures 4 & 5). Although a phase of weakened monsoon conditions is evident during this interval, the pollen record does not display a sharp or abrupt vegetation response comparable to that observed in North Atlantic climate archives. This muted signal may reflect regional buffering of monsoon systems, vegetation resilience, or limitations related to sampling resolution and pollen preservation. The findings suggest that the impact of the 8.2 ka event on the Indian monsoon system was likely complex and spatially variable, with weaker expression in central India compared to higher-latitude regions.

The "8.2 ka event", as a prominent, centennial-scale, abrupt cooling event, stratigraphically marks the end of the Greelandian (11.7–8.2 kyr BP; Early Holocene) and the beginning of the Northgrippian (8.2–4.2 kyr BP; Middle Holocene), due to the global or near global expression of the cited event. The cause of this prominent cooling has been linked to a glacial outburst flood of freshwater from Lake Agassiz thorough the Hudson Bay into the North Atlantic. Freshening of the North Atlantic may have resulted in diminished production of North Atlantic Deep Water (NADW) and a weakening of Atlantic Meridional Overturning Circulation (AMOC). The resulting decrease in ocean heat transport caused a southward shift of the Inter Tropical Convergence Zone (ITCZ) and weakening of monsoons in the Northern Hemisphere. However, high-resolution multi-proxy research is further required to be carried out from the study area in order to get clearer signal of the '8.2 ka' event.

IMPLICATIONS FOR CLIMATE–HUMAN INTERACTIONS

The persistence of cereal pollen (Figure 2) through much of the record indicates that human communities adapted to changing monsoon conditions by modifying land-use practices. Periods of stronger monsoon rainfall would have supported agricultural expansion, whereas later fluctuations may have encouraged changes in cropping patterns and settlement strategies. The study underscores the close coupling between monsoon variability, vegetation dynamics, and human activities in central India during the Holocene.

Reference

Prasad, N., Quamar, M.F., Tiwari, P., Thakur, B. and Sharma, A., 2026b. Vegetation dynamics, corresponding climate change and Indian Summer Monsoon variability during the Middle-to Late Holocene from the Core Monsoon Zone, India: Reflection of the 8.2 ka event?. Quaternary International, 756, p.110103.

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Tracing Oceans and Climate History Through Microfossils: The Earth's Tiny Storytellers

Shivani Pathak, Brijesh Kumar and Pawan Govil

OCEANS are a defining feature of our planet, covering most of its surface and appearing as a beautiful blue sphere from space. They contain about 97% of Earth's water, while less than 3% is found in glaciers, groundwater, lakes, and rivers. More than just vast bodies of water, oceans play a crucial role in regulating the global climate and weather (Figure 1).

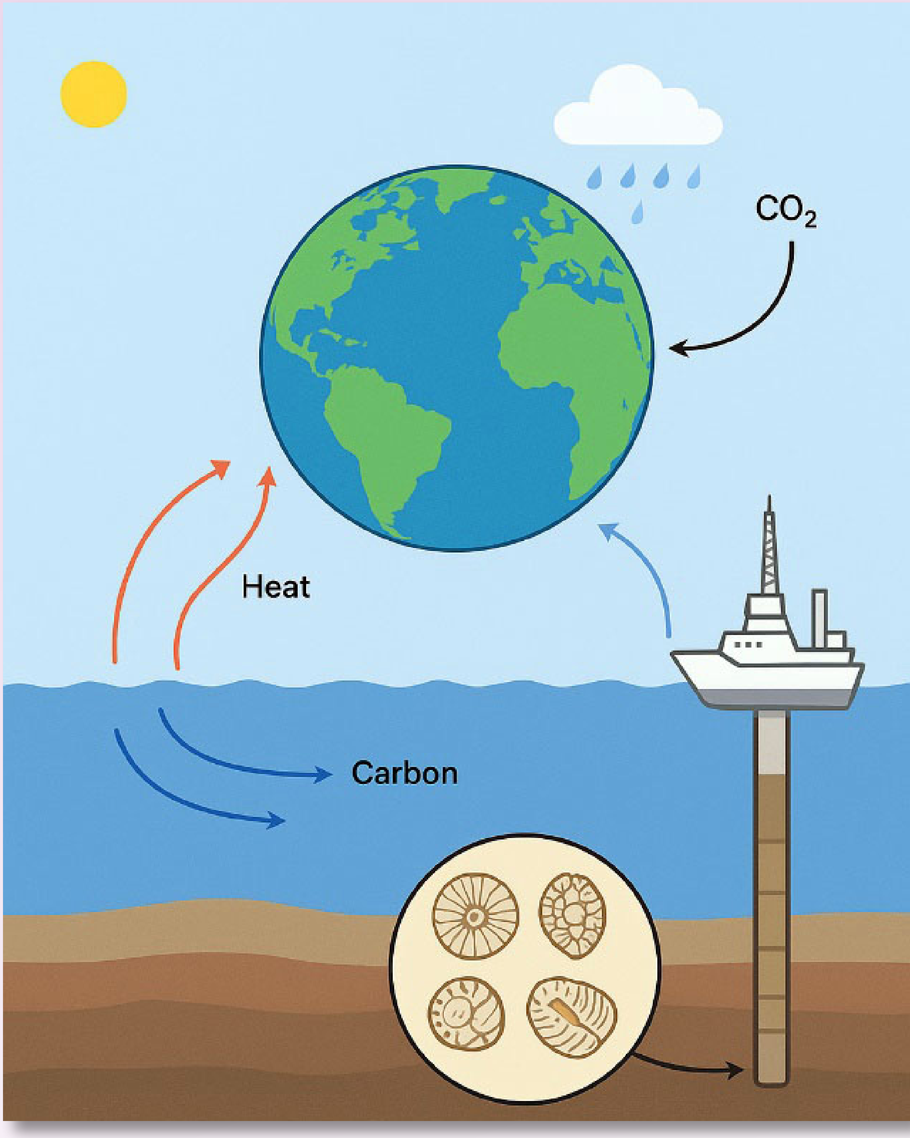

Figure 1. Interactions between the ocean and atmosphere, showing how oceans regulate Earth's climate by exchanging heat and carbon while storing evidence of past environmental change in microfossil-bearing sediments.

Ocean currents influence rainfall, monsoons, and land temperatures, impacting agriculture, fisheries, and freshwater availability. Healthy oceans are essential for sustaining life on the Earth. This raises an important question: How can we determine what changes occurred in the oceans thousands or even millions of years ago? Since we cannot travel back in time, scientists rely on natural clues that the Earth has preserved. One of the most important clues comes from microfossils, tiny remains of ancient ocean organisms that reveal the story of past climates and ocean conditions.

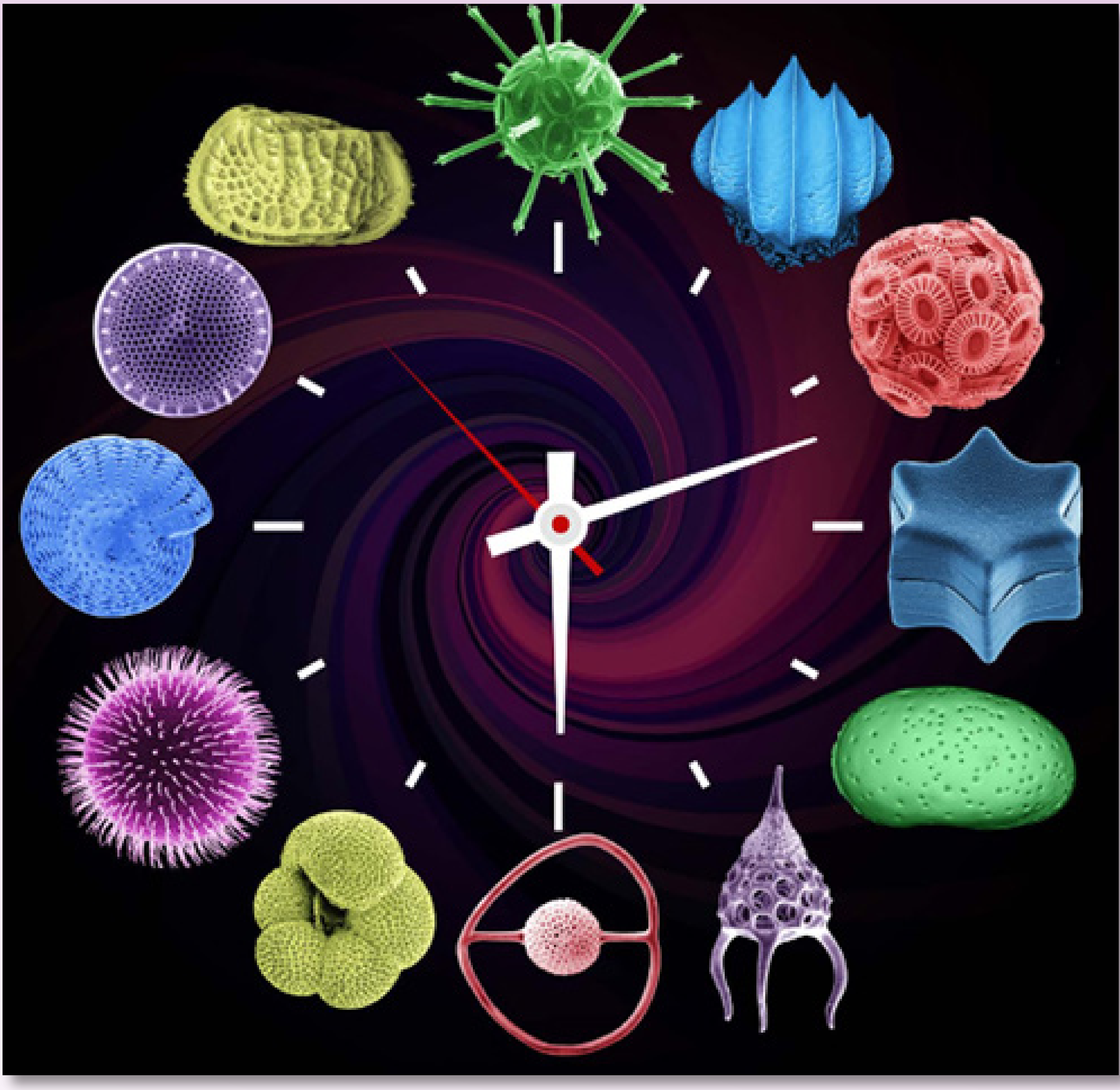

Figure 2. Images showing diverse marine microfossils from deep-sea sediments, including diatoms, ostracods, radiolarians, planktic and benthic foraminifera, and coccolithophores, are represented as a time machine (Oceanography, Vol. 33, No. 2, June 2020).

Microfossils, though microscopic, are invaluable to science. Found abundantly in ocean sediments, they evolve rapidly, allowing scientists to date sediment layers accurately. Each species thrived under specific environmental conditions: some in warm waters, others in cold or nutrient-rich regions. By analyzing microfossils from ocean cores, researchers reconstruct past changes in the ocean and climate. These tiny fossils act as natural time machines, preserving records of Earth's ancient environments. Understanding how oceans and climate behaved in the past helps predicts future changes. Oceans regulate Earth's climate, and microfossils, though unseen, reveal the planet's long, dynamic story of environmental evolution and transformation.

MICROFOSSILS: TINY CREATURES WITH BIG STORIES

Beneath the endless blue of the ocean lies a hidden world filled with microscopic fossils, known as microfossils, tiny remnants of ancient marine life that record Earth's history. A handful of ocean mud viewed under a microscope reveals countless shapes resembling footballs, snowflakes, flowers, or spinning tops. These beautiful structures act as time capsules, preserving clues about past oceans and climates. The concept of microfossils dates back to the 5th century B.C., when Herodotus described fossil shells called Nummulites in Egyptian pyramid stones, mistaking them for petrified lentils. With the invention of the microscope, scientists recognized them as marine remains. Today, microfossils are found in nearly all sediments, their types reflecting the age and environment of deposition. Geologists use them to determine a rock's age and depositional setting. Micropaleontology, the study of these tiny fossils, plays a crucial role in research, oil exploration, and understanding the Earth.

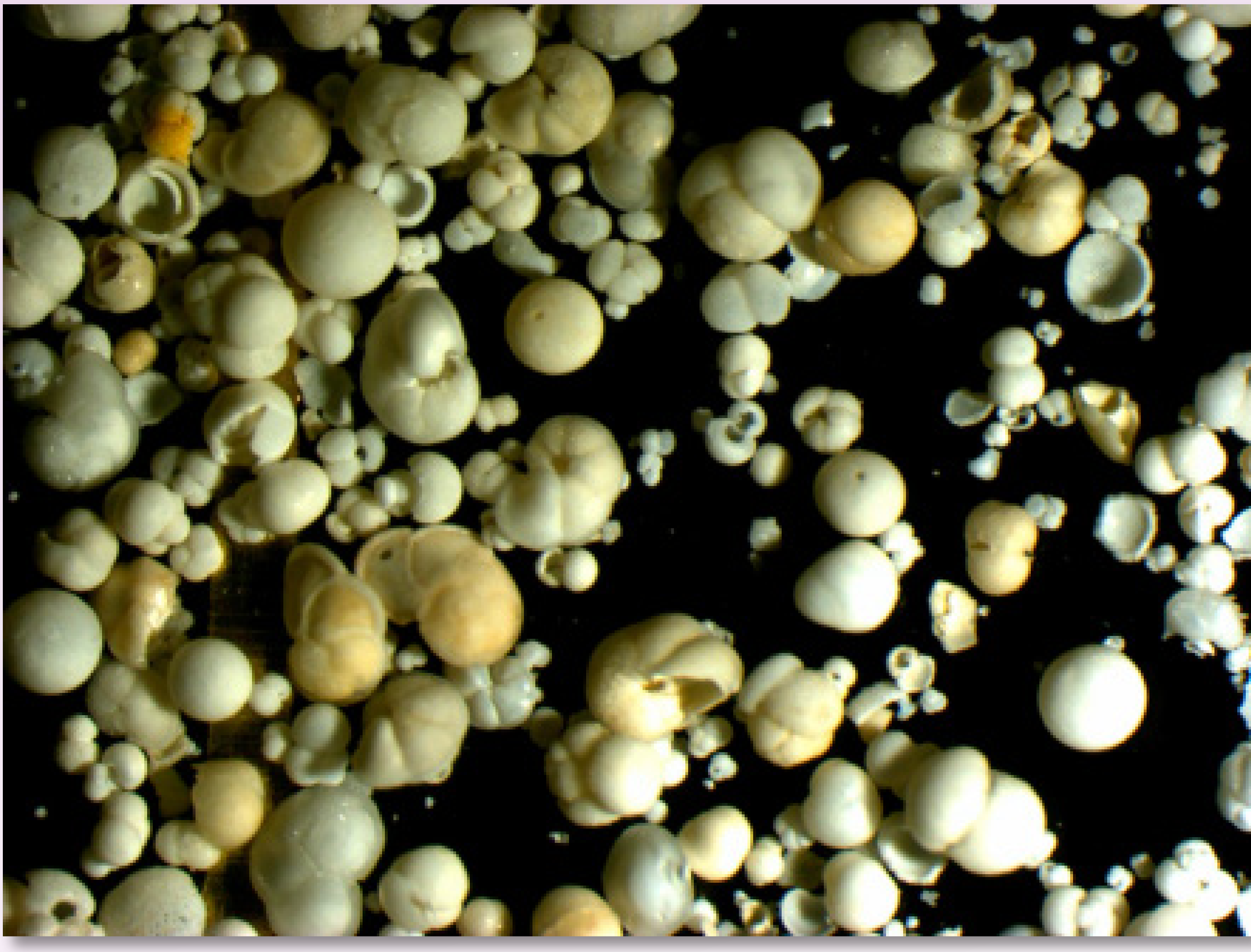

Figure 3. Different planktic foraminifera species seen under the microscope, showing their varied shell shapes, which are used in paleoceanographic studies.

DIFFERENT TYPES OF MICROFOSSILS

Microfossils can be classified in many ways by their biological origin, the material of their shells, or their ecological habits (Figure 2). Some of the most important and widely studied groups include:

- **Foraminifera (Forams):** Single-celled organisms with calcium carbonate shells. Planktic forams float, dating sediments and revealing surface ocean conditions. Benthic forams live on the seafloor, indicating bottom-water environments.
- **Calcareous Nannoplankton:** Tiny algae (coccolithophores) that produce exquisite calcium carbonate plates (coccoliths). They form chalk deposits (e.g., White Cliffs of Dover) and are vital for dating rocks and reconstructing ocean productivity.
- **Ostracods:** Small, clam-like crustaceans with a long fossil record. Found in various water bodies, they help reconstruct ancient water chemistry and salinity.
- **Pteropods:** Delicate "sea butterflies" whose aragonite shells are sensitive to acidity, making them indicators of ocean acidification and climate change impacts.
- **Spores and Pollen:** Microscopic plant remains that provide clues about ancient land vegetation and climate, even determining burial temperatures.

WHY MICROFOSSILS MATTER

Each group of microfossils offers a unique piece of Earth's puzzle. Together, they allow scientists to:

- Date rocks and sediments
- Reconstruct past climates and oceans
- Understand environmental changes
- Support industries

In short, microfossils are nature's storytellers, tiny yet powerful tools that record the evolution of life, oceans, and climate over millions of years.

FORAMINIFERA: THE OCEAN'S NATURAL KALEIDOSCOPE

The word *foraminifera* comes from two Latin roots: *foramen* (an opening) and *ferre* (to bear), referring to the small holes in their shells. Despite being single celled, foraminifera build intricate shells, or tests, using minerals or organic materials. These tests may consist of a single chamber or multiple chambers separated by thin walls called septa. Their shapes vary greatly: round, spiral, tubular, or even conical.

Foraminifera live throughout the world's oceans, both floating as planktic forms and living on the seafloor as benthic forms. Every year, they produce around 1.4 billion tons of calcium carbonate, contributing significantly to the ocean's carbonate sedimentation. When they die, their shells settle on the ocean floor, forming thick deposits known as calcareous ooze that blanket large areas of the seabed.

The fascination with foraminifera goes back centuries. Ancient scholars, such as Strabo observed large fossil forams (*Nummulites*) in Egyptian rocks. In the 17th century, Robert Hooke studied them under a microscope and described them in his famous book *Micrographia*. Later, Alcide d'Orbigny, a French naturalist, classified around 600 species and laid the foundation for modern foram taxonomy.

During the 19th century, ocean exploration revealed their global significance. John Murray, one of the scientists on the *Challenger Expedition*, discovered that much of the deep seafloor was covered with foraminiferal remains and that species diversity was highest in tropical regions and lowest near the poles.

Today, foraminifera are among the most powerful tools for scientists studying the Earth's history. Their fossils help date sediments, reconstruct past ocean and climate conditions, and reveal changes in sea-level, currents, and carbon cycles. In short, these tiny creatures not only build the ocean floor, but also hold the keys to unlocking our planet's environmental past.

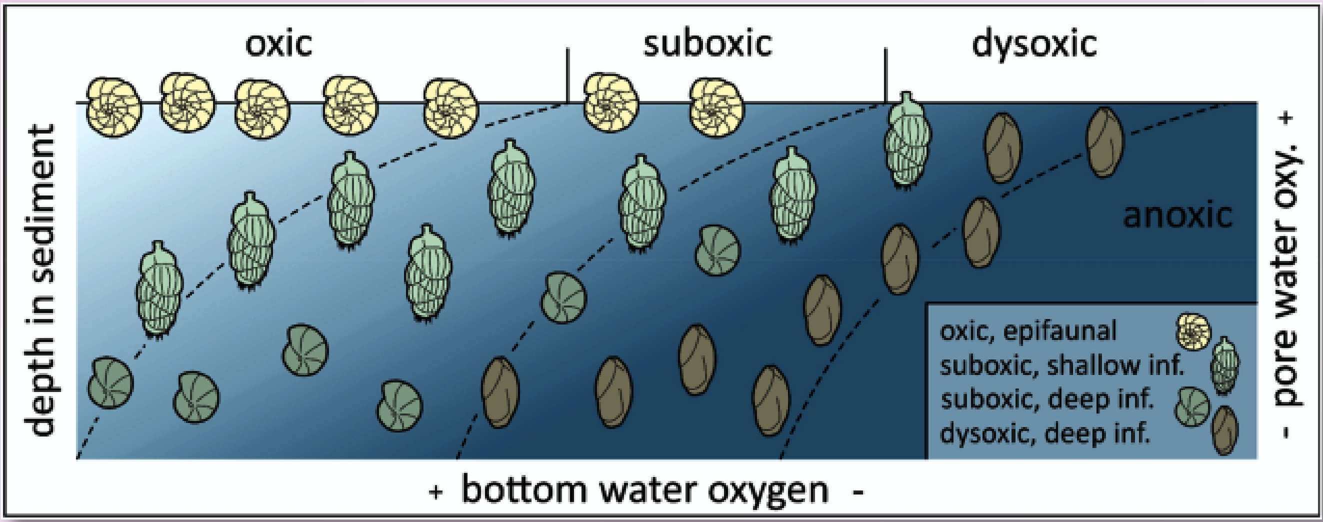

Figure 4. Oxygen model [(modified TROX model after Jorissen; modeled after Koho] combining bottom water oxygenation and pore water oxygenation using benthic foraminifers.

PLANKTIC FORAMINIFERA

Planktic foraminifera (Figure 3) float in the upper layers of the ocean and build beautiful spiral shells from calcium carbonate. Although each organism lives for only a few weeks, its contribution to the marine ecosystem is immense. Different species thrive under specific conditions some in warm, tropical waters, while others prefer cooler or nutrient-rich regions.

Due to their sensitivity to temperature, salinity, and nutrient levels, planktic forams serve as excellent indicators of environmental conditions. When they die, their shells sink to the seafloor, forming continuous layers of sediment that provide one of the best fossil records on Earth. These shells also transport carbon from the surface to the deep sea, thereby playing a crucial role in Earth's carbon cycle.

Applications of Planktic Foraminifera

- Dating sediments and biostratigraphy
- Reconstructing past climate (Paleoceanography)
- Tracing ocean currents
- Monitoring productivity
- Understanding the carbon cycle

BENTHIC FORAMINIFERA

Benthic foraminifera live on or within ocean sediments and have existed for over 500 million years. They are found everywhere from shallow coastal waters to the deepest ocean trenches. What makes them special is their ability to respond quickly to environmental changes, such as fluctuations in oxygen levels, food supply, and temperature. Their shells preserve chemical and structural information about the environment in which they lived. By studying them, scientists can reconstruct changes in deep sea oxygen levels, monsoon intensity, and ocean circulation through time.

Benthic forams display great diversity in shell composition:

- **Organic-walled forms** (like *Allogromiids*) have flexible shells.
- **Agglutinated forms** glue together sediment particles common in deep, carbonate-poor oceans.
- **Calcareous forms** produce shells from calcite or aragonite, including smooth porcelaneous and glassy hyaline types.

Ecologically, they are divided into:

- **Epifaunal forms**, which live on the sediment surface or attach to rocks.
- **Infaunal forms**, which burrow into sediments, sometimes several centimeters deep.

Applications of Benthic Foraminifera (shown in the Figure. 4)

- **Paleoenvironmental reconstruction**
- **Paleoclimatology**
- **Sea-level studies**
- **Carbon cycle research**
- **Biostratigraphy**
- **Environmental monitoring**

CONCLUSION

Microfossils may be invisible to the naked eye, but they are among the most powerful tools in Earth science. From tiny shells buried deep in ocean mud, scientists can read stories of vanished seas, ancient climates, and long-term changes in our planet's systems.

By studying microfossils, especially foraminifera, we gain a window into Earth's deep past and a guide to its uncertain future. These microscopic storytellers remind us that even the smallest forms of life can leave an everlasting mark on our planet's history.

About authors

Dr Shivani Pathak is currently working as a CSIR–Research Associate in the Marine Micropaleontology and Geochemistry Laboratory at the BSIP, Lucknow. Her research focuses on understanding tropical climate variability and paleoceanographic changes using planktic foraminifera and geochemical proxies.

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Dr Pawan Govil is a Senior Scientist (Scientist-F) at the BSIP, Lucknow. His expertise lies in paleoceanography, its geochemistry, and paleoclimate reconstruction. His research integrates elemental and isotopic proxies to understand past climate and ocean dynamics.

Diatom Evidence of Monsoon-Driven Environmental Changes from Tuman Lake, Core Monsoon Zone of India

Shivansh Saxena and Biswajeet Thakur

DIATOMS are siliceous microalgae that respond rapidly to changes in limnological and climatic conditions, making them sensitive indicators of past environmental variability. Their species composition, abundance, and preservation in lake sediments reflect key ecological parameters, such as water depth, salinity, nutrient availability, pH, and hydrological balance, all of which are strongly influenced by monsoon-driven precipitation.

India is basically a monsoon-driven subcontinent and the major contribution of the rainfall is brought by southwest monsoon (SWM) primarily. In monsoon-dominated regions, such as the Core Monsoon Zone of India is a climatically stable belt over central India that receives the bulk of Indian Summer Monsoon rainfall and plays a pivotal role in regulating the country's hydroclimate. Extending across eastern Rajasthan, Madhya Pradesh, Chhattisgarh, Maharashtra, Odisha, Telangana, and parts of Uttar Pradesh and Gujarat, the CMZ accounts for nearly half to two-thirds of India's seasonal monsoon precipitation. Rainfall in this zone is mainly controlled by the position and strength of the monsoon trough and the westward movement of low-pressure systems and monsoon depressions originating in the Bay of Bengal, supplemented by moisture transport via the Arabian Sea low-level jet. The CMZ exhibits comparatively low interannual variability but strong intraseasonal active–break cycles, making it the backbone of the Indian Summer Monsoon system. Owing to its sensitivity to monsoon intensity, the CMZ is also a key region for diatoms study in context of limnology, palaeolimnology and palaeoclimate studies, where sedimentary, biological, and geochemical proxies effectively record past monsoon fluctuations.

Diatoms provide valuable insights into fluctuations in effective moisture, lake-level changes, and shifts between fluvial and lacustrine conditions. The variations in planktonic and benthic diatom taxa are particularly useful for distinguishing phases of intensified monsoon rainfall from periods of reduced precipitation and hydrological stress. Diatom-based palaeoenvironmental reconstructions from lake archives offer a robust framework for assessing the response of freshwater ecosystems to Indian Summer Monsoon variability during the Holocene Epoch. The study utilizes diatom assemblages from the Tuman Lake sediments to reconstruct past environmental conditions and to evaluate their implications for monsoon dynamics and regional hydroclimatic evolution within the Core Monsoon Zone of India. Tuman Lake (TL) is located at 22º 34' 15.1" N and 82º 24' 54.9" E (elevation 372 m a.s.l.) (Figure 1). It is positioned 10 kilometers from Katghora town, which lies 30 kilometers northwest of the district headquarter (Korba city), of the Korba District, Chhattisgarh, Central India.

A total of 30 sediment samples were analyzed for diatom content from a 120 cm long sediment profile of Tuman Lake. Diatoms, which are siliceous microalgae and highly sensitive to changes in hydrology, water chemistry, and nutrient status, were recorded in eight samples, and their taxonomic composition and distribution are illustrated in the diatom plate (Figure 2). The diatom assemblage is

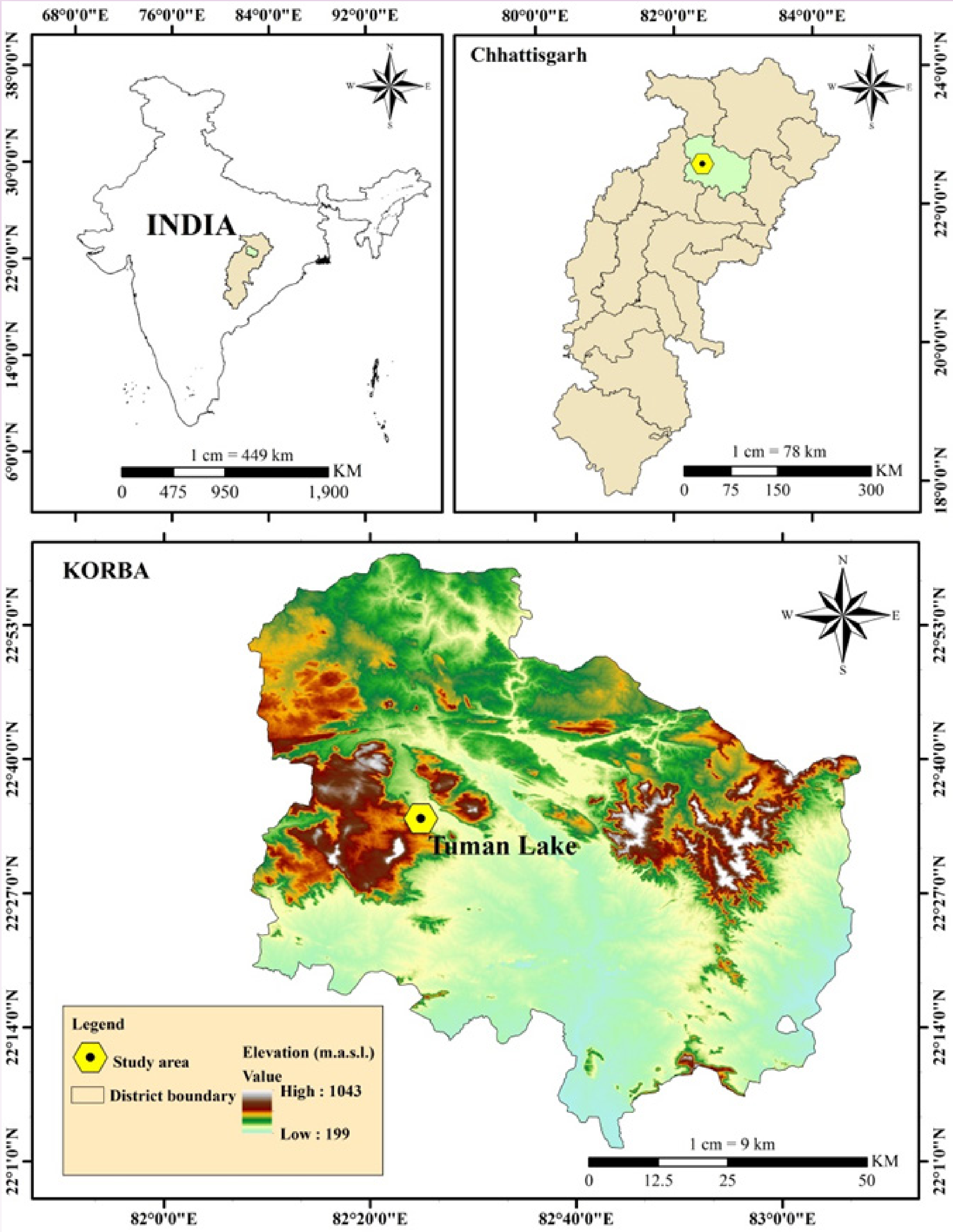

Figure 1. Location map of the study area showing (a) the geographical position of Tuman Lake within India, (b) its location in the state of Chhattisgarh, and (c) a detailed topographic map of Korba District highlighting the position of Tuman Lake. The elevation map illustrates regional relief (199–1043 m a.s.l.).

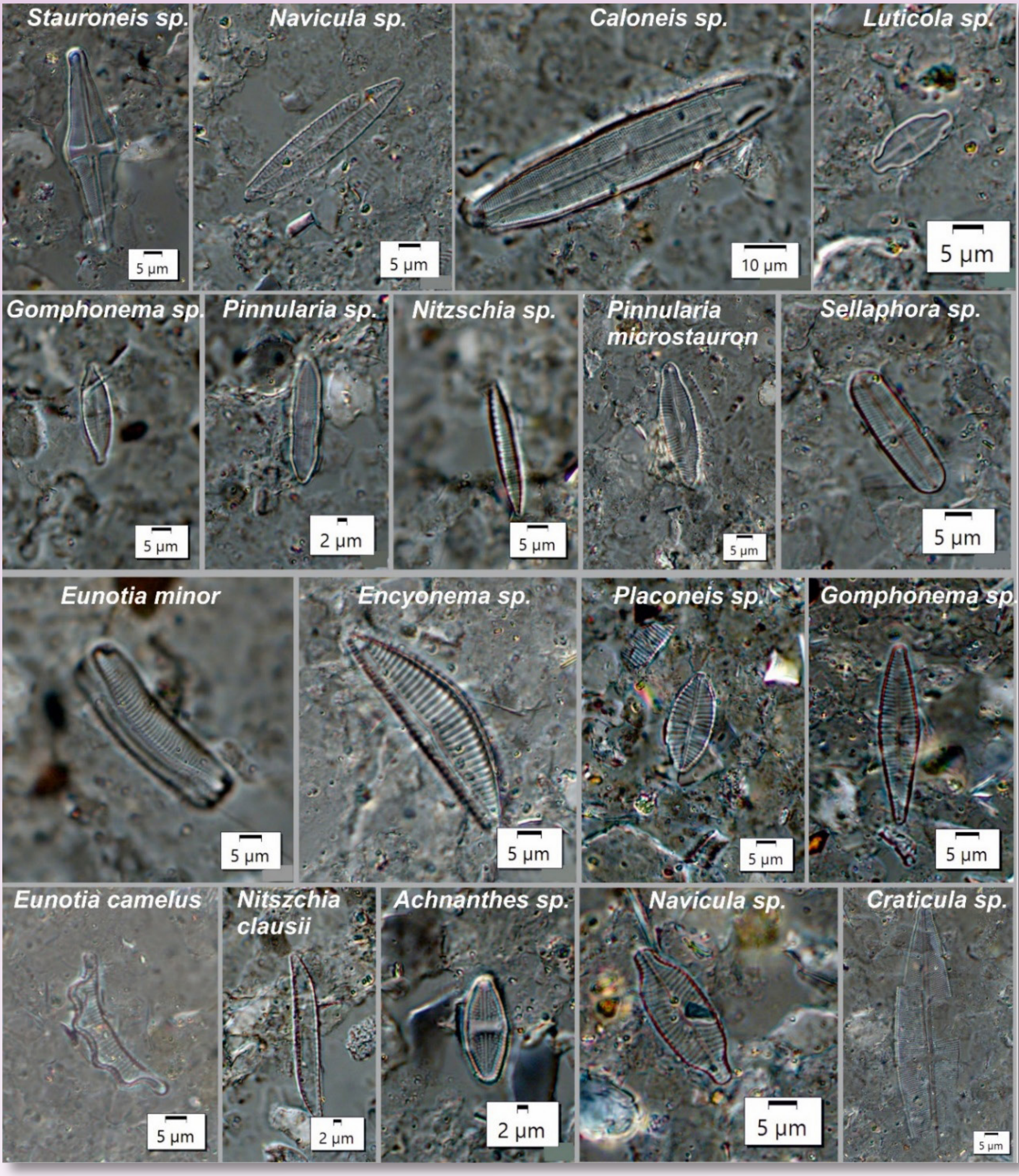

Figure 2. Light micrographs showing dominant and associated diatom taxa recovered from the sediments of Tuman Lake, Korba District, Chhattisgarh (Core Monsoon Zone of India). The assemblage comprises *Stauroneis*, *Navicula*, *Caloneis*, *Luticola*, *Gomphonema*, *Pinnularia*, *Nitzschia*, *Sellaphora*, *Eunotia*, *Encyonema*, *Placoneis*, *Achnanthes*, and *Craticula*, reflecting a range of ecological preferences.

dominated by benthic forms, with comparatively low representation of planktic taxa, indicating limited open-water conditions during most phases of sediment deposition. The dominant diatom genera identified in the lake sediments include *Nitzschia*, *Pinnularia*, *Navicula*, *Eunotia*, and *Gomphonema*, taxa commonly associated with shallow freshwater environments. Several other taxa such as *Frustulia*, *Luticola*, *Stauroneis*, *Achnanthes*, *Synedra*, *Achnanthidium*, *Sellaphora*, *Caloneis*, *Encyonema*, and *Planothidium* occur in low abundances, while sporadic occurrences of *Diploneis*, *Neidium*, *Amphora*, *Surirella*, *Anomoeoneis*, and *Cocconeis* are also observed. Planktic diatoms are represented by *Discostella* and *Cyclotella*, though their presence is restricted to low counts, further emphasizing the dominance of benthic habitats within the lake system.

The predominance of benthic diatoms over planktic forms suggests that Tuman Lake remained shallow for much of its depositional history or experienced pronounced seasonal fluctuations in water level. The presence of taxa, such as *Eunotia* and *Gomphonema*, known for their sensitivity to water chemistry, indicates slightly acidic to near-neutral pH conditions, potentially influenced by groundwater contributions and the surrounding geological setting. The occurrence of sporadic taxa, together with the diversity of low-abundance genera, reflects dynamic hydrological conditions, possibly linked to seasonal monsoon-driven flooding and intermittent dry phases that periodically exposed the lake margins and substratum.

The diatom assemblages from Tuman Lake indicate a predominantly shallow and hydrologically dynamic lacustrine system, characterized by strong benthic productivity supported by sustained light penetration and periodic substrate exposure. The taxonomic composition points towards mesotrophic to mildly eutrophic conditions, implying moderate nutrient availability, likely derived from catchment runoff and localized organic inputs during monsoon phases. The rapid ecological response and excellent preservation in sediments, diatoms provide a reliable record of past limnological and hydrological conditions. The low abundance of planktic taxa, coupled with the dominance of benthic and tychoplanktonic forms, reflects fluctuating water levels and seasonally controlled limnological conditions. The presence of environmentally sensitive genera, along with sporadic occurrences of several taxa, points to short-term hydrological variability linked to active and weak phases of the Indian Summer Monsoon. The diatom-based reconstruction underscores the sensitivity of Tuman Lake to monsoon variability and highlights its potential as a valuable archive for understanding palaeoenvironmental and hydroclimatic changes within the Core Monsoon Zone of India.

About authors

Mr Shivansh Saxena is pursuing Ph.D. program at BSIP, Lucknow. His research focuses on limnological and sedimentary organic matter characterization from the Central Ganga Plain and Core Monsoon Zone of India, during the Late Quaternary.

Dr Biswajeet Thakur is currently serving as Scientist 'F' at the BSIP, Lucknow. His research focuses on multi-proxy approaches to investigate past climate variability across diverse geographical settings, particularly the western and eastern coastal margins of India.

Tracing Monsoon Variability through Archaeological Seeds of Central India

Ruchita Yadav, Mohammad Firoze Quamar and Anil K. Pokharia

ARCHAEOBOTANY, the study of ancient plant remains recovered from archaeological settings, provides a direct line of evidence for reconstructing past human- plant relationships, encompassing diet, palaeoenvironment, exploitation of floral wealth, origin, domestication, diffusion and diversification, cropping pattern, medicinal practices. Plant remains, most commonly preserved through charring or waterlogging, enable detailed reconstructions of past subsistence strategies, agricultural practices, vegetation history, and domestication processes, thereby offering insights into how human societies interacted with and adapted to their environments.

Within the Indian subcontinent, these human-environment interactions were profoundly influenced by the Indian Summer Monsoon (ISM), the primary climatic system governing rainfall patterns and agricultural productivity. Variations in monsoon intensity directly affected crop choices, sowing schedules, yield stability, and the balance between rain-fed and irrigated agriculture. Even relatively minor fluctuations in the ISM have historically triggered significant changes in food production, economic resilience, and social organization, with cascading effects on settlement stability, population dynamics, and cultural development (Pokharia et al. 2020, 2024).

By integrating archaeobotanical data with an understanding of long-term ISM variability, it becomes possible to contextualize agricultural decision-making and adaptive strategies adopted by past societies during the Holocene. Changes in crop spectra, the adoption of drought-tolerant or water-demanding species, shifts between C_3 and C_4 crops, and evidence for agricultural intensification or diversification can be directly linked to monsoon-driven hydroclimatic conditions. Thus, archaeobotany provides a direct window into past agricultural practices and their relationship with climate variability.

The archaeological site, Nagardhan (Lat. 21.3370° N; Long. 79.3158° E) is situated in Vidarbha region near Nagpur, Maharashtra, India (Figure 1), offers an important case study. Vidarbha experiences some of the highest monsoon variability in India, and has historically supported prosperous agrarian societies. Nagardhan, the capital of the Vakataka dynasty and earlier associated with Satavahana rule, preserves a long cultural sequence spanning from the Early Historic to Late Historic periods (400 BCE–1900 CE). This temporal depth allows for an assessment of how agricultural strategies responded to major climatic events, such as the Roman Warm Period (RWP), Medieval Warm Period (MWP), and Little Ice Age (LIA). Multiproxy paleoclimate records from central India indicate strengthened ISM conditions during the during the RWP (300 BCE–600 CE) and MWP (600–1200 CE), characterized by warm and humid climates. These phases broadly coincide with periods of political consolidation, urbanization, and economic expansion in the subcontinent, including the Mauryan, Satavahana, and Gupta periods. Conversely, the LIA (1200–1900 CE) was marked by weakened monsoon rainfall, increased aridity, and heightened climatic instability, conditions that correlate with economic stress, political decline, and recurrent famines. (Uberoi 2012).

Archaeobotanical evidence from Nagardhan reflects these climatic oscillations with remarkable clarity. During the Early Historic and Historic periods, when monsoon conditions were relatively strong, agricultural systems were diversified and dominated by large-grained cereals, such as rice,

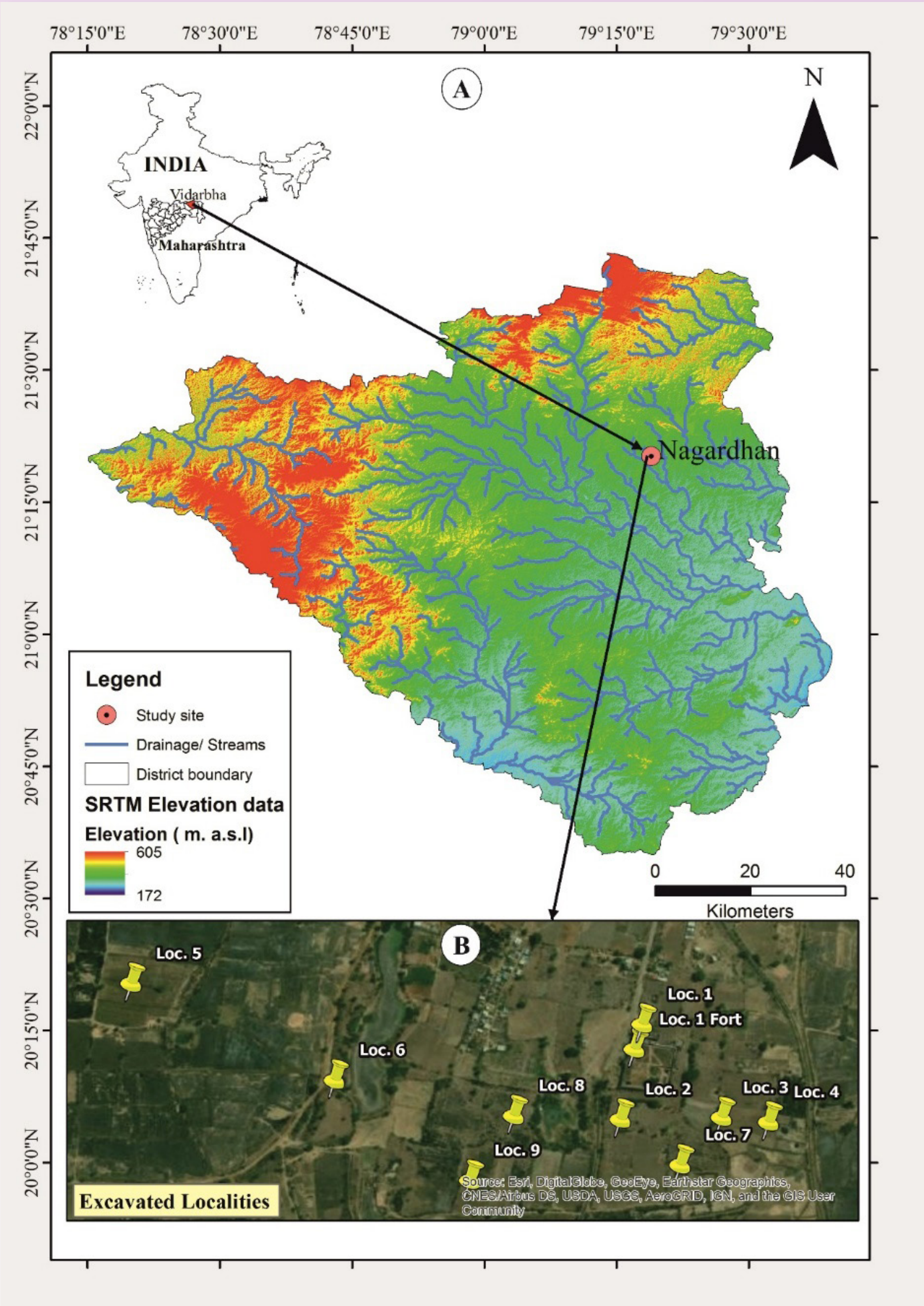

Figure 1. Map of India showing Vidharba region, archaeological site Nagardhan (A) and excavated localities (B).

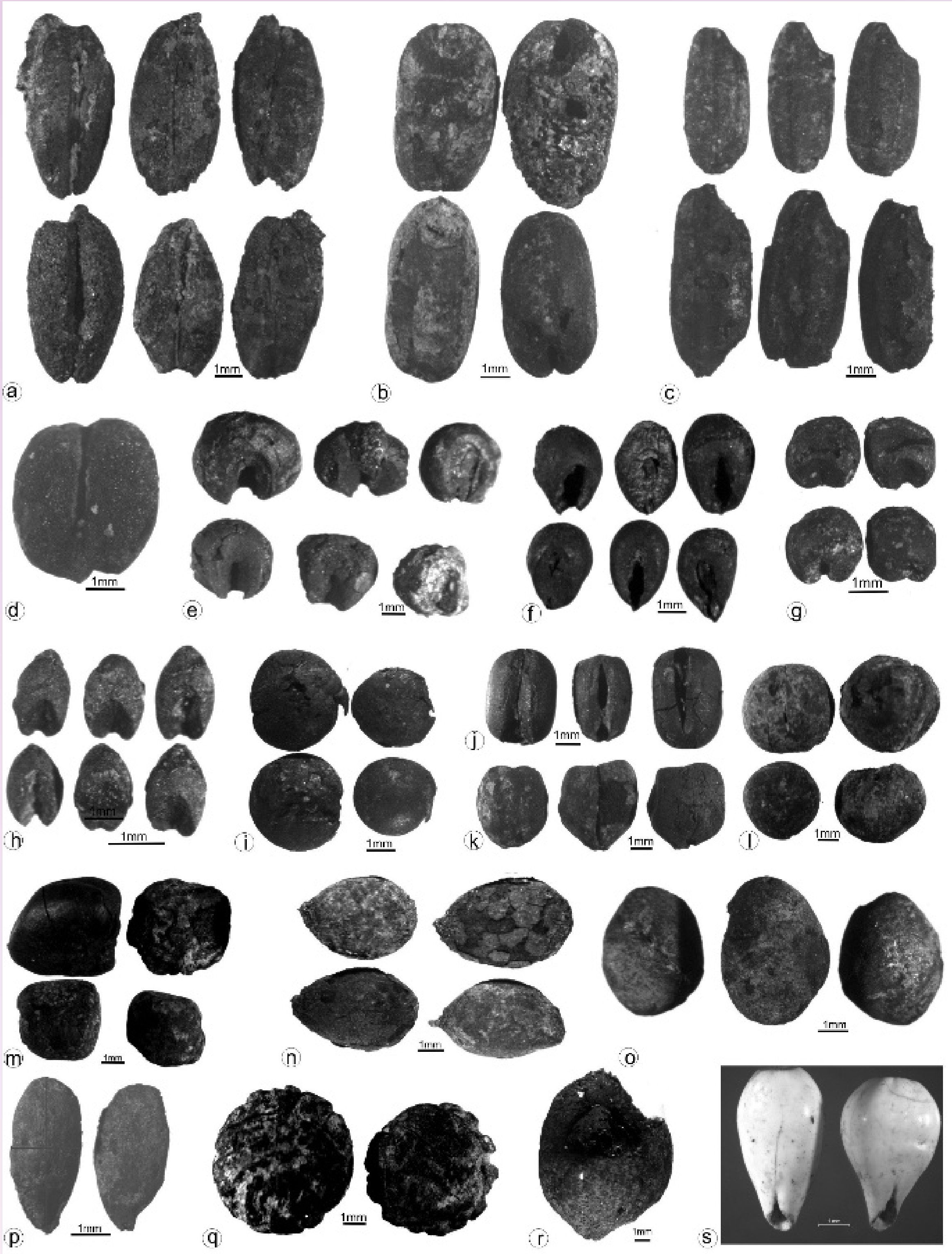

Figure 2. Selected botanical remains from Nagardhan archaeological site: a. *Hordeum vulgare*, b. *Triticum aestivum*, c. *Oryza sativa*, d. *Triticum sphaerococcum*, e. *Sorghum bicolor*, f. *Pennisetum glaucum*, g. *Paspalum scrobiculatum*, h. *Setaria* sp., i. *Lens culinaris*, j. *Vigna radiata*, k. *Cicer arietinum*, l. *Pisum arvense*, m. *Lathyrus sativus*, n. *Gossypium arboreum/ herbaceum*, o. *Lablab purpureus*, p. *Linum usitatissimum*, q. *Ziziphus* sp., r. *Terminalia* sp., s. *Coix lachryma-jobi*

wheat, and barley, along with a wide range of pulses, oilseeds, and fibre crops (Figure 2). Rice**,** in particular, formed the staple crop, indicating the availability of adequate water resources and stable hydrological conditions. This mixed cropping system, incorporating both winter and summer crops, points to agricultural intensification and surplus-driven economies during phases of enhanced ISM rainfall.

Continuity in crop choice and subsistence strategies is evident through the Historic period,

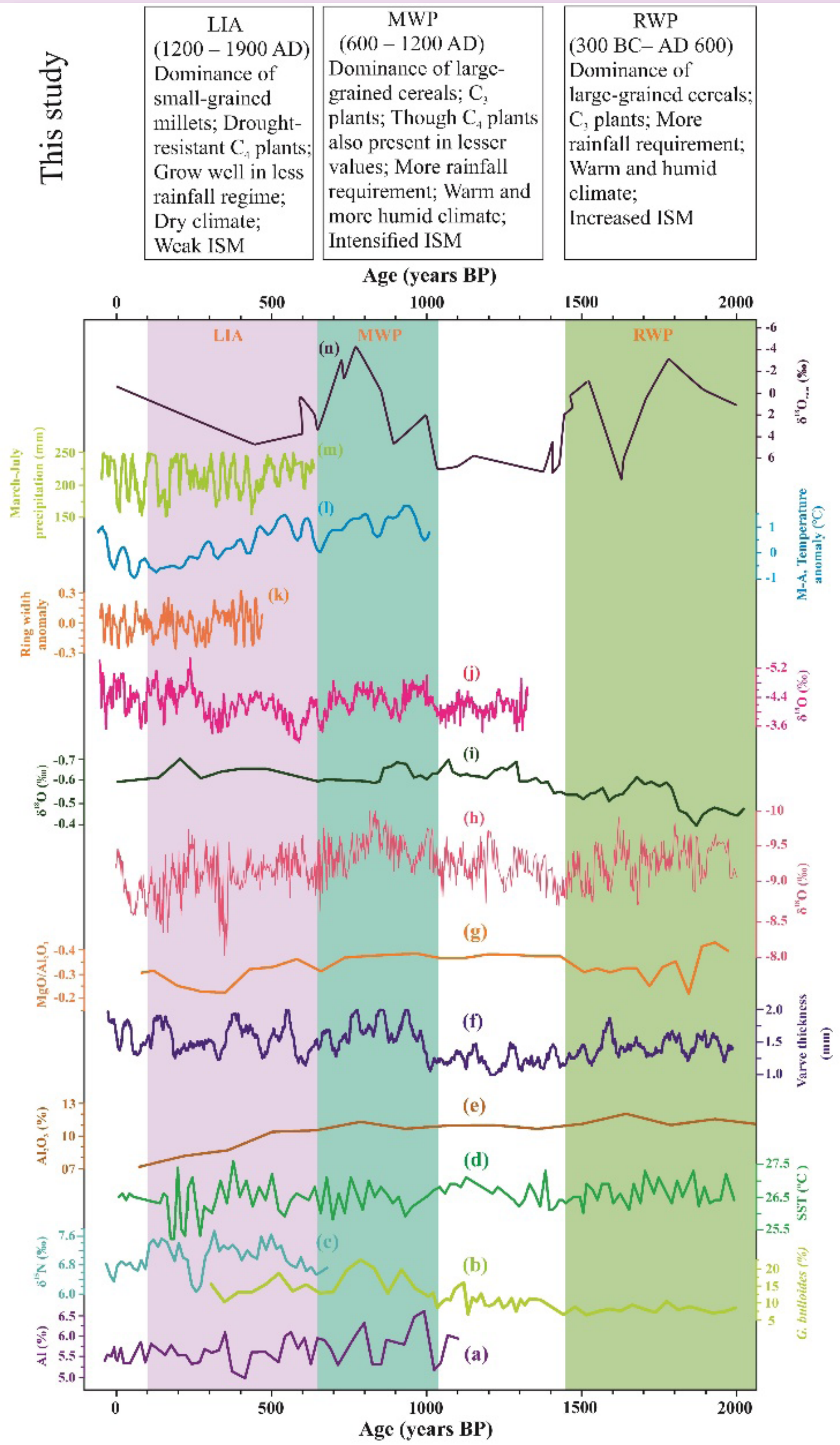

Figure 3. Summary diagram showing the ISM variability recorded during global climate events, such as RWM (300 BCE/BC–AD/CE 600; 2250–1300 years BP), MWP (600–1200 AD/CE; 1300–750 years BP) and LIA (1200–1900 AD/CE; 750–50 years BP) in the present study, and comparison of globally accepted climate anomalies during the Roman Warm Period (RWP; 2500-1650 years BP), the Medieval Warm Period (MWP; 1050-650 Years BP) and Little Ice Age (LIA; 650-100 years BP), recorded from (a). the Eastern Arabian Sea (Agnihotri et al., 2002) (b). North-west Arabian Sea (Gupta et. al., 2005); (c). Eastern Arabian Sea (Agnihotri et al., 2008); (d). NE Arabian Sea (Doose-Rolinski et al., 2001); (e). Diu Island (Banerji et al., 2017); (f). NE Arabian Sea (Von Rad et al., 1999); (g). Rohisa, Gujarat (Banerji et al., 2019); (h). Speleothem δ18O record of the Sahiya Cave, Uttrakhand (Kathayat et al., 2017); (i). Andaman Island (Laskar et al., 2013); (j). Jhumar Cave, Chhattisgarh (Sinha et al., 2011); (k). Teak (*Tectona grandis*) tree ring width records from Kerala (Borgaonkar et al., 2010); (l). HPJ, Himachal Pradesh (Yadav et al., 2011); (m). Purbani, Himachal Pradesh (Singh et al., 2009) and (n) Vadnagar Archaeological Site, Gujarat, India (Sarkar et al., 2024).

corresponding to the MWP, when warm and humid conditions further supported cereal-based agriculture. High proportions of rice and wheat at Nagardhan and other contemporary sites in North West India highlight the resilience and productivity of agrarian systems under favorable monsoonal regimes (Pokharia et al. 2020, 2024).

A pronounced shift is observed during the Late Historic period, coinciding with the LIA. Archaeobotanical assemblages from this phase show a sharp decline in crop diversity and a dominance of small-grained millets, particularly drought-resistant C_4 crops, such as *Sorghum bicolor* and *Pennisetum glaucum*. This transition reflects an adaptive response to declining rainfall and increased aridity. Millets, being hardy and less water-dependent, became central to subsistence strategies during prolonged monsoon failure. Similar patterns of millet intensification during the LIA have been documented from other regions of India, reinforcing the broader climatic control on agricultural decision-making (Pokharia et al. 2014, 2020, 2024).

The long-term archaeological record of central India demonstrates that agricultural communities were not passive recipients of climate stress. Instead, they actively restructured their cropping systems in response to changing monsoonal conditions. Periods of increased rainfall encouraged crop diversification and the dominance of water-demanding cereals, while phases of climatic deterioration prompted a strategic shift toward resilient, drought-tolerant crops.

In summary, the archaeobotanical evidence from Nagardhan illustrates a strong linkage between ISM variability and agricultural adaptation over the last two millennia. (Figure 3). The observed transitions in crop composition underscore the role of climate as a key driver of subsistence strategies, economic stability, and cultural resilience in central India. These findings highlight the capacity of past societies to adapt to long-term climate variability through flexible agricultural practices a lesson of continued relevance in the context of contemporary climate change.

Reference

Patel, H., Yadav, R., Sontakke, V.G., Vaidya, S., Ganvir, S., Quamar, M.F., Morthekai, P., Tang, L., Swaroop, M., Srivastava, A. and Spate, M., 2026. Evaluating the Indian Summer Monsoon intensity using archeological seeds from early–late historic Vidarbha, Central India. The Holocene, 36(1): 80-94.

About authors

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Dr Mohammad Firoze Quamar is Scientist-E at the BSIP, Lucknow. His research interests mainly include the reconstruction of ISM-driven vegetation dynamics and contemporary climate change during the late Quaternary in the CMZ of India, as well as in the Himalaya, Western Ghats and Western India. He also takes keen interest in studying Non-Pollen Palynomorphs (NPPs), especially the Spores of Coprophilous Fungi (SCF), as well as in aerobiology and melissopalynology.

Dr. Anil K. Pokharia is Scientist-F at the BSIP Lucknow. His research interest mainly includes investigation of agriculture origin, cropping pattern, diffusion and diversification of crops during Neolithic, Indus valley civilization, Chalcolithic, Iron Age, Early historic and Medieval periods in ancient India.

GENERAL ARTICLE

Rings of Resilience:
What Trees Remember About Our Past

Anwesha Sarkar, Arushi Kumar, Devi Lal, Wagmare Balraju, Pushpendra Pandey, Avanish Mishra, Amalava Bhattacharyya and Mayank Shekhar

PROLOGUE: THE FOREST THAT REMEMBERS

DEEP in the silence of the Himalayas, a centuries old deodar tree stands guard. It has no voice, yet it holds the perfect memories. It remembe rs the severe drought that parched the soil, the forest fire that swept through the valley leaving scars on its bark. They remember climatic events better than any human record. Deep inside trees like these, deodar, pine, and even tropical giants like teak, lies nature's hard drive: the tree rings. While human records go missing, the trees have been diligently writing its autobiography, one ring at a time. Dendrochronology,

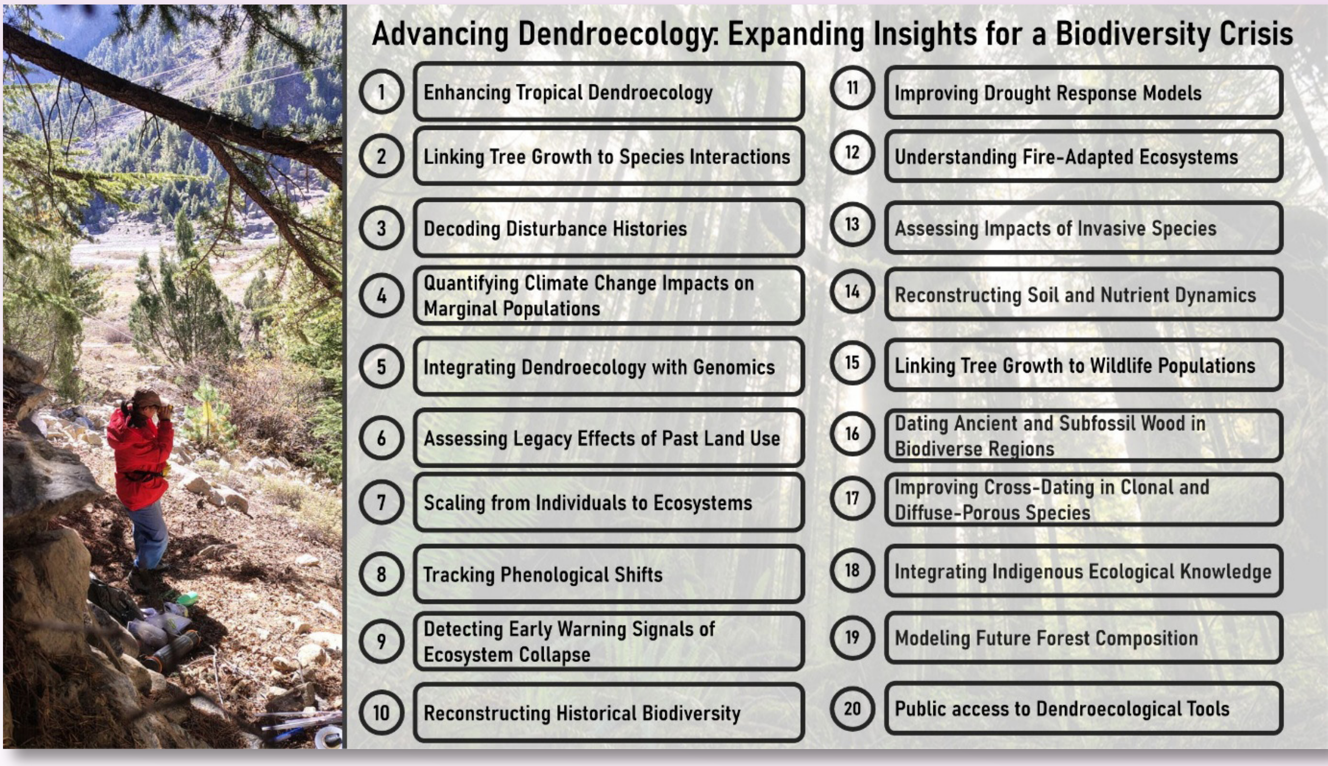

Figure 1. Advancing dendroecology for biodiversity conservation. Conceptual overview illustrating key research frontiers where tree-ring science informs biodiversity dynamics and ecosystem management, including tropical dendrochronology, species interactions, disturbance histories, climate-change impacts on marginal populations, genomics integration, land-use legacies, cross-scale modeling, phenological shifts, early warning signals, and the democratization of dendroecological tools for locally led, globally relevant conservation.

the science of dating these annual growth layers in woody plants, uncovers environmental stories in ecology, climate, landforms, and even archaeology. This is the essence of Dendroecology. It is the science of reading these "silent archives", the annual growth rings hidden inside tree trunks to understand not just the tree's history, but also the history of the entire ecosystem. For over a century, scientists have used tree rings to reconstruct past climates. But as Earth faces unprecedented pressures from habitat loss and climate change, scientists are turning to these wooden scrolls for a new purpose: to save the future. Below, we explore 20 crucial research frontiers where dendroecology can guide biodiversity conservation, transforming trees from passive victims of change into active narrators of resilience. To make sense of this vast landscape, we have grouped these frontiers into three stories: **The Climate Diary**, **The Web of Life** and **Tools for Tomorrow**.

I. THE CLIMATE DIARY: DECODING STRESS AND DISTURBANCE

Trees are long-term environmental journalists. They record every storm, fire, and dry events they survive. By reading these records, we can predict future stresses.

1. Enhancing Tropical Dendroecology: Most tree ring research has been conducted in temperate regions where annual rings are clearly visible. However, tropical forests contain the highest biodiversity, and many tropical species form indistinct or irregular rings. Developing reliable dating methods for these trees is essential to understand how rainforest ecosystems respond to climate stress.

2. Decoding Disturbance Histories: Tree rings serve as vital historical records, documenting significant geological and biological events, including fires, droughts, insect outbreaks, and storms. By analysing tree rings, researchers can reconstruct detailed timelines of these disturbances, enabling them to understand the conditions of forests prior to human impact. This information is essential for establishing natural reference conditions, which are crucial for restoring ecosystems to a state that aligns with the actual ecological history, rather than relying on arbitrary historical snapshots influenced by recent human memory.

3. Quantifying Climate Change Impacts on Marginal Populations: Trees located at the edges of their geographical ranges, such as alpine and desert species, act as biodiversity indicators, termed biodiversity sentinels. These trees are particularly vulnerable to climate change, often being the first to show stress and decline in response to environmental shifts. Dendroecology, plays a crucial role in understanding the causes and time of the decline of these sensitive species. By analysing the tree ring records, researchers can inform and guide targeted conservation efforts to protect those species from the risk of extinction due to changing climatic conditions.

4. Detecting Early Warning Signals of Ecosystem Collapse: Slowing growth rates, increased variability, and loss of growth synchrony in tree rings may signal approaching ecological tipping points in forests. These changes suggest that a significant number of trees may experience slower or uneven growth, indicating a potential decline. Tree rings serve as early warning systems, providing alerts years before any visible damage. By identifying these increased variability and repeated growth failures, forest management can implement preventive measures to mitigate visible declines, which will further aid conservation efforts.

5. Improving Drought Response Models: Not all trees show uniform responses to drought conditions, which highlights the importance

of dendroecology in identifying specific vulnerabilities among tree species or sites. Some species demonstrate greater resilience during dry years, thus, necessitating a targeted approach to conservation and management. Tree rings serve as a crucial tool in determining which trees are best suited for protection or should be introduced in areas prone to drought. The analysis of tree rings reveals significant differences in species' reactions to water scarcity, allowing for informed species selection in regions affected by drought.

6. Understanding Fire-Adapted Ecosystems: In fire prone ecosystems like savannas and Mediterranean forests the analysis of tree rings provides vital information regarding historical fire intensity and frequency over centuries. This information is essential for designing prescribed burns, which aim to maintain habitat diversity and support species that depend on fire. Tree scars serve as indicators of the regularity and severity of past fires, which helps in informing the development of controlled burns that are safe and effective. The data derived from these fire scars aids in implementing scientifically-backed prescribed burning practices, crucial for managing fire dependent ecosystems.

7. Dating Ancient and Subfossil Wood in Biodiverse Regions: Floating tree ring chronologies that are not anchored to calendar years are commonly found in tropical regions and wetlands. Anchoring these chronologies to the calendar years enables the uncovering of centuries of ecological history in biodiversity rich areas. With the analysis of these tree ring chronologies, it is possible to correlate fallen or buried wood with living trees, allowing scientists to push ecological histories back by hundreds of years. This method of matching dead and buried wood with living tree chronologies extends ecological records significantly, offering insights into long-term ecosystem history beyond what can be directly observed.

8. Improving Cross-Dating in Clonal and Diffuse-Porous/complex Species: Diverse ecosystems with diverse trees have species with indistinct or complex ring structures like maples and eucalypts. The development of new imaging and analysis techniques enhances the field of dendroecology which will enable the scientists to accurately date these trees. This progress also enables the matching of fallen or buried wood with living trees, thereby extending the ecological history research hundreds of years into the past. Such advancements in technology are crucial for understanding the complexity of these ecosystems.

9. Modeling Future Forest Composition: By integrating growth responses to historical climate patterns with species distribution models, dendroecologists can predict the future viability of tree species and their associated ecosystems. This approach helps to analyze past growth in relation to climate data, thereby estimating which tree species are likely to endure more in changing conditions and identify potential shifts in forest locations. This provides insights about how species ranges in different forest structures and how they may evolve due to climate change.

II. THE WEB OF LIFE: INTERACTIONS AND BIODIVERSITY

Trees don't live alone. They compete for sunlight, share nutrients through fungi, and depend on animals. Their growth reflects these complex relationships.

10. Linking Tree Growth to Species Interactions: Trees don't live alone. They compete for sunlight, share nutrients through fungi, and depend on animals. Tree growth reflects competition, cooperation, and interactions with these neighbouring plants, fungi, and animals. Integrating tree-ring analysis with community ecology can reveal how changes in biodiversity influence forest functioning over time.

11. Integrating Dendroecology with Genomics: Combining tree-ring data with genetic analyses provides insights into how tree populations react to environmental stress. This integrated approach enables scientists to identify stronger families of trees that demonstrate greater resilience, which is crucial for adapting forests to changing climates. By pinpointing evolutionarily resilient lineages, conservation efforts can be made for breeding and assisted migration of these trees, enhancing the overall adaptability of forest ecosystems in these climate challenges.

12. Tracking Phenological Shifts: Tree rings do not capture the exact time of budburst or leaf fall, but they provide valuable isotopic and anatomical indicators, such as latewood density that can proxy the phenological changes. These markers reveal potential mismatches between plants and their mutualists, such as pollinators and seed dispersers indicating disruptions in their synchrony which can be possibly caused by the climate change. Thus, although trees do not directly log flowering or leaf-fall events their wood structure and chemical characteristics can serve as indicators of seasonal variations affecting the ecological relationships.

13. Reconstructing Historical Biodiversity: Tree rings serve as indirect indicators of past species richness by showcasing growth alterations linked to the loss of predators, declines in pollinators, or the extinction of keystone species. This concept, referred to as "dendro-biodiversity" which is used in establishing achievable restoration objectives. Researchers by analyzing these changes in tree growth, can identify periods of extinctions or key species declines, providing insights into the historical state of a "healthy forest". Such growth pattern variations effectively mirror past ecological shifts thereby aiding in the formulation of realistic conservation and restoration targets.

14. Assessing Impacts of Invasive Species: Long-term tree ring records reveal that invasives, such as bark beetles and fungal pathogens cause distinct scars and growth suppressions in tree rings. These records enable scientists to differentiate between natural outbreaks and human amplified invasions thereby informing biocontrol efforts. The presence of sudden growth damage in rings is indicative of the impact of invasive insects and diseases and recognizing these patterns allows researchers to identify whether ecosystem change is part of natural forest dynamics or the result of modern environmental pressures guiding more appropriate management and biosecurity responses

15. Reconstructing Soil and Nutrient Dynamics: Stable isotopes, such as $\delta^{15}N$ and $\delta^{13}C$ found in tree rings serve as crucial indicators of historical changes in nitrogen cycling and water use efficiency, which are both key factors affecting soil health and terrestrial biodiversity. These minute chemical signatures within wood function much like fingerprints, revealing variations in soil nutrients and water utilization over significant periods, ranging from decades to centuries. By analysing these stable isotopes, researchers can gain long-term insights into

past nutrient cycling and water use efficiency leading to getting information about soil health and overall ecosystem productivity.

16. Linking Tree Growth to Wildlife Populations: Years with episodic heavy seed production are called mast years and they are recorded in tree rings. These years significantly impact population booms in birds, rodents, and insects. By reconstructing mast chronologies, researchers can enhance predictions concerning wildlife dynamics and associated disease risks, such as Lyme disease. The cycles of abundant seed production leads to increase in animal populations, and the analysis of tree rings facilitates the understanding of these patterns. This research improves insights into ecosystem dynamics and the relationships between wildlife and disease outbreaks.

III. TOOLS FOR TOMORROW: TECHNOLOGY, PEOPLE, AND POLICY

To protect the future, we must combine ancient wood with modern innovation and human wisdom.

17. Assessing Legacy Effects of Past Land Use: Abandoned farmland, logged forests, and indigenous landscapes significantly influence tree growth patterns, creating lasting imprints even after such activities stop. This legacy affects tree growth for decades, which can be revealed through tree rings. Understanding these historical impacts is crucial for developing effective rewilding and restoration strategies that is crucial for both ecological and cultural histories. By recognizing the long-lasting effects of these past activities like agriculture and logging, forest restoration efforts can be improved, ensuring a comprehensive approach that considers both ecological restoration and the cultural perspectives of these landscapes.

18. Scaling from Individuals to Ecosystems: Ecosystem level responses, including the carbon storage and habitat quality can be inferred from tree ring records. Advancements in statistical models that connect individual tree data to broader ecosystem predictions are crucial for effective landscape conservation planning. The individual tree growth patterns provide insights about the carbon storage, wildlife habitat, and overall forest health. Scientists are currently developing methodologies to translate these growth patterns observed in tree rings into larger ecosystem forecasts, emphasizing the necessity for improved and advanced statistical models to accurately interpret tree ring data for landscape study.

19. Integrating Indigenous Ecological Knowledge: Tree ring data validate and enhance oral histories regarding environmental changes, particularly in the context of Indigenous communities. By employing collaborative strategies that integrate scientific and traditional knowledge systems these approaches ensure that conservation efforts are both respectful of cultural histories and scientifically informed. The records obtained from tree rings can uphold and verify the local communities' memories of past environmental events, thus, leading to more informed and culturally sensitive conservation decisions.

20. Public access to Dendroecological Tools: Open-access databases, AI-assisted ring detection, and portable scanners significantly enhance the field of dendroecology for community scientists and researchers around the globe. These tools facilitate collaborative efforts among students, citizens, and

researchers to study trees collectively, promoting a shared commitment to conservation. These advancements support community-based conservation strategies, biodiversity solutions guided by the locals and also encourage wider participation in tree ring research.

DENDROECOLOGY IN ACTION: LESSONS FROM THE HIMALAYAN MONSOON SHADOW FORESTS

A powerful example of these emerging research frontiers in action is the National Mission on Himalayan Studies (NMHS) project, entitled "Structure and Functioning of Himalayan Monsoon Shadow Forest Ecosystems" (NMHS 2024 25/SC XIII/MG/SL 16). The Himalayan monsoon shadow regions lying in the rain deficient zones beyond the main monsoon barrier, which harbour unique, slow growing forests dominated by species, such as deodar, blue pine, and juniper. These forests survive under extreme climatic stress, making them ideal natural laboratories for dendroecological research.

This project is not just a study; it is a real-world application of the frontiers outlined above. It aims to (1) reconstruct long term climate variability in regions where instrumental records are scarce (Frontier 1 & 7), (2) understand how forest growth responds to monsoon failure, drought, and warming trends (Frontier 5 & 11), (3) identify climate resilient tree populations that could serve as conservation priorities (Frontier 3 & 5), and (4) assess how past disturbances both natural and human induced have shaped forest structure and ecosystem functioning (Frontier 2 & 6).

By integrating dendroecology with ecological monitoring, climate analysis, and landscape level observations, the NMHS project directly addresses several of the priority frontiers outlined in this article. It turns ring width measurements into real world action, tackling priority frontiers including the climate sensitivity of marginal populations, legacy effects of disturbance, and future forest composition under changing climate scenarios.

A VISION FOR THE FUTURE

Solving these challenges is not just about better science; it is about smarter conservation. For example, knowing that a particular pine species only regenerates high intensity fires (revealed through fire scars) means land managers can design burns that sustain both the tree and the cavity nesting birds that depend on it. Priority frontier exercises are increasingly framing future agendas in conservation, identifying research foci with high policy relevance. To date, however, a coherent synthesis of priority research areas for dendroecology remains unexplored, yet very necessary. The next decade of dendroecology must be interdisciplinary, inclusive, and applied. Partnerships with geneticists, remote sensing experts, Indigenous communities, and conservation practitioners will turn data into action.

As climate chaos accelerates, it is becoming increasingly difficult to guess how ecosystems will respond. Trees have been taking notes for millennia. It is time to read them not just to understand the past, but also to protect the web of life that depends on forests for survival. Dendroecology is not just about tree rings; it is about time, memory, and survival. Emphasising this narrative ensures the science resonates beyond the laboratory, inspiring a broader readership to appreciate how forests quietly chronicle and help protect the future of life on Earth.

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Dr Mayank Shekhar, Scientist C at the BSIP, Lucknow, specializes in Quaternary climate, monsoon dynamics, glacier fluctuations, natural hazards, ecological responses, climate variability, modeling, and vegetation changes. His research uses tree rings and diverse palaeodata to reconstruct past climates and hazards, supporting global sustainable goals, and contributing to climate adaptation, disaster risk reduction, and sustainable ecosystem management.

The Ice Age you did not see in the movies

Harshita Bhatia and Gaurav Srivastava

DO YOU REMEMBER THE ICE AGE?

Not from textbooks, but from the unforgettable scenes of the movie Ice Age. A frozen world stretches endlessly under snow and ice. Woolly mammoths march across white plains. A clumsy, talkative sloth named Sid slips his way through danger, while Scrat, the frantic little creature endlessly chasing his acorn, triggers chaos wherever he goes.

These images have shaped how we imagine the Ice Age: dramatic, funny, dangerous, and frozen. But, while we laugh at Scrat's obsession and remember Sid's sloppy adventures, we almost never stop to ask a quieter question:

WHAT HAPPENED TO PLANTS DURING THE ICE AGE?

Animals could walk, migrate, and search for food. Plants could not. When much of the Earth turned cold, dry, and unstable, how did forests, grasses, and fragile plants survive? And which ones vanished forever?

A WORLD UNDER ICE

Between about 2.6 million and 11,700 years ago, the Earth experienced repeated Ice Age cycles. Massive ice sheets advanced across Europe and North America. Temperatures dropped. Rainfall patterns shifted. Entire ecosystems collapsed or reorganized. In Europe, many plant groups disappeared completely. Bamboo, now absent from the continent, was one of them. The cold and dryness of the Ice Age proved too severe. Yet the Ice Age did not turn the entire planet into a frozen ice ball. Some places stayed green.

HIDDEN GREEN REFUGES

While ice dominated much of the world, pockets of warmth and humidity survived elsewhere. These regions, known as refugia, became sanctuaries where plants endured while disappearing from harsher landscapes.

One such refuge existed in an unexpected place: Northeast India.

Sheltered by mountains and sustained by monsoon moisture, this region remained relatively warm even during global cooling. Rivers flowed. Forests persisted. And one Ice Age plant left behind an extraordinary clue.

A BAMBOO FROM THE ICE AGE

Along the banks of the Chirang River in Manipur's Imphal Valley, scientists discovered a fossil bamboo stem buried in fine sediments. Dating back 37,000 years, this bamboo lived right in the middle of the Ice Age, the same world we imagine filled with mammoths and saber-toothed cats.

Bamboo fossils are exceptionally rare. Their hollow, fibrous stems usually decay quickly. Yet this specimen was preserved in remarkable detail, retaining its nodes, buds, and, most strikingly the scars of thorns. The fossil was identified as *Chimonobambusa manipurensis*, making it Asia's earliest thorny bamboo fossil. Its age was determined using thermoluminescence dating of the surrounding sediments, while its name reflects both its close similarity to modern thorny bamboos of the genus *Chimonobambusa* and its place of discovery, Manipur, the land where this Ice Age survivor once grew.

Asia's first thorny bamboo fossil (*Chimonobambusa manipurensis*) from Manipur, dating back 37,000 years, with preserved thorn scars (black arrows) and nodal buds (sky-blue arrow) (Bhatia et al., 2025).

Asia's first thorny bamboo fossil from Manipur, with preserved thorn scars (black arrows), internodes (red arrows) and nodal buds (sky-blue arrows) (Bhatia et al., 2025).

DEFENSE IN A DANGEROUS WORLD

During the Ice Age, India was home to large grazing animals, such as elephants, deer, and wild cattle. For these herbivores, tender bamboo shoots would have been an easy and nutritious meal. But, bamboo was not defenseless. Its thorns were not decorative features, they were survival armor. The preserved thorn scars reveal that bamboo was actively responding to ecological pressure, developing physical defenses against grazing at a time when animals themselves were adapting to cold, scarcity, and environmental stress. Even during the Ice Age, plants were evolving.

WHY BAMBOO SURVIVED HERE

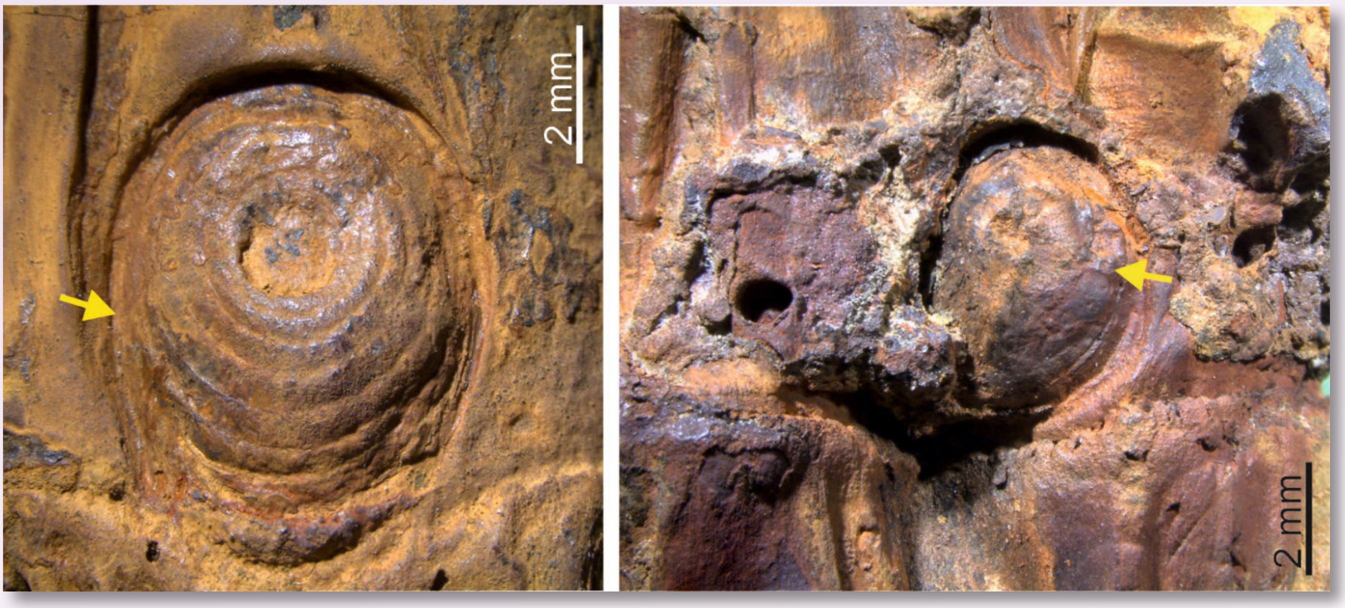
While bamboo disappeared from much of Europe as climates became colder and drier, it survived in Northeast India because the region never fully froze. Warm and humid conditions persisted, supported by monsoon systems and sheltered landscapes. This stability allowed bamboo to endure when it vanished elsewhere. As large herbivores continued to roam these Ice Age landscapes, bamboo adapted by growing sharp thorns, turning its soft, vulnerable shoots into a well-defended resource. This combination of favorable climate and effective defense helped bamboo survive the harsh conditions of the Ice Age and confirms Northeast India as an important refuge for tropical plants, one that still shapes the region's forests today.

LESSONS FROM A FROZEN PAST

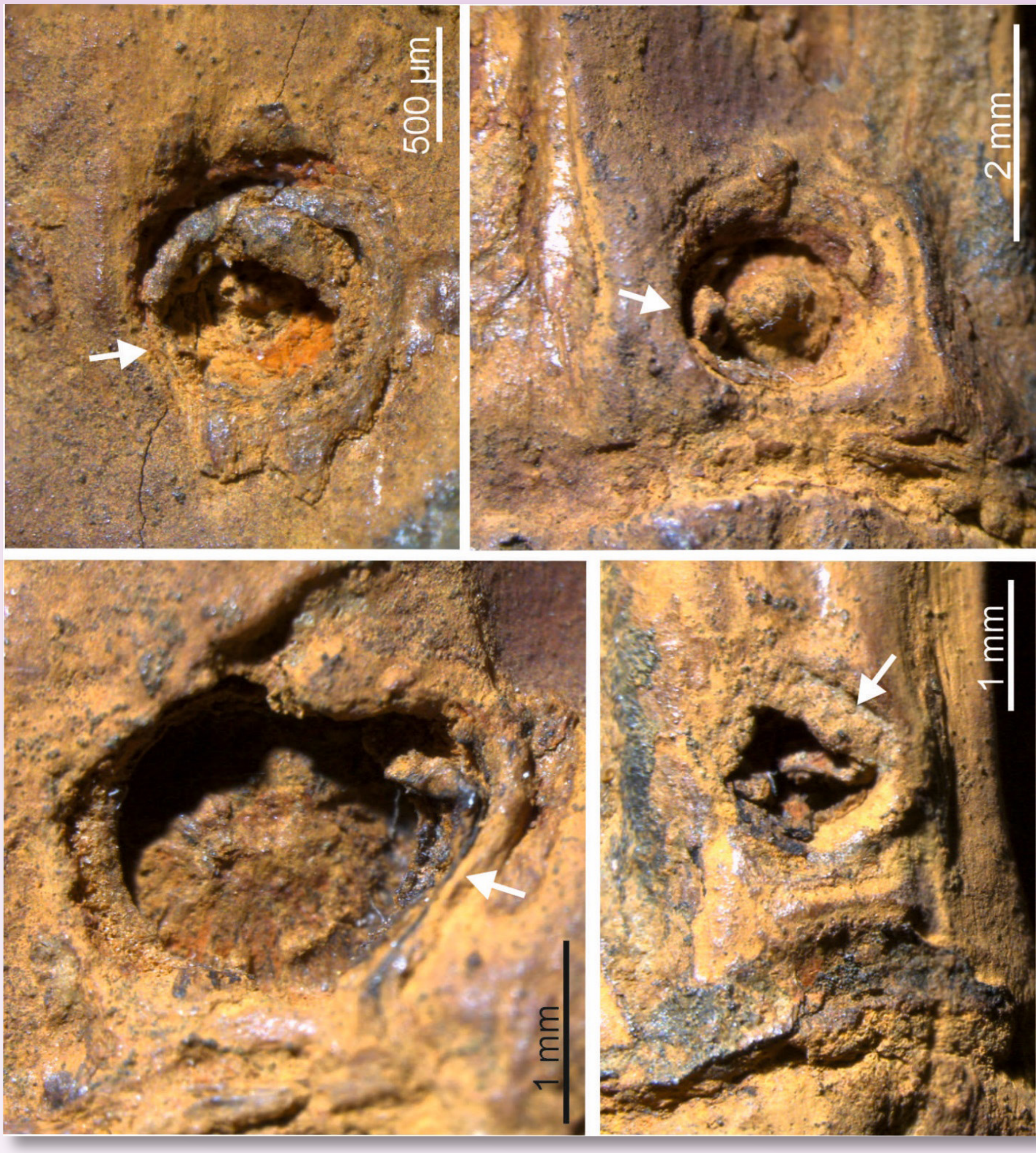
The Ice Age reminds us that survival is not just about strength or speed. For plants, survival depends on place. As the Earth warms again today, protecting regions that once served as refuges may be crucial for biodiversity in the future. The Ice Age bamboo of Manipur shows that even in the coldest chapters of Earth's history, green life found a way to persist—quietly, patiently, and sometimes with thorns.

Reference

Bhatia, H, Kumari, P., Singh, N.H., Srivastava, G., 2025. Earliest thorny bamboo from Pleistocene of Asia characterizing spinescence and paleoclimatic adaptations in bamboos. Review of Palaeobotany and Palynology, 338, 105347. https://doi.org/10.1016/j.revpalbo.2025.105347



Enlarged microscopic view of the fossil bamboo (*Chimonobambusa manipurensis*), showing preserved buds (yellow arrows) (Bhatia et al., 2025).



Enlarged microscopic view of the fossil bamboo (*Chimonobambusa manipurensis*), showing rare preservation of thorn scars (white arrows) (Bhatia et al., 2025).

About authors

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GENERAL ARTICLE

Palaeo-wildfires: Tracing Ancient Fires in Earth's History

Sneha Santhosh and Runcie Paul Mathews

FIRE is often thought of as a modern challenge that we associate with the news reports, forest loss, and climate change. Have you ever thought of the flames that once moved across the landscapes long before people, cities, and familiar plants existed? This question leads us into the fascinating world of palaeo wildfires, which were responsible for the burning of different ecosystems at various points in Earth's geological past and quietly shaped the planet we live today.

NOT HUMAN THEN WHO?

Palaeo wildfires refer to the wildfires that occurred on the Earth before human documentation. Wildfires became extensive in the Silurian Period (~420 million years ago), following the emergence and spread of land plants. If humans were not there at that time, then what was responsible for igniting vegetation? The answer lies in the natural processes, such as lightning, volcanism, climate, atmospheric composition, etc.

One of the most common sources of paleo wildfire ignition was lightning strikes. The lava flows including the hot volcanic debris also ignited the surrounding plant matter. Warm climatic conditions can dry out plant material thereby increasing the probability of ignition and fire spread. Strong winds can cause dry tree branches to rub against each other and produce heat that may cause ignition during dry climates. Periods of high rainfall keep vegetation moist, reducing the frequency and extent of the fire activity. Atmospheric conditions during certain geological periods were also favourable for wildfire. Burning in the presence of oxygen is known as combustion. As wildfires occur due to the combustion of plant material, variations in the atmospheric oxygen levels have a direct impact on the behaviour, intensity, and spread of fire. Scientists suggest that wildfires cannot occur when atmospheric oxygen levels are below about 13%, and they are rare when oxygen levels lie between 13% and 16%. For fires to spread effectively, oxygen levels generally need to be above 18%, along with dry vegetation and dry seasonal conditions. In regions with wetter climates, widespread wildfires can still occur if oxygen levels rise above 25%. When oxygen exceeds 30%, fire activity may become widespread globally, and at levels above 35%, fires would be extremely difficult to control or extinguish. Higher levels of oxygen in the ancient atmosphere allowed vegetation to burn more easily and sustain fire over larger areas. So, abundant plant fuel, natural ignition sources, and elevated oxygen levels created ideal conditions for promoting wildfires long before human influence.

NOT ALL FIRES ARE THE SAME

Wildfires are commonly divided into 3 types;

1. **Ground fire**- As the name indicates, fire happens below the ground surface. Burning of plant matter, including dead branches, fallen leaves, and peat formed from decomposing plant matter beneath the soil surface. They burn typically at temperatures below ~400 °C.

2. **Surface fire**- This is the most common type of wildfire, burning vegetation at the ground surface. Surface fuels are predominantly grass, shrubs, short herbaceous plants, leaf litter, including fallen tree branches, etc., igniting at temperatures from approximately 400 °C to 650 °C.

3. **Crown fire**- Crown fire is referred to as extremely intense and fast-moving burning of the canopy of the trees that spreads from treetop to treetop, generally burning at temperatures exceeding 650 °C. Sometimes, the tree trunks can act as a ladder, helping surface fires to climb up to the canopy.

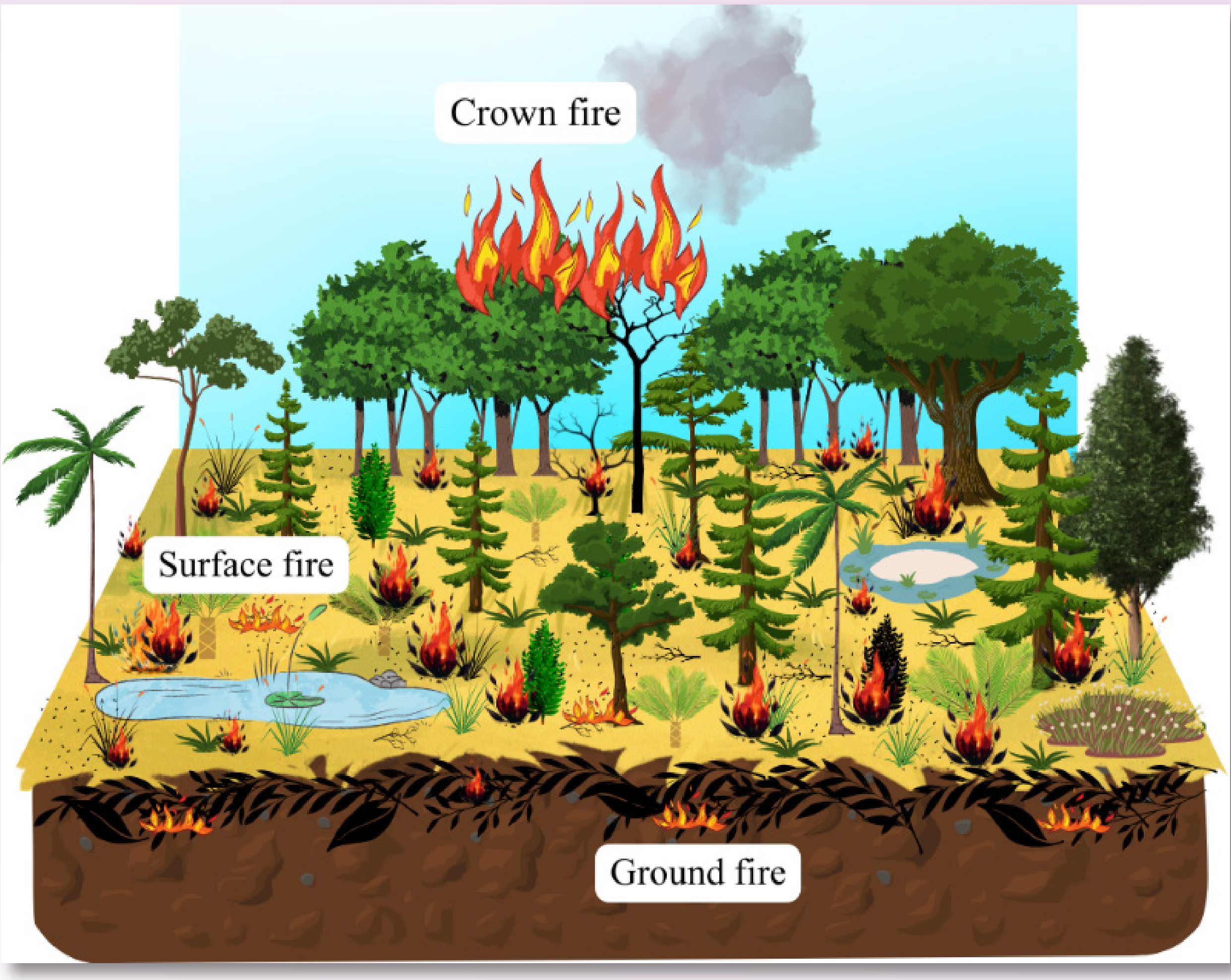


Figure: Types of wildfires

Figure: Macroscopic fossil charcoal fragments found in lignite

READING FIRE SIGNALS FROM THE PAST

Earth has preserved these ancient fire signals in natural archives, such as sediments, rocks, coal, and lignite deposits, mainly in the form of fossil charcoal, pyrogenic inertinite macerals, Polycyclic Aromatic Hydrocarbons (PAHs), and ash layers. Charcoal is a highly inert and chemically stable product of incomplete floral combustion and acts as an indicator of regional palaeo-wildfire activity. This may raise a doubt among you: if oxygen is an essential factor for wildfires, how does charcoal, one of the main products of wildfire, form under conditions of little or no oxygen? Wildfires require oxygen to spread and intensify, and when plants are exposed to very high temperature ignition sources, their tissues heat up rapidly and break down, releasing gases, such as carbon monoxide, carbon dioxide, and methane. These gases mix with oxygen in the air and burn, producing more heat and sustaining fire. This heat penetrates the plant areas with little or no oxygen and it causes the charcoalification of plant tissues through a process known as pyrolysis. If this process ends before the plant material is completely burned, charcoal remains as the final product. If this charcoal is buried quickly by sediments, it can survive for millions of years. These charcoal fragments are found in macroscopic size, as well as microscopic sizes in the sedimentary horizons. Macroscopic charcoal fragments are commonly known as fossil charcoal, while microscopic charcoal particles are referred to as pyrogenic inertinite macerals, particularly in coal geology.

Macerals are microscopic organic components of coal or lignite formed from different parts of ancient buried plants. Pyrogenic inertinite macerals, such as fusinite, semifusinite and inertodetrinite originate from the charcoal particles and are considered the major indicators of palaeo-wildfires.

Certain organic compounds known as biomarkers (molecular fossils) form only during the combustion of plant materials. Pyrogenic Polycyclic Aromatic Hydrocarbons (pyro-PAHs) are generated during the burning of plant materials and are primarily unbranched, typically consisting of 3 to 6 ring PAHs. They are less prone to the diagenetically induced changes and their structure can record the intensity and source of wildfires. The levels of pyro-PAHs in sediments rise after forest fires and can be differentiated from petrogenic PAHs, which frequently exhibit a branched or substituted configuration. The presence of pyro-PAHs confirms the presence of palaeo wildfire activity even when visible charcoal is scarce.

Ash layers preserved within sediments provide additional evidence of palaeo wildfires. These thin layers consist of fine particles produced during vegetation burning and can be found in lake deposits, floodplains, and peat sequences.

DECODING THE MESSAGE OF THE ANCIENT FLAMES

Studying palaeo wildfires is not only about understanding the destruction in the past, but also about understanding the change. Fire influences the growth, recovery, and evolution of the ecosystems. Ancient wildfires had cleared dense vegetation, which, in turn, allowed new plants to emerge. It played an important role in shaping the biodiversity and also interacted closely with the climate and the environment. Therefore, exploring the palaeo wildfire events and studying its sedimentary signatures gives insights into the evolution of plant species, climatic conditions and palaeo atmospheric composition.

The quantification of the pyrogenic inertinites present in the coal/lignite deposits through the maceral analysis enables us to infer about the intensity and frequency of the palaeo wildfire events, and the estimation of palaeo atmospheric oxygen concentration. The reflectance of fusinite maceral is directly proportional to the combustion temperature. Therefore, by measuring the reflectance values

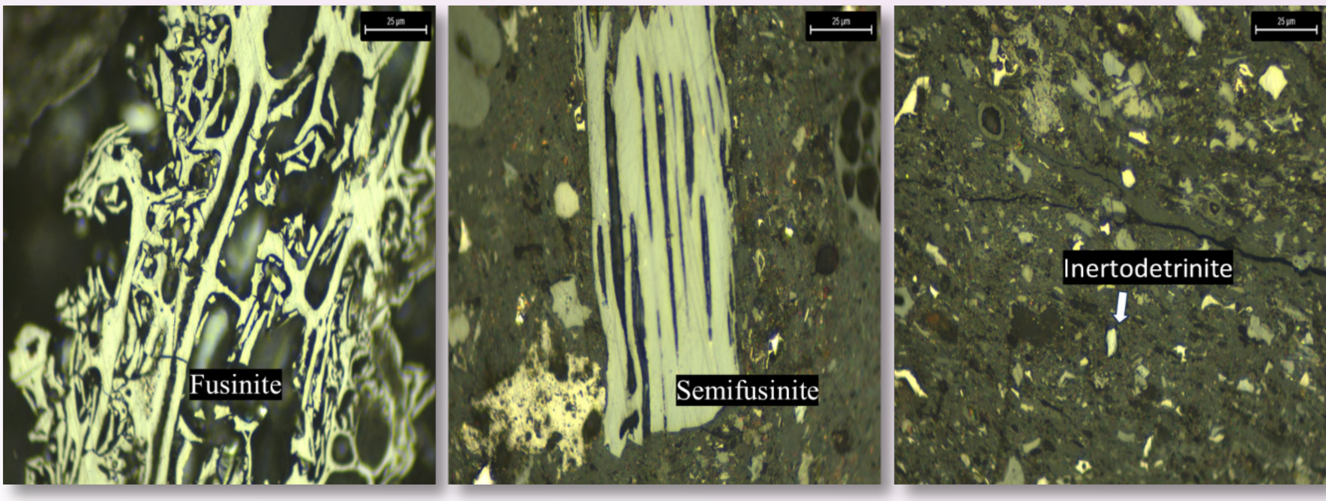


Figure: Pyrogenic inertinite macerals

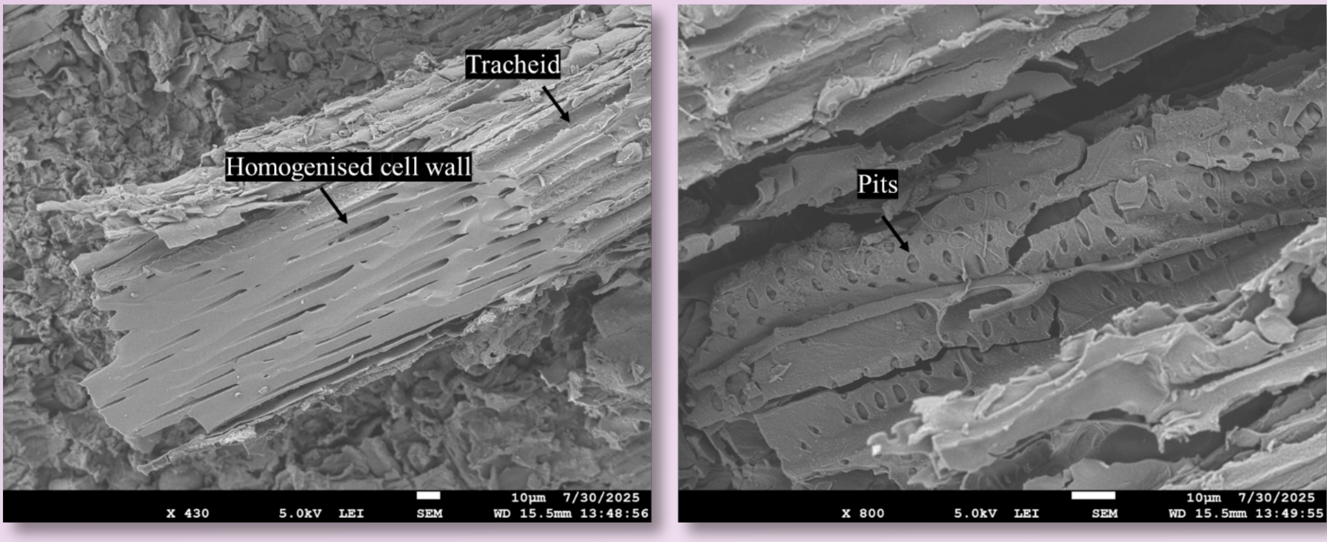
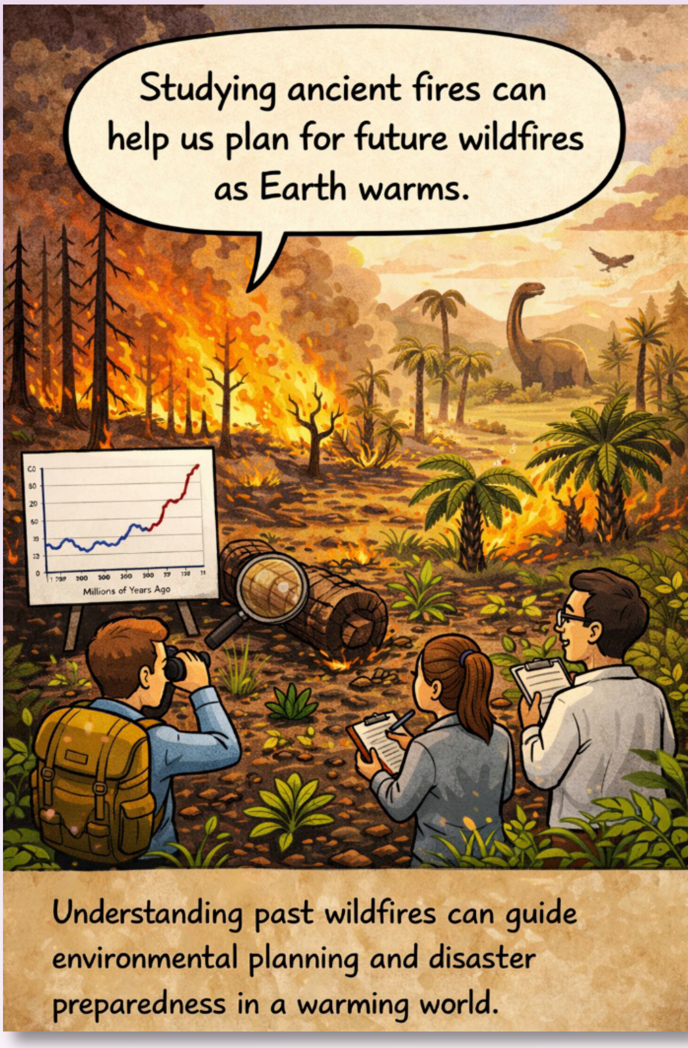


Figure: Scanning Electron Microscopic images of charcoal fragments.

of the fusinite, we can calculate the combustion temperature and can infer the wildfire type. Combustion temperatures can also be deduced from certain PAHs because certain high molecular weight PAHs are associated with increased combustion intensity due to their formation at elevated temperatures. For example, phenanthrene is a low molecular weight pyro-PAH with 3 aromatic rings which forms at a temperature range of 200–400



°C. 5 ring pyro-PAHs, such as benzo[b]fluorene, benzo[k]fluoranthene, benzo[a]pyrene, etc., and 6 ring pyrogenic PAHs, such as benzo[ghi]pyrene, indeno[1,2,3-cd]pyrene, etc. have high molecular weight and high temperature origin. These PAHs can be identified using geochemical analysis known as Gas Chromatography-Mass Spectrometry (GC-MS).

The anatomical characteristics of the ancient plant species that are found preserved in the fossil charcoal fragments can be observed with the help of Scanning Electron Microscopy. Plant species can be identified by the types of pits, presence of tracheids, vessels, etc. Homogenisation of cell walls, that is, the disappearance of the middle lamella, happens only if the combustion happens above 300 °C.

Spectroscopic techniques, such as Fourier Transform Infrared Spectroscopy and Raman Spectroscopy, can be used to identify the influence of wildfires on the chemical structure of the charcoal and other geochemical analysis, such as carbon isotopic studies are also important.

WHY DOES STUDYING PALAEO WILDFIRES MATTER TODAY?

One of the most important contributions of palaeo wildfire research is its role in understanding the past climate conditions, which improves our understanding of climate-fire relationships. Recording palaeo wildfire events provides a natural reference to compare with present wildfire activity. This helps us to identify whether it is natural, driven by climate change or human actions. The knowledge on how ecosystems respond and adapt to fire over long time scales help to plan better forest management, biodiversity conservation, and ecosystem restoration in the fire prone regions. Palaeo wildfire study help us to evaluate the carbon balance and the climate feedbacks. Another important application of palaeo wildfire research is that it strengthens the future wildfire prediction models. Learning how fire behaved during the past warm periods can help to anticipate the wildfire risks in a warming world. This can support environmental planning and disaster preparedness. These represent only a few of the many applications of palaeo wildfire research and many other exciting applications are still waiting to be discovered.

About authors

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Can fossil records help us forecast future biodiversity shifts?

Harshita Bhatia and Gaurav Srivastava

INDIA is home to some of the most unique plant life on the Earth, especially in the Western Ghats, a stretch of ancient mountains running parallel to the country's southwestern coast. These evergreen forests are filled with species that exist nowhere else, shaped by millions of years of evolution and isolation. But, a surprising discovery in the far northeast, in the coal-rich lands of Assam, has revealed a forgotten chapter in this story, one written not in living trees, but in fossilized leaves.

Deep beneath layers of Earth in the Makum Coalfield (Figure 1), researchers uncovered fossil leaves of an ancient plant called *Nothopegia*, a genus that today grows only in the Western Ghats and parts of Sri Lanka (Figure 1). These fossils are around ~24 million years old, dating back to a time when Assam wasn't yet covered in tea gardens or broken up by railway lines. Instead, it was a tropical rainforest: warm, humid, and rich in evergreen trees, much like the Western Ghats are today.

The presence of *Nothopegia* in the northeast was unexpected. It meant that this plant, now seen as a Ghats native, once had a much wider distribution across the Indian subcontinent. But something

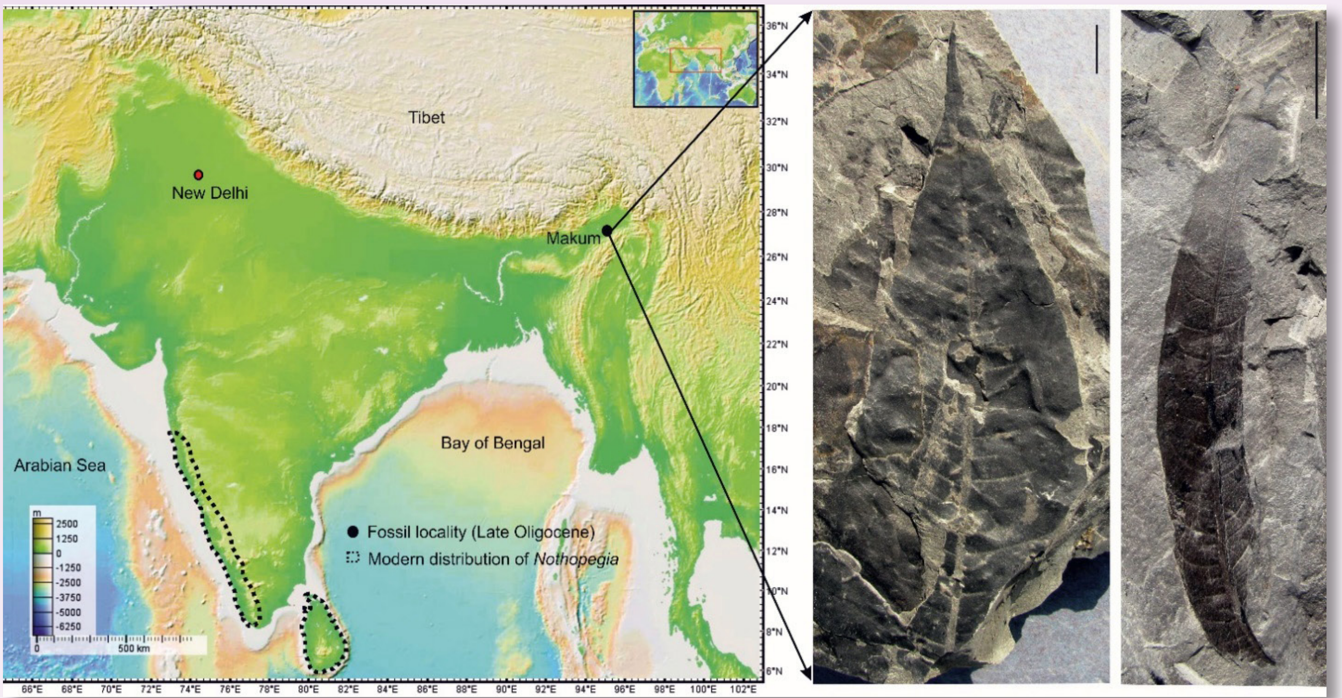

Figure 1. The diagram shows how climate change over millions of years caused the disappearance of *Nothopegia* from northeast India, while the species survived and became endemic to the Western Ghats (after Bhatia and Srivastava, 2025).

changed. As the Indian tectonic plate collided with Asia, the Himalaya began to rise, slowly but steadily. These growing mountains altered the region's climate, cooling northern India, shifting rainfall patterns, and transforming once-lush forests into drier landscapes.

Over time, conditions in the northeast became less suitable for species like *Nothopegia*. Unable to thrive in the changing environment, the plant disappeared from the north. But, it didn't vanish completely. It survived in the southern Western Ghats, where the climate remained relatively stable. The plant became restricted to this smaller range, where it still exists today, tucked away in isolated patches, a living relic of a much broader past.

By closely comparing the fossil leaves with those of modern species, scientists found striking similarities with two trees still growing in the Ghats today: *Nothopegia travancorica* and *Nothopegia castaneifolia*. Their distribution today may look narrow, but their story stretches back millions of years and across a moving continent.

This discovery also supports the idea of an ancient forest corridor, a continuous green belt that may once have connected northeast India to the Western Ghats. Such a corridor would have allowed tropical species to migrate over time, escaping shifting climates and finding refuge where conditions remained favorable. Fossil evidence from other plant groups suggests similar journeys, pointing to a time when India's forests were far more connected than they are today.

In a world facing rapid climate change, stories like that of *Nothopegia* carry an important message. They show how species respond to environmental upheaval, not just in decades or centuries, but across geologic time. Some adapt, some move, and some disappear entirely. The plants we see as unique to certain regions may, in fact, be the last survivors of a much larger, ancient world, one shaped by the rise of mountains, the fall of forests, and the ever-changing breath of climate. What makes this story particularly relevant today is its connection to ongoing climate change. Just as plants once adapted, or failed to adapt, to major shifts in temperature and rainfall, modern species face similar pressures in a rapidly warming world. Studying ancient fossils like *Nothopegia* helps scientists understand how ecosystems responded to past changes, offering crucial insights into which regions might serve as future refuges, and which species are most vulnerable to extinction. In this sense, every fossil is a messenger across time, a biological narrative etched in stone that warns of both loss and resilience. As the world faces mounting environmental challenges, such stories from deep time serve as both a scientific guide and a call to protect what remains.

Reference

Bhatia, H., Srivastava, G., 2025. Rising Himalaya and climate change drive endemism in the Western Ghats. Fossil evidence insights. Review of Palaeobotany and Palynology 338, 105348.

About authors

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The Quaternary Story from the Third Pole: The Ladakh Chapter

Binita Phartiyal

LADAKH is part of what scientists call the 'Third Pole'. It's termed so because, after the North and South Poles, the Himalayan and Tibetan Plateau region holds the largest fresh water reserves on Earth and is also called the 'Water Tower of Asia.' The glaciers and snowfields feed several mighty rivers. The rivers Indus, Zanskar, Nubra, and Shyok have their origins in Ladakh, sustaining millions of people far downstream. But Ladakh has more to add to the Earth's story. It is also a time capsule, a place where past climate shifts and tectonic forces have left their records across the land, waiting to be unravelled.

This is a land of extremes. Summers are short, with temperatures barely reaching 20 degrees celsius, while winters plunge far below freezing. Rainfall is scarce, vegetation is thin, leaving much of the land bare resembling the Lunar topography or Moon like. Yet these harsh conditions have one advantage- they help preserve the traces of the past. Across Ladakh, glaciers once filled valleys, rivers shifted course, landslides dammed gorges, and ancient lakes rose and fell. Each event left behind sediments–clays, sands, gravels–layered like pages in a book. By studying these layers, scientists have reconstructed Ladakh's history.

Two forces above all have shaped this land: climate and tectonics.

Firstly the climate- Ladakh sits at the crossroads of two great systems: the Indian Summer Monsoon reaching from the south and the Westerlies entering from the northwest directions. Their balance has shifted many times. In the early Holocene, about 10 to 8 thousand years ago, the global rainfall belt expanded northwards, resulting in a stronger monsoon. This brought wetter conditions and encouraged the

Intermorainal lakes with Leh town (valley) and the Zanskar snow covered range & Confluence of the Indus and Zanskar Rivers formation of lakes. At other times, weaker monsoons and stronger westerlies brought cold and dryness, pushing glaciers forward. Sudden swings are also part of the story. The 2010 Leh cloudburst, when hours of intense rain triggered flash floods and landslides, was a reminder of just how fragile this landscape is. Secondly the tectonics- Ladakh lies in the vicinity of the India–Asia collision zone. And we all know that the Himalayas themselves are a product of this immense impact. The Indus River flows along the suture zone–marks that collision, and faults in the region remain active, triggering earthquakes and landslides. Massive amounts of debris fall from the mountains, sometimes damming rivers. When those natural dams burst, they leave fresh scars and thick deposits downstream. In this way, tectonics continually reshapes Ladakh's landscape.

Why do these stories matter? Imagine it as a natural laboratory. Unlike wetter regions where erosion erases history, Ladakh's dry cold climate preserves it. Walking here is like strolling through an open library of Earth's past.

So let's open some of those pages.

Imagine standing in the Indus, Nubra, and Shyok valleys. Today you might see wide dry channels and distant glaciers, but beneath your feet lies memories stretching back hundreds of thousands of years. Scientists have traced at least five major phases of glaciation, each one smaller than the last. These phases are the Indus Valley stage nearly 430,000 years ago, the Leh stage about 150,000 years ago, the Kar stage around 120,000 years ago, followed by the Bazgo stage some 50,000 years ago and the latest Khalling stage that happened about 10,000 years ago. In the Ladakh Range, scientists have found evidence for smaller, more local glacier advances as old as 81,000 years ago and as recent as just 1800 years ago. Together, these phases reveal a rhythm of glacial advance and retreat, with ice covers encompassing vast areas before shrinking steadily back.

In the Indus Valley, the Holocene left another imprint. As monsoons strengthened, unstable slopes collapsed along tectonic faults, damming rivers and creating enormous lakes. Their sediments–neatly laminated silts resting on older gravels–can still be seen at Nyoma, Shey, Spituk, Gupuk, Saspol, Khalsi and Batalik. The Indus River valley in Ladakh was dammed four times in the last 35,000 years, in four phases - at ~35–26 thousand years forming the Lamayuru palaeolake-commonly known as "Moonland"; 14–5 thousand years (Saspol-Khalsi Palaeolake) and 13–3 thousand years (Spituk-Leh

Winding Roads; Lamayuru palaeolake commonly known as Moonland

Palaeolake) and also upstream at Nyoma around 17 thousand years before present. Ladakh also hosts closed-basin lakes like Tso Moriri and Tso Kar. Tso Kar, in particular, is now on the verge of drying out. Geological evidence shows that in the Early Holocene, its water level once stood 90 meters higher than today. Ancient shorelines etched into the hillsides prove it. Even the local tribes preserve folklore that the lake would one day disappear. Looking at its shrinking waters today, that prophecy feels close.

But, none of these ancient lakes lasted forever. Their dams of loose debris were fragile. Some failed catastrophically, releasing flood-waters like modern-day glacial lake outburst floods. Others drained slowly as water seeped or cut through the natural barriers. Today, deep channels, stepped terraces, and wide sediment fans remain as evidence of these vanished waters.

Meanwhile, the mountain crests recorded their own story. Here, glaciers advanced and retreated with every climate shift. From about six thousand years ago, these rhythms were captured in high-altitude lakes, such as South Pulu, North Pulu, Tsoltak, and Yaya Tso, all perched above 5,000 meters. And yet, despite all we know, Ladakh still keeps many secrets. Scientists are still working to answer questions about when lakes formed, how long they lasted, and how local changes affected the broader patterns across Asia. Each new study adds detail, but the full picture is still being pieced together.

What we do know is already remarkable. Ladakh's landscapes are never still. Glaciers advance and retreat, rivers cut and fill, lakes appear and vanish. They show us how even small shifts in rainfall or temperature can reshape entire valleys. This is a story of resilience, but also of fragility. And the warning is clear: the changes that once took thousands of years are now unfolding in just decades.

But, Ladakh's story is not only about ice and water. It is also a land of sand dunes sculpted by winds, stretches of frozen ground known as permafrost, and human history carved into rocks as ancient petroglyphs.

It has long functioned as a key corridor for trans-Eurasian exchanges of people, culture, agriculture, and language, particularly along the Silk Road. People have lived here for thousands of years, leaving behind their art, traditions, and monasteries that still thrive today. Recent studies highlight a genetically heterogeneous population shaped by recurrent migration and admixture events, primarily from South and East Asia.

Ladakh-the land of extremes-Frozen waterfall in winters; Palaeolake section

For researchers, Ladakh's barren high-altitude deserts also make one of the best natural analogues for Mars. Researchers come here to test equipment, study survival in extreme conditions, and research on the possibility of life in these extreme conditions, hence, finding a clue on whether life might exist beyond Earth.

So, when you picture Ladakh, don't just see the monasteries clinging to cliffs, the wide desert valleys, or the snowy passes. Imagine the hidden archive beneath your feet–a layered memory of rivers that once roared, glaciers that carved deep valleys, and lakes that shimmered before vanishing. Ladakh is more than scenery. It is an open-air museum of

Famous Petroglyph-the Ta`ngtse Chase

Wetland of Tsokar


Faulting seen in the palaeolake section; Expression of the Indus Suture Zone upstream Karu village

Earth's history, a true geoheritage site with a variety of rock types-igeneous, sedimentary and metamorphic. And it is also warning us, as the changes that once unfolded slowly over millennia are now racing ahead. Ladakh's story is not only about the past –it is about our future too.

About author

Dr Binita Phartiyal, Scientist-F and Head of the Palaeomagnetism Laboratory, BSIP, Lucknow, has 28 years of research experience in Quaternary paleoclimate, geomorphology, and neotectonics. A geologist by training, she has led Himalayan (Tethyan and Trans-Himalayan) and participated in the Indian Scientific expeditions to Arctic and Antarctic.

Remote Sensing and GIS: Technological Advancements in Palaeosciences

Biswajeet Thakur, Pooja Tiwari, Nazakat Ali and Shivansh Saxena

PALAEOSCIENCES aim to reconstruct Earth's past environments, climates, ecosystems, and surface processes through geological, biological, and geochemical archives preserved in sediments, landforms, fossils, and geochemical signatures. Traditionally, palaeoscientific reconstructions relied heavily on field observations, stratigraphic correlations, laboratory-based proxy analyses, and chronological techniques. While these approaches remain fundamental, the last few decades have witnessed a transformative shift, driven by rapid advancements in remote sensing and **Geographic Information System (GIS)** technologies. These tools have revolutionized the way palaeoscientists visualize landscapes, analyze spatial patterns, integrate multi-proxy datasets, and interpret Earth system processes operating over geological timescales. The synergy between remote sensing and GIS has significantly enhanced the accuracy, scale, and efficiency of palaeoenvironmental and palaeoclimatic studies.

Remote sensing provides synoptic, repetitive, and non-invasive observations of the Earth's surface using satellite- and airborne-based sensors operating across optical, thermal, microwave, and hyperspectral domains. In palaeosciences, these capabilities are invaluable for identifying and mapping relict landforms, sedimentary features, palaeochannels, and geomorphic signatures that are often obscured by vegetation, urbanization, or modern depositional processes. The early palaeoenvironmental studies relied on aerial photographs to recognize ancient river courses and coastal features, but modern satellite platforms, such as Landsat, Sentinel, Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and Indian Remote Sensing (IRS satellite series) have dramatically improved spatial, spectral, and temporal resolutions. The use of multispectral imagery enables discrimination of lithological units, soil types, and moisture conditions, which are critical for interpreting past depositional environments and landscape evolution (Figure 1).

One of the most significant advancements in remote sensing for palaeosciences is the use of high-resolution digital elevation models (DEMs). The use of DEMs derived from Shuttle Radar Topography Mission (SRTM), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), TanDEM-X, and LiDAR have allowed detailed reconstruction of palaeotopography and geomorphic processes. The subtle elevation differences preserved in floodplains, deltas, and coastal plains often reflect abandoned river channels, palaeo-shorelines, beach ridges, and tectonic deformation. In fluvial palaeosciences, DEM-based morphometric analysis helps identify palaeochannel networks, avulsion patterns, and river migration histories, which are essential for understanding hydrological changes linked to monsoon variability or glacial–interglacial climate oscillations.

The Radar remote sensing has emerged as a powerful tool in palaeoscientific investigations, particularly in arid and semi-arid regions. Furthermore, Synthetic Aperture Radar (SAR) sensors, such as Sentinel-1, ALOS PALSAR, and RADARSAT can penetrate dry sand and sparse vegetation, revealing buried palaeochannels and ancient drainage systems invisible in optical imagery. These buried fluvial systems often record palaeohydrological regimes associated with past humid phases, such as the

African Humid Period or intensified Indian Summer Monsoon (ISM) phases during the Holocene. The ability of radar data to operate independently of cloud cover also makes it highly suitable for tropical regions where persistent cloudiness limits optical observations.

The use of Hyperspectral remote sensing represents another technological leap with significant implications for palaeosciences. Hyperspectral sensors capture hundreds of narrow spectral bands, enabling precise identification of minerals, clay assemblages, carbonates, and iron oxides. These mineralogical signatures provide clues to weathering intensity, provenance, and depositional conditions, which are directly linked to palaeoclimate. For example, the spatial distribution of kaolinite, illite, or smectite can be used to infer variations in humidity, temperature, and erosion regimes in the geological past. The hyperspectral data also facilitate mapping of evaporites, paleosols, and authigenic minerals that form under specific redox and climatic conditions.

Thermal remote sensing contributes to palaeoscientific studies by revealing subsurface moisture variations, lithological contrasts, and geothermal anomalies. The Thermal inertia differences observed in thermal infrared data can distinguish between sediment types and degrees of compaction, aiding in the identification of buried channels and ancient sedimentary bodies. In coastal and marine palaeoscience, sea surface temperature datasets derived from satellite observations help contextualize proxy-based palaeotemperature reconstructions and improve understanding of ocean–atmosphere interactions over Quaternary timescales.

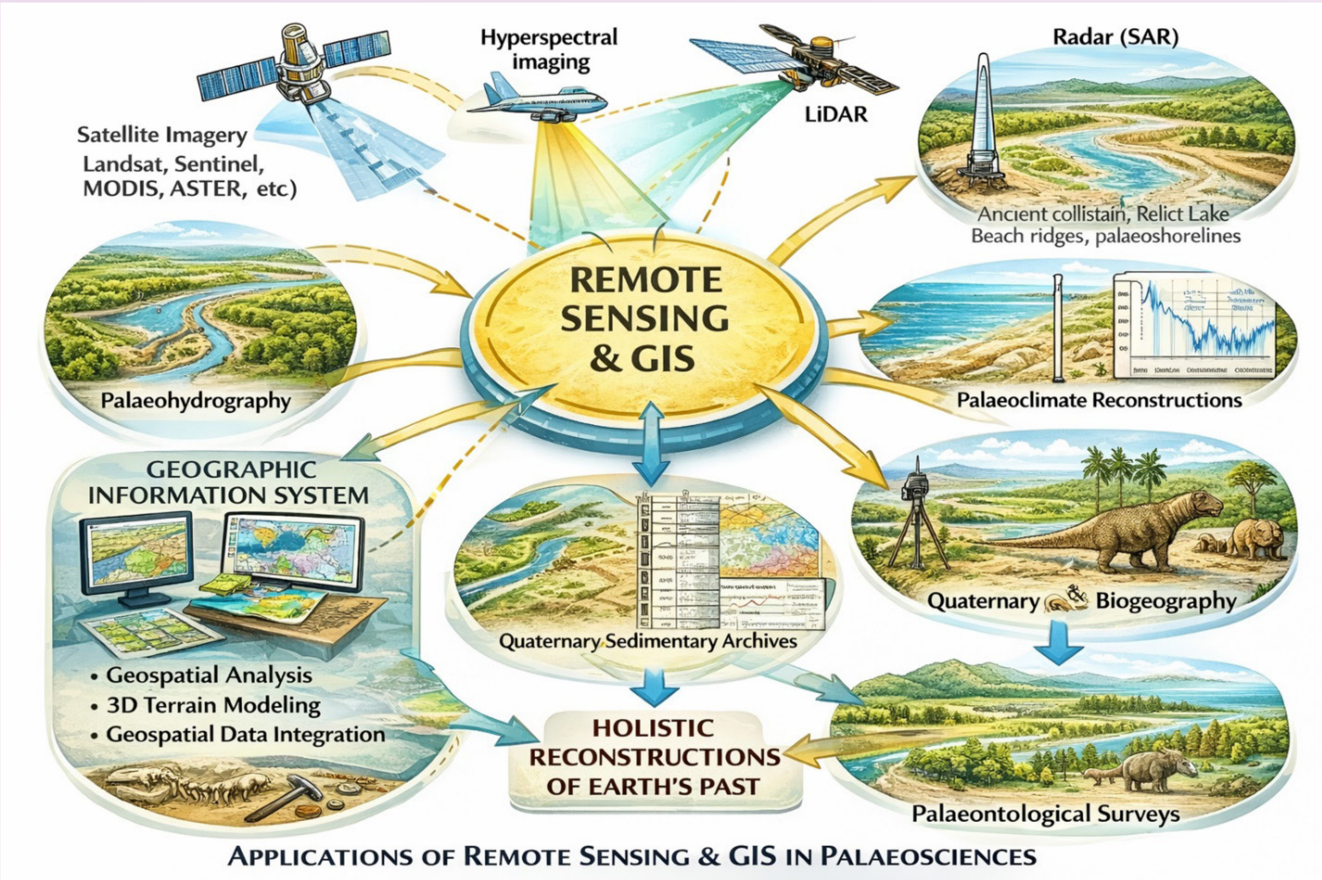

Figure 1: Schematic pictorial description of Remote Sensing and Geographical Information System (GIS) in palaeoscientific studies

While remote sensing provides spatially continuous observations, GIS serves as the integrative framework that enables storage, analysis, visualization, and modeling of palaeoscientific data. GIS has transformed palaeosciences from largely descriptive disciplines into quantitatively driven, spatially explicit sciences. One of the major strengths of GIS lies in its ability to integrate diverse datasets, including satellite imagery, DEMs, sedimentological logs, geochemical proxies, fossil distributions, chronological data, and climatic model outputs. This multi-layered integration allows palaeoscientists to examine complex relationships between environmental variables and Earth system processes across space and time.

The Spatial analysis tools within GIS have been extensively applied to reconstruct palaeolandscapes and palaeohydrological systems. The techniques, such as watershed delineation, flow accumulation, slope analysis, and terrain ruggedness mapping help infer ancient drainage configurations and erosional regimes. In floodplain and deltaic settings, GIS-based spatial statistics are used to quantify channel belt dimensions, sediment dispersal patterns, and accommodation space changes. These analyses are crucial for understanding sedimentary responses to sea-level fluctuations, tectonic subsidence, and climate-driven discharge variability.

GIS also plays a central role in palaeoclimate studies by enabling spatial interpolation and visualization of proxy records. The data derived from pollen, diatoms, foraminifera, isotopes, and geochemical indices are often point-based and unevenly distributed. With the aid of GIS-based interpolation methods, such as kriging and inverse distance weighting (IDW), it allow the generation of continuous palaeoclimate surfaces representing temperature, precipitation, vegetation cover, or salinity gradients. Such spatial reconstructions provide a more holistic understanding of regional climate dynamics and facilitate comparison with outputs from numerical climate models.

Advancements in geospatial modeling have further strengthened the role of GIS in palaeosciences. Process-based models integrated within GIS environments simulate landscape evolution, sediment transport, shoreline migration, and glacier dynamics under varying boundary conditions. These models help test hypotheses about past environmental changes and quantify the relative influence of climate, tectonics, and sea-level change. In coastal palaeosciences, GIS-based shoreline change models combined with remote sensing-derived palaeoshoreline indicators provide insights into relative sea-level history and coastal response to climate variability.

The integration of remote sensing and GIS has also significantly advanced palaeoecological and biogeographical studies. The fossil distributions, pollen assemblages, and faunal remains can be spatially analyzed within GIS to reconstruct past ecosystems and migration pathways. The Species distribution modeling (SDM), originally developed for modern ecological studies, is increasingly applied to palaeoecological data to infer habitat suitability under past climatic conditions. These approaches enhance understanding of biodiversity responses to climate change and extinction events over geological timescales.

The recent technological advancements, such as cloud-based geospatial platforms have further transformed palaeoscientific research. The platforms like Google Earth Engine (GEE) allow large-scale processing of multi-temporal satellite datasets without the need for extensive local computational resources. This has enabled palaeoscientists to analyze long-term landscape changes, vegetation dynamics, and hydrological variations at unprecedented spatial and temporal scales. The accessibility of such platforms also promotes reproducibility and collaborative research across disciplines and regions.

With the advent of machine learning and artificial intelligence, the new era represents emerging frontiers in the application of remote sensing and GIS to palaeosciences. The automated classification algorithms are increasingly used to detect palaeochannels, landforms, and lithological units from large satellite datasets. The pattern recognition techniques help identify subtle geomorphic features that may be overlooked through manual interpretation. When combined with GIS-based validation using field and proxy data, these methods significantly improve the efficiency and objectivity of palaeoenvironmental mapping.

However, despite these advancements, challenges remain in the application of remote sensing and GIS to palaeosciences. The temporal resolution is a key limitation, as satellite observations represent modern surface conditions, whereas palaeoscientific interpretations rely on indirect inference. Ground truthing through field investigations and proxy analyses remains essential to validate remote sensing interpretations. Additionally, uncertainties in chronological control and proxy sensitivity must be carefully addressed when integrating spatial datasets in GIS frameworks. Nevertheless, continuous improvements in sensor technology, data availability, and analytical methods are steadily reducing these limitations.

In conclusion, remote sensing and GIS have become indispensable tools in modern palaeosciences, fundamentally transforming how past Earth systems are studied and interpreted. The technological advancements in satellite sensors, DEM generation, radar and hyperspectral imaging, and geospatial modeling have enabled detailed reconstruction of palaeolandscapes, climates, and ecosystems across spatial and temporal scales that were previously unattainable. GIS provides the critical integrative platform for combining remote sensing data with geological, biological, and geochemical proxies, facilitating holistic and quantitative interpretations of past environmental change. As emerging technologies, such as cloud computing, machine learning, and high-resolution Earth observation continue to evolve, the role of remote sensing and GIS in palaeosciences is expected to expand further, offering deeper insights into Earth's past and improving our understanding of future environmental trajectories.

About authors

Dr Biswajeet Thakur is currently serving as Scientist 'F' at the BSIP, Lucknow. His research focuses on multi-proxy approaches to investigate past climate variability across diverse geographical settings, particularly the western and eastern coastal margins of India.

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Mr Nazakat Ali is pursuing Ph.D. from BSIP, Lucknow. His research focuses on Indian Summer Monsoon variability using multi proxy approach, including grain-size studies, clay mineralogy, geochemistry, palynofacies analysis, and environmental magnetism.

Mr Shivansh Saxena is pursuing Ph.D. program at BSIP, Lucknow. His research focuses on limnological and sedimentary organic matter characterization from the Central Ganga Plain and Core Monsoon Zone of India, during the Late Quaternary.

Ancient Climates, Modern Lessons

Kritika Shreya

What if the rocks beneath our feet could warn us about the future?

In many ways, they already do. Long before weather apps and climate models existed, Earth recorded its own climate history: layer by layer, fossil by fossil. Understanding ancient climates is not an academic curiosity about a distant past. It is a crucial key to understanding how our planet responds to change, how ecosystems adapt or collapse, and what the future might hold for humanity in a warming world.

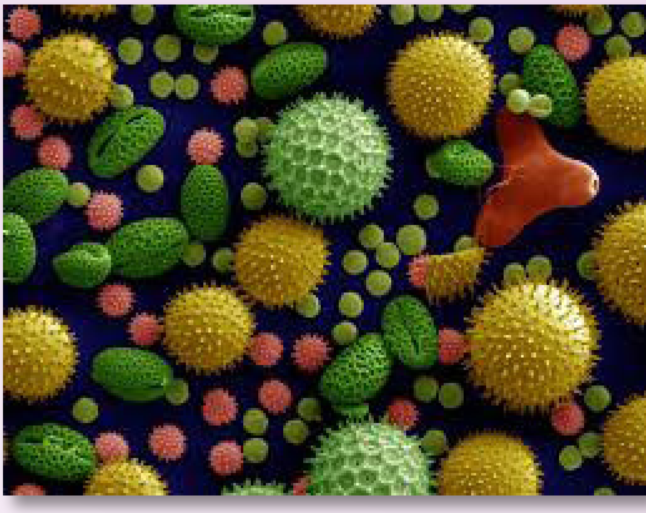
Fossils and layered rocks act as natural archives, preserving evidence of Earth's ancient climates.

Reading Earth's Climate Archive

Earth is about 4.6 billion years old, and over this immense span of time, its climate has never been static. It has swung between extreme cold "icehouse" phases– when glaciers covered vast portions of the continents– and hot "greenhouse" periods, when palm trees grew near the poles and sea levels were dramatically higher.

But, how do scientists know this?

- **Fossils** reveal past vegetation, animals, and marine life, each adapted to specific temperature and rainfall conditions.
- **Sedimentary rocks** preserve evidence of ancient rivers, deserts, glaciers, and oceans.
- **Pollen grains**, microscopic yet incredibly durable, record shifts in vegetation and rainfall patterns.
- **Isotopes** in shells, ice, and minerals provide precise information about past temperatures and atmospheric composition.



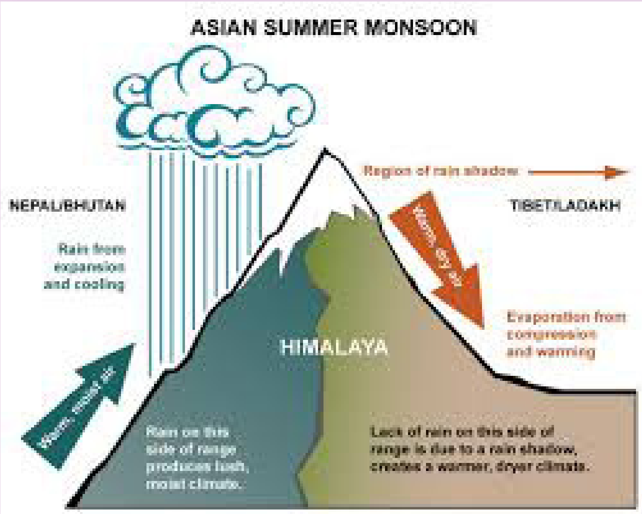
Pollen grains in sediment layers provide evidence of past vegetation and rainfall patterns.

India's Ancient Climate Story

India's climate history is closely linked to one of the most dramatic geological events on Earth–the collision of the Indian plate with Asia around 50 million years ago. This collision led to the rise of the Himalayas, which, in turn, reshaped atmospheric circulation and gave birth to the South Asian monsoon system.

Fossil plants and pollen from different geological periods show that India once supported lush tropical forests even in regions that are semi-arid today. At other times, extended dry phases turned green landscapes into open grasslands. These shifts were driven by changes in global temperatures, sea levels, and the strength of monsoon winds.

Such studies remind us that the monsoon– a lifeline for agriculture and water security in India– is sensitive to even small changes in global climate.



The rise of the Himalayas significantly influenced atmospheric circulation and the evolution of the Indian monsoon.

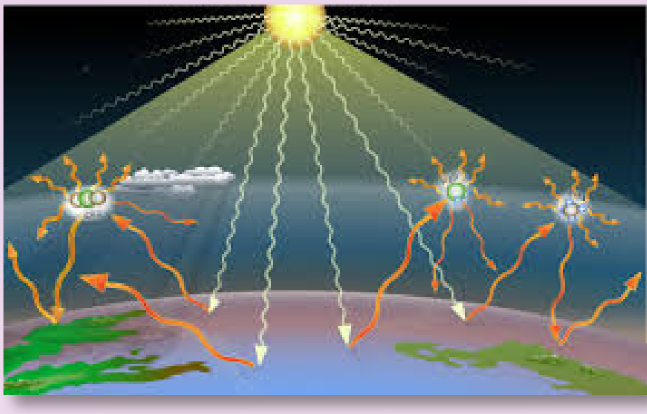
Lessons from Ancient Warming Events

One of the most striking examples from Earth's past is the Paleocene–Eocene Thermal Maximum (PETM), which occurred about 56 million years ago. During this period, global temperatures rose rapidly by about 5–8 °C due to a massive release of carbon into the atmosphere.

The consequences were profound:

- Oceans became warmer and more acidic.
- Many marine organisms went extinct.
- Ecosystems took tens of thousands of years to recover.

What makes the PETM particularly relevant today is its similarity to modern climate change. Although the ancient carbon release occurred more slowly than today's human-driven emissions, the impacts were still severe. This comparison highlights a sobering lesson: Earth's systems are sensitive, and recovery from rapid warming is slow.



Ancient warming events demonstrate the long-term impacts of rapid carbon release on Earth's systems.

Climate Change and Life: Adapt, Migrate, or Vanish

The fossil record repeatedly shows that climate change reshapes life on the Earth. Species faced with changing temperatures and rainfall patterns have three options:

1. **Adapt** to new conditions,
2. **Migrate** to more suitable environments, or
3. **Go extinct**.

In the past, many species had the advantage of time and open landscapes to migrate. Today, human-made barriers–cities, roads, farms–limit these natural responses. Ancient extinctions, therefore, serve as warnings about biodiversity loss in the modern era.

Fossil record shows that when climates change, species must adapt, migrate, or face extinction.

Why the Past Matters for the Future

Modern climate models are powerful tools, but they rely on assumptions about how Earth systems behave. Ancient climate records act as real-world experiments, showing what actually happened when greenhouse gases increased, ice melted, or monsoon patterns shifted.

For a country like India, with its dependence on monsoons and rich biodiversity, these insights are invaluable for policy-making and sustainable planning.

Bridging the gap between scientific research and public understanding

One of the most important challenges today is bridging the gap between scientific research and public understanding. Journals, conferences, and technical reports are essential for scientists, but the broader public needs stories–stories that explain *why* ancient climates matter to our everyday lives. Researches in simple, engaging, and story-like narratives, help students, educators, and the science-curious public see the deep connections between Earth's past and humanity's future. Imagine a small coastal village thousands of years ago. The sea slowly began to rise, flooding fields and forcing families to move inland. Archaeologists today find abandoned homes buried under sand, while palaeoclimatologists study ancient sediments to confirm a period of rapid warming and melting ice.

This is not just a story of the past. It mirrors what many coastal communities face today as sea levels rise due to climate change. Presented as a story, this research helps the public understand that climate change is not an abstract concept; it is a repeating pattern with real consequences, reminding us why lessons from the past are crucial for planning a safer future.

Ancient climate research is not just about fossils and rocks; it is about food security, water availability, natural disasters, and the kind of planet we will leave for future generations. For a climate-sensitive country like India, lessons from the deep past are essential for building a resilient future.

A Final Reflection

Earth has survived dramatic climate changes before, but survival often came at a great cost to life. The lesson from ancient climates is clear: change is inevitable, but the speed and scale of change matter.

By listening carefully to Earth's deep past, we gain the wisdom needed to make better decisions today. Ancient climates are not distant, irrelevant stories; they are mirrors held up to our present, offering guidance, warnings, and hope, if we choose to learn from them.

Ancient climates are not distant stories, they are messages from Earth's past. Listening to them can help us make informed choices for a sustainable tomorrow.

Ancient climates whisper lessons through stone and fossil. It is up to us, in the modern age, to listen.

About author

Ms. Kritika Shreya is a dedicated Social Science teacher who emphasizes critical thinking, inquiry-based learning, and real-life connections to help students understand society and the world around them. By integrating content with interactive activities and digital tools, she strive to create an inclusive and learner-centric classroom that encourages curiosity, discussion, and informed citizenship.

Cycads: Living Fossils In Peril

Pragya Gautam

CYCADS are among the most ancient seed-bearing plants on the Earth. They represent the earliest stage in plant evolution where insect pollination first appeared. In the course of time, flowering plants (angiosperms) evolved from these primitive plant forms. Botanically, cycads are classified as gymnosperms. They do not produce flowers; instead, they form naked seeds on cone-like structures. All plants belonging to the order *Cycadales* are collectively known as cycads.

Around 145 million years ago, when dinosaurs dominated the Earth, cycads flourished across vast landscapes. They were a favored food source for herbivorous dinosaurs. With the mass extinction at the end of the Jurassic Period, dinosaurs vanished, and the cycads of that ancient world also largely disappeared. Yet, some of their descendants survived the test of time. These surviving lineages persist today as living fossils, reminding us of Earth's deep and ancient botanical past.

CYCADS: SILENT WITNESSES OF DEEP TIME

Resembling ancient palm trees, cycads are dioecious plants, with male and female individuals existing separately. They are among the slowest-growing plants on the Earth, unfolding their lives with remarkable patience. Once or twice a year, a graceful crown of leaves emerges at the summit of the stem, as if time itself pauses to witness their quiet renewal. The stem, unlike that of modern trees, is not solid, but soft and pith-filled, preserving a primitive architectural design. Their leaves, elegant and feathery, echo the form of palms and lend the plants a timeless dignity.

Beyond their ordinary roots, cycads develop extraordinary coralloid roots, living chambers that shelter blue-green algae (*Anabaena*) in a delicate symbiosis. Within this ancient partnership, atmospheric nitrogen is transformed into life-sustaining nourishment, allowing cycads to survive in nutrient-poor soils.

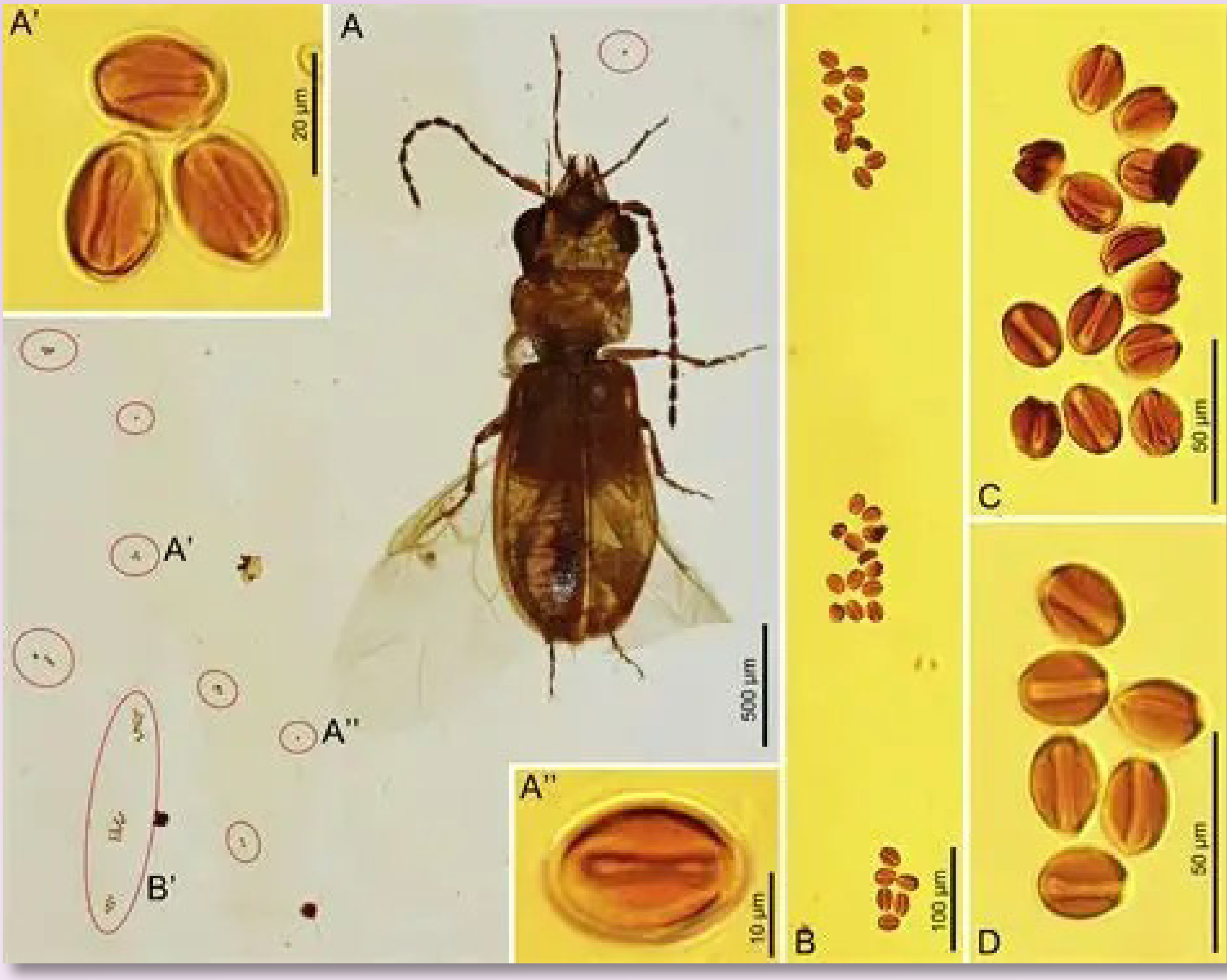
For long, it was believed that the subtle art of insect pollination belonged solely to flowering plants. Yet, cycads quietly challenge this assumption. Despite lacking flamboyant flowers, they engage in an age-old dialogue with select species of beetles, relying on them to carry pollen from one cone to another. Today, these living relics of Earth's distant past stand on the brink of extinction. The loss of their natural habitats and the disappearance of their pollinators threaten to silence a lineage that has endured for millions of years, a gentle reminder of the fragile bond between time, life, and survival.

For many years, it was believed that cycads relied solely on wind for pollination. However, an incident in the early twentieth century quietly overturned this long-held assumption.

In South Africa, a naturalist named Alice Pegler was the first to observe beetles crawling over cycad cones, an observation that hinted at a far more intimate relationship between plant and insect. Later, in 1906, Professor Harold Pearson presented Alice Pegler's findings before the Royal Society. Yet, at the time, the evidence for insect pollination was considered insufficient. It seemed almost inconceivable that such primitive plants, whose seeds had evolved nearly 280 million years ago, could engage in insect-mediated pollination. After all, flowering plants had not even appeared on Earth during that distant era.

It was not until 1986 that researchers in the United States conclusively demonstrated that insect pollination does indeed occur in certain species of cycads. Remarkably, evidence revealed that insect

Female and male plants of the *Cycas revoluta* (image source- biologyprimer)



A beetle preserverd in amber with cycad pollens (Image source -chenyang Cai)

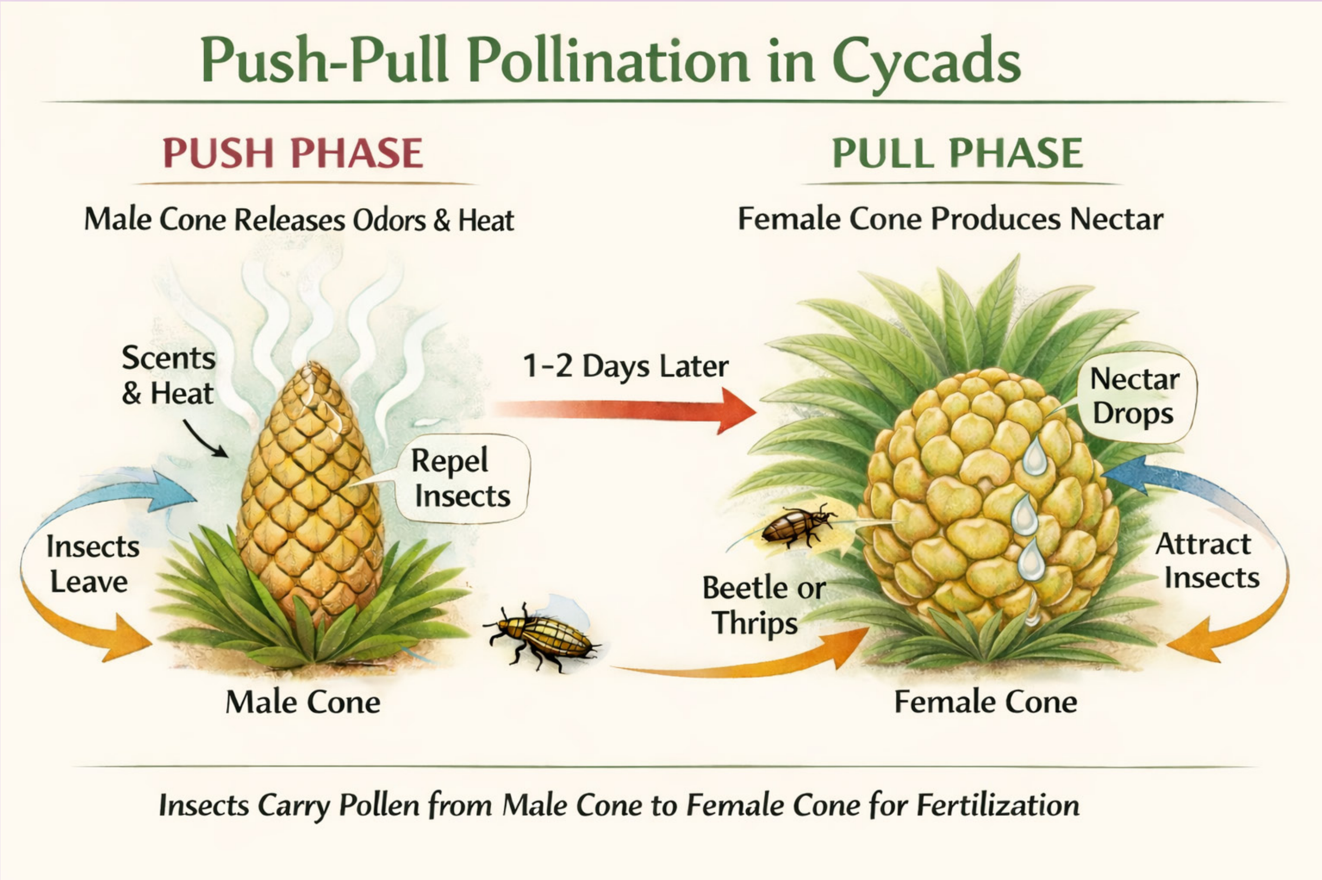
species, such as *Rhopalotria furfuracea* complete their entire life cycle within the male cones of the cycad *Zamia furfuracea*. Both larvae and adults feed exclusively on the tissues of the male cone, forming an intricate and ancient biological partnership.

Today, it is firmly established that insect pollination occurs across all ten genera and nearly 350 species of cycads. This discovery reshapes our understanding of plant evolution and reveals that the alliance between insects and seed plants is far older, and far more profound, than once imagined.

CYCADS AND THEIR ANCIENT INSECT ALLIES

Cycads depend on highly specialized insects for their reproduction. The process of insect pollination in cycads is extraordinarily ancient, tracing its origins to a time even before the Middle Cretaceous Period.

In 2018, Chenyang Cai and his colleagues at the Nanjing Institute of Geology and Palaeontology (NIGPAS) studied a remarkable piece of amber discovered in Myanmar. This amber, dated to nearly 99 million years ago, preserved within it a beetle named *Cretoparacucujus cycadophilus*, belonging to



the family Boganiidae. Alongside the fossilized beetle, grains of cycad pollen (*Cycadopites*) were also trapped in the amber. The beetle's legs and mouthparts showed clear adaptations for carrying pollen, including specialized mandibular cavities beneath the jaws.

Phylogenetic analysis of *Cretoparacucujus cycadophilus* revealed that this ancient beetle is closely related to modern *Paracucujus* beetles that pollinate cycads in present-day Australia and South Africa. Even more striking is the fact that these modern beetles continue to pollinate the very same cycad lineage (*Encephalarteae*). This enduring co-evolutionary relationship has remained remarkably stable for millions of years.

Fossil studies of other ancient beetle families, such as Parandrexidae, Nitidulidae, and Kateretidae, further reinforce the evidence for insect pollination in cycads. Modern representatives of these groups are often pollen feeders, echoing an ancient ecological role that has persisted since deep geological time.

HOW POLLINATORS ARE DRAWN IN

In most cycads, a form of *brood-site pollination mutualism* is observed. To achieve this, cycads employ an ancient push–pull mechanism, a strategy refined long before the evolution of showy flowers. Scientific research has revealed a striking and unexpected insight: the same mechanism used by weevil pollinators in New World cycads is also employed by thrips pollinators in their distant relatives, the Old World cycads. This remarkable similarity in pollination behavior among such different insects is known as behavioral convergence.

The push–pull pollination mutualism is among the most ancient pollination strategies on the Earth. It evolved at a time when flowering plants, with their vivid blossoms and visual allure, had not yet appeared. In cycads, pollination is carried out by beetles, weevils, and thrips. These insects inhabit the male cones, feeding on their tissues and using them as brood sites.

At a certain point during the day, the temperature of the male cone rises and reaches a peak. Simultaneously, the cone releases a burst of aromatic volatile compounds. When both heat and scent reach their maximum intensity, they effectively *push* the insects away, forcing them to abandon the male cone. At precisely the same moment, the female cone undergoes a subtle rise in temperature and begins to emit its own fragrance. This gentle warmth and scent *pull* the insects toward the female cone, where they deposit the pollen grains they carry.

At this critical moment, a honey-like, sticky substance oozes from the micropyle, the opening of the ovule within the female cone. Rich in sugars and amino acids, this secretion signals that the ovule is receptive and ready to receive pollen. Produced only in minute quantities, the substance cannot truly nourish the insects; instead, it serves as a delicate illusion of reward–a final, subtle deception in an ancient evolutionary dance between plant and pollinator.

ANCIENT PLANTS UNDER A DOUBLE THREAT

These neglected ancestors of modern plants are slowly bidding farewell to the Earth. Naturalists now fear that, battered by the destruction of their habitats and relentless illegal collection, cycads may vanish silently from the planet. Among all plant groups today, cycads are considered the most endangered.

At the Royal Botanic Gardens, Kew, a vast living collection of cycads dating back to the nineteenth century is preserved. Within this collection stands a solitary and poignant specimen: *Encephalartos woodii*. This lone male plant has no surviving female counterpart anywhere on the Earth. Though it remains alive, propagated through cloning from its offsets, its lineage is trapped in biological isolation, for there is no female plant left to ensure its natural continuation.

In India, cycads are represented solely by the genus *Cycas*. Twelve species of this genus occur across various states of southern India. Among them, *Cycas andamanica* (Andaman Islands), *Cycas annaikalensis* (Kerala), and *Cycas nayagarhensis* (Odisha) are critically endangered. In addition, species, such as *Cycas beddomei* (Andhra Pradesh), *Cycas circinalis* (Kerala), and *Cycas orixensis* (Odisha) have also slipped into the threatened category.

These ancient plants, once witnesses to the age of dinosaurs, now stand at the edge of oblivion, quiet reminders of how fragile even the most enduring lineages can be in a rapidly changing world.

Thriving in tropical and sub-tropical climates, cycads grow at an exceptionally slow pace. They take nearly twenty to thirty years to reach maturity. If a mature plant is destroyed, it takes decades for another to take its place. Drawn by their striking beauty, people often remove cycads from their natural habitats and transplant them into gardens. At the same time, rapid urbanization continues to erode their native landscapes. In the wild, their populations become scattered and sparse; male and female plants drift far apart. As habitats disappear, so do their pollinators, and with this loss, reproductive failure steadily increases.

In their natural environments, cycads once coexisted in delicate harmony with their pollinators, each dependent on the other to complete their life cycles. In cultivated gardens, however, these plants often fail to reproduce, as their ancient insect partners are absent. Meanwhile, some of the rarest wild species fall prey to collectors, quietly vanishing from their last refuges.

Local indigenous communities also harvest cycads for their attractive ornamental leaves and seeds. Male cones are used for medicinal purposes, while starch extracted from the stem and the seeds serves as food. Yet, these plants contain a highly toxic compound, cycasin, making careful processing essential before consumption. Among the many forces threatening Earth's biodiversity, human activity stands foremost. Protecting natural habitats, enforcing strict bans on illegal harvesting, and conserving cycads in botanical gardens are all urgently necessary. Through genetic analysis, vulnerable and declining species must be identified and safeguarded before they disappear.

The responsibility lies with all of us to ensure that these beautiful survivors of deep time continue to endure on our planet, rather than fading silently into extinction.

Cycas beddomei (image source -eflora of india)

About author

Ms. Pragya Gautam is a Lecturer in Biology, based in Kota, Rajasthan. She is actively engaged in teaching and mentoring students and, as a science communicator, works to popularize life sciences and scientific thinking through talks, outreach activities, and student-focused initiatives.

Investigation of the Effect of Black Carbon and Organic Lipids in Antarctica's Changing Climate Begins at BSIP

Antarctic Researchers **Dr Srinivas Bikkina** and **Dr Manoj MC**
in conversation with **Dr Nimish Kapoor**

THE Birbal Sahni Institute of Palaeosciences (BSIP) is pioneering groundbreaking research to shape and influence global climate change policies, providing critical insights for a sustainable future. BSIP has long been at the forefront of scientific research, contributing valuable insights into Earth's changing environment. With its pioneering study on black carbon and organic lipids in Antarctica, BSIP continues to play a vital role in advancing climate science, providing crucial data to inform and shape global climate change policies.

As concerns over climate change intensify, understanding the impact of pollutants on the polar regions has become more critical than ever. A new investigation is underway at the BSIP to explore the presence and movement of black carbon and organic lipids in Antarctica's rapidly changing environment.

This study, focused on the Schirmacher Oasis region, aims to unravel the sources and transport mechanisms of these pollutants, distinguishing between local and long-range contributors. The findings from this research will support India's ongoing polar scientific endeavours and add valuable data to global climate models, enhancing our understanding of the broader effects of these pollutants on the Earth's climate system.

Fig. 1. Field team (Dr. Srinivas Bikkina & Dr. Manoj MC) measuring lake water parameters using a multiparameter probe in a partially frozen Antarctic Lake during sampling operations.

Fig. 2. Collection of sediment and surface material along the margin of an Antarctic Lake. Dr. Srinivas Bikkina & Dr. Manoj MC documenting and sampling glacially derived sediments.

As part of the 44th Indian Scientific Expedition to Antarctica (ISEA), Dr. Srinivas Bikkina and Dr. MC Manoj have embarked on a crucial Antarctic mission to investigate the transport and depositional impacts of regional wildfire-emitted black soot on the ice surfaces of Schirmacher Oasis in a rapidly changing climate.

The journey began on November 7, 2024, at the National Centre for Polar and Ocean Research in Goa, where pre-expedition activities, including issuing official passports and fire-fighting training, were conducted from November 7-16, 2024. On November 20, 2024, the team arrived at Maitri Station and quickly began discussions with the station leader and the logistics team to set up the necessary sampling equipment. Within days, the high-volume dust sampler (APM-430) was successfully installed, and the team began collecting crucial samples on November 24, 2024, marking the official start of their research efforts in Antarctica. In this interview, we discuss their exciting journey to Antarctica, their personal experiences at the South Pole, and how they plan to study the samples collected to reveal the secrets of the Antarctic environment and its role in global climate systems.

In this insightful conversation, Dr Nimish Kapoor, Science Communicator & Scientist, BSIP, delves into the pioneering research being conducted by Dr Srinivas Bikkina and Dr MC Manoj at the Birbal Sahni Institute of Palaeosciences (BSIP). As part of the 44th Indian Scientific Expedition to Antarctica, the duo shares their experiences from the frozen continent. It sheds light on their groundbreaking study on black carbon and organic lipids. Here, they discuss the challenges, the science behind their research, and the broader implications of their work on global climate change policies. Here are the excerpts from the discussion with Dr Srinivas Bikkina and Dr MC Manoj:

- **Can you briefly introduce the scope and objectives of your study in Antarctica, particularly focusing on black carbon and organic lipids?**

Did you know that Antarctica is the coldest place on Earth, covered in ice, sometimes as thick as 4 kilometres? That is taller than the most prominent mountains. Our work helps ensure this icy wonderland stays frozen, so you can visit it one day. We went to Antarctica to study something called *black carbon*—like tiny bits of soot from wildfires or machine smoke—and organic lipids, like tiny pieces of fat from plants and animals. We wanted to find out where this soot and these fats come from and how they travel to Antarctica. Some might

Fig. 3. Field team posing with the sediment cores collected from a proglacial lake in Antarctica.

Fig. 4. Preparation of an ice corer on the margin of a frozen lake.

come from faraway places, like wildfires in Australia, and some might come from nearby activities, like the ships or stations in Antarctica. Our big goal is to understand how these things change Antarctica's ice and climate, which helps us learn how to protect our planet.

- **Before heading to Antarctica, there were several pre-expedition activities, including medical tests, fire-fighting training, and passport formalities. How did you prepare for the physically and mentally demanding conditions of the expedition?**

Antarctica is super cold and windy, so we had to prepare for a big adventure. Before going, we underwent a series of medical/psychological tests at the All India Institute of Medical Sciences (AIIMS) in New Delhi to ensure we were healthy enough to withstand the extreme climates. Following these tests, we attended pre-Antarctic snow-ice acclimatization training at Indo-Tibetan Border Police (ITBP), Auli. The Instructors and the ITBP team provided specialized training in trekking, camping, rappelling, climbing, and rescue techniques. Also, they taught different knots for different operations. We practised staying safe in the cold, like wearing many layers of clothes, and learned to work together as a team.

Before our journey to this cold, barren, and icy world, we were briefed at the National Centre for Polar and Ocean Research (NCPOR) in Goa on the rules and regulations at the Indian research base, Maitri Station, in Schirmacher Oasis, during the Expedition by previous Antarctic veterans from various fields.

We also learned how to fight fires in Goa- a one-day professional and mandatory training course organized by the NCPOR—just in case—because there's no firefighter station in Antarctica. It was like getting ready for a big camping trip, but in a freezing, icy world.

- **How did you determine which environmental samples to collect during the expedition? Could you walk us through the different types of samples you gathered?**

We planned to collect various samples to tell us about Antarctica's environment. We wanted to know about the air, snow, ice, water, and even the dirt. We collected the following samples.

- **Dust in the Air**: We used a high-volume dust sampler (APM-430) to capture tiny dust particles in the air.

Fig. 5. Researchers examining freshly recovered ice sections during field investigations.

Fig. 6. Atmospheric sampling setup near the Antarctic research station (Maitri) using a high-volume air sampler.

Fig. 7. Measurement of water column parameters in the Priyadarshini Lake from a platform near the Maitri research station using a water-quality probe.

- **Snow and Ice**: We collected snow from places like Mount Vataya and Mount Gruber, and a snow core (like a long ice stick) from near Priyadarshini Lake to see if it contained soot.
- **Sediments and Rocks**: We collected many sediment samples from lakes and soil samples around Maitri Station, as well as rocks, to learn about the chemistry and understand the sources.
- **Water from Lakes**: We collected water from multiple lakes in the Schirmacher Oases to study particulate organic matter.
- **Algal Mats and Moss**: We collected slimy algae and soft moss from lakes to see which plants and tiny creatures live there and how soot contributes to their growth.

Also, we picked these samples because each one tells us a different story about how pollution reaches Antarctica and how it affects the ice, water, and life there.

- **What are black carbon and organic lipids, and how do they impact the environment in Antarctica? Specifically, how does black carbon contribute to warming and ice melt, and what role do organic lipids play in understanding biological and ecological changes in the polar ecosystem?**

  Black carbon is like tiny black soot from burning things, like when there's a wildfire or when cars and ships make smoke. This soot lands on the white snow and ice in Antarctica, making them darker. Usually, white snow reflects sunlight, but when it's dark, it soaks up the sun's heat and starts to melt faster. This melting can make the climate warmer and cause more ice to disappear, which is terrible for penguins and the whole planet because it increases sea levels.

  Organic lipids are like tiny bits of fat from plants, animals, or sea creatures. They are like clues that tell us what living things were around in the past and how the environment has changed. They help us understand how life in Antarctica's lakes and land is changing because of pollution or climate change.

- **You collected nine dust samples at intervals of 8–10 days. What specific analysis do you plan to conduct on these samples, and what are you hoping to uncover about black carbon and organic tracers in the atmosphere?**

  We collected nine dust samples from the air using a special machine, taking one every 8–10 days to see how the air changes over time. Back at our lab at the BSIP, we'll do some cool experiments:

  We will use an Elemental Analyzer machine to check how much black carbon (soot) is in the dust. Also we will look at the dust with a "stable isotope test" (using $\delta^{13}C$) to see if the soot came from burning plants or other sources. Another test (using $\Delta^{14}C$) will tell us if the soot is old or new. We will look for unique markers called *anhydrosugars* (from burning plants) and *fatty acids* and *n-alkanes* (from plants and animals) to find out what kinds of things were burning. We want to figure out if the soot came from faraway wildfires in places like Australia, or from nearby ships and stations in Antarctica. This will help us understand how pollution travels and how it affects Antarctica's air and climate.

- **What insights are you hoping to gain from the surface sediments, permafrost, and rock samples collected from Schirmacher Oasis and surrounding areas? How do these samples contribute to understanding the environmental influences in Antarctica?**

  To learn about Antarctica's past and present, we collected sediments, frozen sediments (called permafrost), lake sediment cores, and rocks from Schirmacher Oasis. Here's what we're looking for:

  In the sediments and permafrost, we'll check for black carbon and organic lipids to see if pollution has been around for a long time or just recently.

  The rocks will tell us about the land itself—like what kind of rocks Antarctica has and how they've changed over time.

  We'll look for tiny clues in it to see if wildfires or pollution reached Antarctica long ago. These samples help us understand how pollution has changed Antarctica over time, and how the environment, like the ice and lakes, has been affected by things like warming or human activities.

- **The snow samples were taken from Mount Vataya, Mount Gruber, and Maitri surroundings. How will these snow samples help assess the background levels of black carbon in the region?**

Snow in Antarctica is super white and clean, right? But sometimes, tiny bits of black carbon (soot) can land on it. We collected snow from Mount Vataya, Mount Gruber, and around Maitri Station to see how much soot is naturally present or coming from other sources. We will melt the snow and filter it with tiny nets (0.45 µm filters) to catch the soot. Then, we will use other machines at the BSIP to measure how much black carbon is in it. This tells us the amount of soot in Antarctica's snow. If we find more soot later, we'll know it's from sources like wildfires, ships, or other pollutions. This helps us understand how these soot particles are coming to Antarctica and how they are changing the ice (reflecting type to absorbing type).

- **You also collected a snow core from Priyadarshini Lake. Can you explain the significance of the isotopic analysis you plan to perform on the ice core?**

We drilled a 1-meter-long ice core from Priyadarshini Lake—like a long, frozen popsicle that holds secrets from the past. Inside this ice, there are tiny bits of air, water, and even soot trapped from years ago. We will perform a special test, called isotopic analysis, on the ice core, looking at parameters called $\delta^{13}C$ and $\Delta^{14}C$. These are like codes that tell us whether the black carbon in the ice came from burning plants (like wildfires) or from fossil-fuel combustion. How old is the soot? Is it new or from several years ago? This helps us figure out how long these soot particles have been arriving in Antarctica and where they came from. It is like being detectives looking at an icy history book.

- **You collected water samples from multiple lakes, including Priyadarshini Lake. What does the study of particulate organic matter (POM) dynamics in these lakes reveal about the local ecosystem?**

We took water from Priyadarshini Lake and some from the Schirmacher Oases to study particulate organic matter (POM). POM is like tiny bits of plants, algae, and other living things floating in the water. By looking at POM, we can learn - What kinds of tiny plants and animals live in the lakes—like algae and moss. How healthy the lake is. If there's too much POM, it might mean the lake is changing because of warming or pollution. This tells us how the lake's ecosystem is doing and if climate change or pollution affects the water and its life.

- **How do you plan to analyze the water samples collected daily at noon to study the ecological dynamics of particulate organic matter during the lake's peak productivity period?**

We collected water from Priyadarshini Lake every day at noon because that's when the sun is highest, and tiny plants like algae grow the most—it's their "peak productivity" time. Here is how we will study the water: We will filter it to capture the tiny bits of plants and animals (called POM). Then, we will look at these bits with machines to see what they are made of—like how much carbon and other stuff is in them. We will also check for day-to-day changes, such as whether more algae grow on sunny days or fewer on cloudy days. This helps us understand how the lake's tiny plants grow and how they are affected by sunlight, temperature, or pollution. It is like taking a daily picture of the lake's life.

- **You retrieved algal mats and moss samples from multiple lakes. What role do biological contributions play in the organic matter cycles, and how do you intend to study them through these samples?**

We collected slimy algal mats and soft moss from lakes because they're like tiny gardens in the water. Algae and moss make food using sunlight, just like plants, and they are super important for the *organic matter cycle*. This cycle is like a big recycling system in nature: Just as any other tiny fish or bugs, algae and moss produce food and oxygen for other creatures in the lake. When they die, they break down and turn into nutrients that help other things grow. We will study these samples by analyzing the organic lipids to determine which algae and moss are present. Checking their carbon with special machines (like the Elemental Analyzer and Gas chromatography-mass spectrometry (GC–MS)) to learn how much they add to the lake's nutrients. This helps us see how algae and moss keep the lake alive and how they change in response to climate or pollution.

- **The presence of black carbon in Antarctica has been linked to long-range transport from wildfires and emissions from research and tourism activities. What techniques will you employ to distinguish between these sources, and why is this important for climate modeling?**

Black carbon in Antarctica can come from faraway wildfires in Australia or nearby ships and research stations. To figure out where it is coming from, we will use some methods:

Isotope Tests ($\Delta^{14}C$ and $\delta^{13}C$): These tests are like a fingerprint for the soot. If the soot is really old (from fossil fuels like car fuel), it will have a different code than if it is from plants (like wildfires).

Special Markers (Anhydrosugars): These are clues from burning plants. If we find a lot of them, it means the soot came from wildfires.

Air Path Maps (HYSPLIT): We will use a computer Program to track the wind and see if it carried soot from faraway places to Antarctica.

Satellite Pictures: We will look at satellite images to see where large fires were burning, such as in Australia in 2019–2020.

This is of paramount significance with respect to climate modelling because it tells us how much soot is coming from anthropogenic sources and how much from natural sources (like wildfires). That way, we can make better plans to stop pollution and protect icy continents.

- **Could you explain the molecular-level tracer techniques and stable isotope analysis that will be used in this study? How do these methods help in understanding the movement and source identification of black carbon and organic compounds?**

We are using scientific tools to determine where Antarctica's black carbon and organic materials originate.

Molecular-Level Tracer Techniques: We look for tiny clues in the dust, like *anhydrosugars* (from burning plants), *fatty acids*, and *n-alkanes* (from plants and animals). These are like tags that tell us if the pollution came from a wildfire or something else. For example, if we detect anhydrosugars, we infer that wildfire had some influence on southern-hemisphere continents (such as Australia, South America, and South Africa).

Stable Isotope Analysis ($\delta^{13}C$ and $\Delta^{14}C$): We analyze carbon in the soot using specialized instruments available at the BSIP. Carbon has different "codes" depending on its origin. The $\delta^{13}C$ tells us if the soot is from plants or fuel, and the $\Delta^{14}C$ tells us if it's old (from fossil fuels) or new (from recent fires). These methods help us figure out if the soot travelled a long way (like from Australia) or came from nearby (like a ship at Maitri Station).

- **Living in Antarctica presents unique challenges. Can you describe what life is like on the research station, including how you adapt to the extreme cold and what the daily routine looks like? Also, how do you prepare food and manage your meals during the expedition?**

Living in Antarctica is like being on another planet. It is super cold—sometimes as low as -20°C—and windy, so we had to wear many layers, like oversized jackets, gloves, and boots, to stay warm. We lived at Maitri Station, which is like a big house for scientists. It has Summer Camp, where we have a container room to sleep in and different labs to work in. The central station has rooms for winter members and the station leader's room, kitchen, and other facilities.

Our daily routine was busy. We had to wake up early, eat breakfast (like normal Indian breakfast-roti, paratha, idly dosa, upma, etc.), and then prepare for the fieldwork to collect samples. We returned for lunch, worked in the lab to store our samples, and then had dinner. We took turns cooking and cleaning. We cook using food that was brought to the station during the summertime by flight and ship. There will be a very limited number of fresh fruits or veggies. We had to be careful with water too because it is made by melting water from Priyadarshini Lake.

The best part? Even though it was cold, the sun never set because it was summer in Antarctica—so it was bright all day and night! We had to help each other a lot, like a big team, to stay safe and happy in this icy world.

- **The next phase of the study involves sample processing and data interpretation. What are your expectations for this phase, and how will it contribute to global climate assessments?**

Now that we are back from Antarctica, the samples will be arriving in the coming months by cold shipments from Antarctica. After that, we are going to study all the samples we collected—like the dust, sediment, rocks, snow, ice, and water—in our lab at the BSIP. We will use machines to check for black carbon and organic lipids, and we'll look at the "proxies". We expect to find out how much soot is coming from faraway wildfires and how much from other sources, and how this soot is making Antarctica's ice melt faster. This will help the world because it shows scientists how these soot particles change Antarctica and the climate.

- **How do you plan to share your findings with the broader scientific community, and what impact do you anticipate this research will have on global climate studies?**

We will share our discoveries by writing stories (called papers) in science books (called journals) that other scientists read. We will also attend major science meetings around the world to share what we have found. Our research will help everyone understand how these soot particles travel to Antarctica from faraway places. It is also causing the ice to melt faster, which can raise sea levels and cause problems for people and animals. Our work will help scientists develop better plans to stop or control pollution and protect the Antarctic and Arctic, which will help keep the whole planet cooler and safer.

- **This must have been an extraordinary experience for you both. Can you share some personal reflections or memorable moments from your time in Antarctica during this mission?**

Going to Antarctica was like a dream. One of our favourite moments was seeing penguins waddle near Maitri Station—they are so cute! Another amazing thing was watching the sun never set—it was always bright, even at midnight, which felt strange but beautiful. We also loved working as a team with other scientists, and it felt like we were starting a big treasure hunt for clues about the planet.

- **What were some of the biggest challenges you faced during the sample collection process, and how did you overcome them?**

Collecting samples in Antarctica was tough. It was cold, so our hands got super chilly even with gloves on, and the wind made it hard to stand still sometimes. One big challenge was setting up our big dust sampler—it was tricky to get it working in the icy weather, but we worked with the Maitri Station team to set it up. Another challenge was walking on slippery ice to collect snow and water samples—we had to be super careful not to fall. We overcame these challenges by helping each other, wearing the right gear, and planning our trips carefully so we stayed safe. It was like a big team adventure.

- **How does this research align with global scientific efforts to understand the effects of black carbon and other pollutants in polar regions? What role does international collaboration play in advancing this area of research?**

Our research is part of a global mission to understand how pollution, such as black carbon, affects places like Antarctica and the Arctic. Scientists are worried that soot is accelerating ice melt, which could change the global climate. Our work helps identify the sources of soot, such as wildfires, so we can stop it. Collaborating with scientists from other countries helps us a lot. We share ideas, machines, and discoveries with them, and they share theirs with us. It's like being part of a big science team that works together to save the planet.

- **As you continue your research and analyze the samples collected, what do you hope the broader scientific community will take away from your findings, and how do you envision this research contributing to the global effort to combat climate change?**

We hope our research will educate other scientists about the significant impact of black carbon on Antarctica, despite its remote location. We aim to demonstrate how this soot travels from distant sources and accelerates ice melting. Our findings will contribute to efforts to combat pollution, such as reducing wildfires and controlling human activities. By sharing our knowledge, we hope to aid the global fight against climate change, ultimately protecting Antarctica's ice, preserving wildlife like penguins, and mitigating the effects of rising sea levels.

About Interviewer

Dr Nimish Kapoor is a Scientist and Science Communicator at BSIP. He serves as Co-coordinator of SCoPE – Media Unit and is actively involved in science communication for public engagement and partnership activities.

Dr. B. S. Venkatachala Memorial Lecture

THE **12th Dr. B. S. Venkatachala Memorial Lecture** was delivered on 1 January 2026 by **Prof. S. K. Srivastava**, Department of Geology, Nagaland University, Kohima, on the topic 'Cenozoic Sedimentation in Parts of the Inner Fold Belt, Nagaland, India'.

Kahani Dharti Ki:
When the Earth Found Its Voice on Radio

ON the eve of National Science Day 2026, science stepped out of laboratories and textbooks and found a powerful new voice on radio. Birbal Sahni Institute of Palaeosciences (BSIP) launched a unique weekly science radio programme entitled ***Kahani Dharti Ki – Jahan Dharti Bolegi aur Ham Sab Sunenge*** (Story of the Earth – Where the Earth Speaks and We All Listen).

Formally launched at the BSIP Auditorium, Lucknow, on February 27, 2026, the programme marked a significant step in bringing Earth science research closer to society through an engaging, inclusive, and accessible medium. The first broadcast aired on March 3, 2026, and the programme was scheduled to be broadcast every Tuesday from 3:00 PM to 3:30 PM on Radio KGMU Goonj 89.6 MHz, with simultaneous access through the KGMU Goonj mobile app—extending its reach well beyond the city.

Science Stories for Everyone

The programme was a collaborative initiative of the BSIP and Radio KGMU Goonj, produced under BSIP's Science Communication for Public Engagement and Partnership Programme. Its central aim was both simple and ambitious: to narrate the story of Earth—spanning millions of years—in a language that students, young listeners, and the wider public could easily understand and enjoy.

Through a conversational radio format, *Kahani Dharti Ki* explored how Earth evolved over geological

time, what the fossil record revealed about life's past, and why these ancient stories mattered profoundly for the present and the future.

Poster, Promo, and a Glimpse of What Was to Come

The launch event featured the joint release of the official poster and promotional audio by Prof. Mahesh G. Thakkar, Director, BSIP, and Prof. K. K. Singh, Executive Head, Radio KGMU Goonj. A short audio segment from the inaugural episode was also played, offering the audience a preview of the programme's storytelling style.

Bridging Deep Time and Daily Life

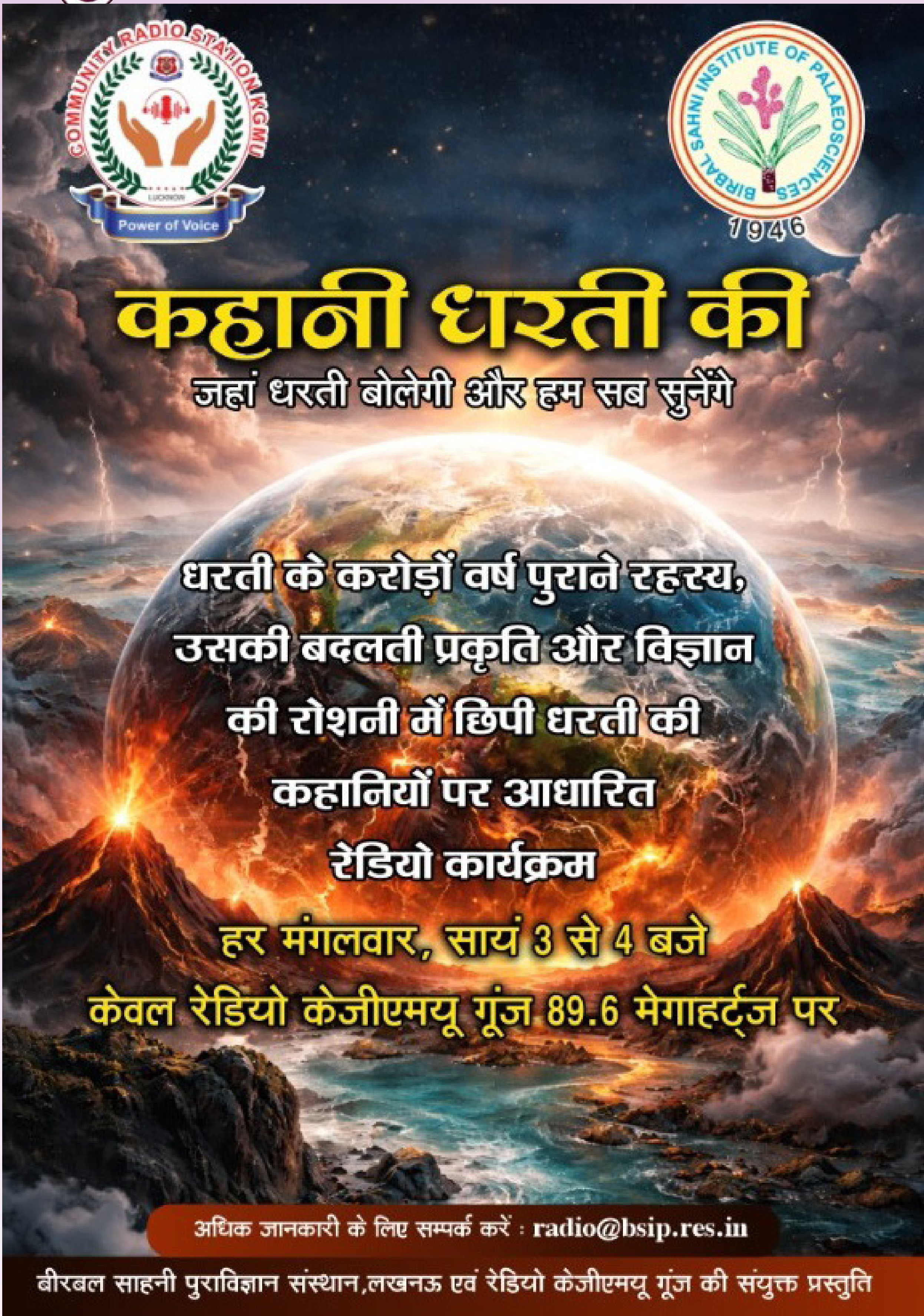
Addressing the audience, Prof. Mahesh G. Thakkar emphasized that *Kahani Dharti Ki* had been designed to bridge the long-standing gap between scientific research and society. He highlighted that themes, such as mass extinction events, the age of dinosaurs, meteoritic impacts, volcanic eruptions, human evolution, and the Last Glacial Maximum were not merely academic subjects, but compelling narratives that helped people understand the dynamic and ever-changing nature of the planet.

He further noted that radio remained an effective medium for reaching rural and remote areas, ensuring that scientific knowledge travelled beyond classrooms and research institutions into villages and communities. Prof. Thakkar also shared a long-term vision for the series under the theme "150 Scientists, 150 Stories," in which the work of individual scientists could be presented across multiple episodes, creating a lasting archive of scientific storytelling.

Community Radio and Climate Conversations

Prof. K. K. Singh underlined the importance of community radio as a vital tool for science outreach. He observed that Radio KGMU Goonj, operated by a medical university, had emerged as a trusted platform for educational and public-interest programming. He stressed that issues, such as global warming, evolution, and climate change represented some of the most urgent scientific challenges of the present time.

Explaining the close link between evolution and climate change, Prof. Singh remarked that historical shifts in climate had shaped the development, adaptation, and extinction of species.


COMMUNITY RADIO STATION KGMU
Power of Voice
BIRBAL SAHNI INSTITUTE OF PALAEOSCIENCES
1946
कहानी धरती की
जहां धरती बोलेगी और हम सब सुनेंगे
धरती के करोड़ों वर्ष पुराने रहस्य,
उसकी बदलती प्रकृति और विज्ञान
की रोशनी में छिपी धरती की
कहानियों पर आधारित
रेडियो कार्यक्रम
हर मंगलवार, सायं 3 से 4 बजे
केवल रेडियो केजीएमयू गूंज 89.6 मेगाहर्ट्ज पर
अधिक जानकारी के लिए सम्पर्क करें : radio@bsip.res.in
बीरबल साहनी पुराविज्ञान संस्थान,लखनऊ एवं रेडियो केजीएमयू गूंज की संयुक्त प्रस्तुति

Understanding these processes, he emphasized, was essential for responding effectively to contemporary environmental crises.

Inclusivity, Inspiration, and the Human Side of Science

Guest of Honour Dr Arvind Mathur, Prant President, Awadh Vigyan Bharati spoke about humanity's scientific quest to determine the age of the Earth, describing it as one of the great achievements of modern geology and radiometric science. He emphasized that science thrived on diversity and inclusivity and highlighted the crucial role of women in research, leadership, and science communication. Encouraging greater participation of women in science, he said, was fundamental to building an innovative and equitable scientific ecosystem.

Dr Mathur also highlighted the enduring relevance of audio platforms, such as radio in inspiring young minds, particularly in rural and remote regions.

Science for All

Reinforcing the programme's core philosophy, Dr Anupam Sharma, Scientist G, BSIP stated that the principle of "Science for all people" served as the true motivation behind initiatives, such as *Kahani Dharti Ki*. Calling it a timely and commendable effort on the occasion of National Science Day, he emphasized the importance of sustained and continuous engagement in science communication.

Mrs Shalini Gupta echoed these views, noting that radio remained one of the most fundamental and pioneering means of communication—particularly effective at the grassroots level—and continued to play a vital role in connecting communities and disseminating knowledge.

A Window into Earth's Past, Present, and Future

Outlining the programme's vision, Dr Nimish Kapoor explained that *Kahani Dharti Ki* offered a rare opportunity for BSIP scientists to interact directly with listeners. Each episode highlighted how palaeoscience, palaeontology, palaeobotany, geology, and Earth sciences helped in understanding the planet's past and applying those lessons to present-day challenges and future sustainability.

Listeners learned how scientists interpreted clues

preserved in rocks, fossils, sediments, and ancient climates, and how BSIP's research contributed to climate change studies, environmental reconstruction, biodiversity evolution, and sustainable planning.

Listening In

Kahani Dharti Ki was broadcast on 89.6 MHz FM, via the KGMU Goonj mobile app, and through live streaming on KGMU's official website. Plans were also shared to make episodes available on the official BSIP website to ensure wider public access to these stories from Earth's deep past.

Through this initiative, science did not merely speak—it told a story, invited curiosity, and reminded listeners that the Earth's long history still had much to teach us today.

When Science Travels: BSIP's Voice at the Global Confluence of Science Tourism

By blending curiosity with culture, and research with travel, popular science tourism is reshaping how the world encounters knowledge. At the heart of this global movement, an Indian scientist carries the voice of Earth sciences from Lucknow to Moscow.

Tourism today is no longer confined to leisure and sightseeing. It is increasingly recognised as a powerful engine for sustainable development, cultural diplomacy, and the growth of intellectual and creative capital. Among its most promising frontiers is popular science tourism—a dynamic convergence of travel, research, education, storytelling, and cultural interaction. This evolving domain invites people not merely to visit destinations, but to engage with ideas, experience discovery, and connect science meaningfully with society.

This global shift finds a vibrant expression at the International Science and Tourism Forum Discover ATOM, held during November 1–2, 2026, at the

Dr Nimish Kapoor delivering his keynote address during the plenary session iconic ATOM Museum, Moscow. The two-day international forum brings together museum leaders, scientists, science communicators, policymakers, educators, creative industries, tourism professionals, and technology innovators from across the world to deliberate on the future of science-led tourism and public engagement.

Against this backdrop, Dr Nimish Kapoor, from the Birbal Sahni Institute of Palaeosciences (BSIP), participates as the Indian delegate at the forum, representing BSIP. His role places BSIP—and Indian palaeoscience—at the crossroads of a vibrant global dialogue focused on reimagining how scientific knowledge, particularly Earth history and climate science, can reach wider publics beyond laboratories and classrooms.

Dr Nimish Kapoor presenting BSIP's science communication initiatives and promoting science and geo-tourism

Science Tourism: Where Knowledge Meets Experience

Popular science tourism is gaining momentum globally because it addresses a fundamental question of our time: how do we make science accessible, engaging, and relevant to everyday life? By opening laboratories, museums, observatories, scientific landscapes, and research narratives to the public, science tourism transforms abstract concepts into immersive, lived experiences.

Throughout the sessions held during November 1–2, 2026, discussions centre on the importance of intersectoral partnerships—between museums, scientific institutions, IT companies, creative industries, and government bodies. Such collaborations help create innovative products that attract domestic and international visitors, strengthen regional identities, and contribute meaningfully to national economies.

Dr Nimish Kapoor's presence as an Indian delegate and keynote speaker in the plenary session highlights BSIP's expanding role in science communication and public engagement, particularly its efforts to link Earth's deep-time archives with contemporary societal challenges, such as climate change, environmental sustainability, and natural resource management.

Speaking at the forum, Dr. Kapoor emphasises the growing relevance of geo-tourism and palaeoscience-based tourism as powerful tools for public engagement. He highlights that India possesses an exceptionally rich scientific heritage, with diverse geological, palaeontological, and geomorphological sites spread across the country—many of which hold immense potential to be developed as destinations for science tourism. From fossil parks and ancient sedimentary basins to unique landforms that record Earth's evolutionary history, these sites, he notes, can serve as open-air classrooms connecting people directly with deep time and natural processes.

Dr Kapoor shares his experience as a delegate speaker of conceptualising and curating the first-of-its-kind Palaeoscience Film Festival of India, envisioned as a global platform to showcase films rooted in Earth sciences, fossils, climate history, and geological heritage. He explains that such creative initiatives help translate complex scientific themes into compelling narratives that resonate with wider audiences. Drawing from his involvement in several national and international science film festivals, he notes that the introduction of a dedicated science tourism category proved particularly effective, attracting filmmakers to explore stories centred on scientific sites, museums, landscapes, and research journeys.

According to him, cinema and visual storytelling have the unique ability to inspire curiosity and travel simultaneously, making them ideal instruments for promoting science tourism. By linking geo-tourism, science films, museums, and educational outreach, Dr Kapoor underlines that India has the capacity to emerge as a major global hub for science tourism—one that celebrates its scientific legacy while fostering sustainable development, public understanding of science, and international collaboration.

Dreaming the Future Through Museums

One of the most compelling thematic strands of the forum explores a deceptively simple yet profound question: What does "dreaming of the future" mean in a scientific context?

Museum leaders and experts debate how to:

- Attract larger audiences without diluting intellectual depth
- Keep science and technology museums relevant in an era of rapid innovation
- Use storytelling, public relations strategies, and local cultural narratives to build strong science brands

From the mysteries of atoms and quantum reality to cosmic evolution, gravity, wormholes, and speculative ideas of time travel, museums are envisioned not merely as exhibition spaces, but as arenas for curiosity, imagination, dialogue, and critical thinking.

Nurturing Young Minds Through Science Tourism

A significant focus of deliberations during November 1–2, 2026 forum is the role of science tourism in shaping the next generation. By engaging school children and young learners, popular science tourism emerges as a powerful system of early career guidance, connecting educational institutions, research centres, and the tourism industry.

Participants discuss future-ready skills, training teachers and science guides, and developing sustainable frameworks that enable young people to perceive science not as distant or difficult, but as exciting, creative, and socially relevant. This vision aligns closely with BSIP's outreach philosophy, advanced through exhibitions, public lectures, radio programmes, and digital science communication initiatives.

A BRICS Moment: Museums Without Borders

A historic highlight of the forum takes place on November 1, 2026, when the Memorandum on the Foundation of the BRICS Alliance of Science and Technology Museums is formally signed at the ATOM Museum.

The newly established Alliance brings together innovative science museums and institutions from India, the Russian Federation, China, the United Arab Emirates, South Africa, and Brazil. Participating organisations include the Birbal Sahni Institute of Palaeosciences (BSIP) and its Palaeoscience Museum from India, the ATOM Museum from Russia, the Museum of Tomorrow (Rio de Janeiro) and Catavento Science Museum (São Paulo) from Brazil, Iziko Museums of South Africa from South Africa, and the Arte Museum, Dubai from the United Arab Emirates. With the support of the Ministry of Foreign Affairs of the Russian Federation and the Ministry of Culture of the Russian Federation, the Alliance aims to strengthen cultural, educational, scientific, and technological cooperation among BRICS nations, positioning science museums as instruments of public diplomacy and international collaboration.

Science as a Universal Language

Reflecting on the significance of this initiative, Ms Elena Mironenko, General Director of the ATOM

A historic moment on November 1, 2026, as the Memorandum on the Foundation of the BRICS Alliance of Science and Technology Museums is formally signed at the ATOM Museum

Museum, underscores that science and technology serve as a universal language, transferring knowledge and values from one generation to another and forming the foundation of social progress and cultural development. She emphasises that museums worldwide play a critical role in helping society understand observed phenomena and their practical applications, thereby ensuring continuity between past knowledge and future discoveries.

According to Ms Mironenko, the language of logic, data, and experimentation employed in science is understood across borders, cultures, and belief systems, making science museums powerful platforms for intercultural dialogue. She highlights that in an increasingly fragmented world, science and technology provide common ground—tools through which people from different backgrounds can communicate, collaborate, and build trust.

She further notes that museums today are no longer static repositories of objects, but dynamic spaces where ideas are tested, values are transmitted, and future-oriented thinking is nurtured. By integrating education, technology, creativity, and public engagement, modern science museums foster curiosity while encouraging responsible citizenship and informed decision-making.

Ms Mironenko also points out that institutions like the ATOM Museum attract millions of visitors precisely because they present complex scientific ideas in ways that are emotionally engaging and socially relevant. In her view, science museums function as instruments of public diplomacy, creating new models of cooperation between nations

Ms. Elena Mironenko, General Director of the ATOM Museum, addressing the press on the role of science museums in societal progress

and communities. Through shared exhibitions, joint educational programmes, and international alliances, such as the BRICS Alliance of Science and Technology Museums, museums contribute to mutual understanding and shared global progress.

In this sense, she concludes, science and technology are not only engines of innovation, but also bridges between cultures—essential for shaping a future rooted in knowledge, cooperation, and universal human values.

Towards a Shared Scientific Future

BSIP's participation in the International Science Museum and Science Tourism Forum symbolises India's growing engagement with global platforms that are redefining how science is communicated and experienced. BSIP's presence through its Indian delegate contributes perspectives rooted in Earth history, palaeoclimate, and long-term environmental change—themes that resonate strongly with global sustainability conversations.

As the BRICS Alliance plans joint museum festivals, exhibitions, scientific competitions, cross-training programmes, and collaborative outreach initiatives in the coming years, science museums are poised to become living bridges between cultures.

In this unfolding narrative of science without borders, the voice of Earth sciences—carried from Lucknow to Moscow—reminds the world that the story of atoms, Earth, and the Universe belongs to all of humanity.

Prepared by SCoPE Desk

Participation at the International platform:

Mr. Anand Rajoriya (Senior Research Fellow at the Radiocarbon Dating Laboratory of the BSIP, Lucknow), has participated and presented his PhD work at the International platform **12th International Conference on Isotopes (12ICI)**, co-organised by the University of Milan, World Council on Isotopes, and Royal Society of Chemistry in the city of Florence, Italy, during 15-19th February 2026. For the same, he received international travel support from the Anusandhan National Research Foundation (ANRF), Government of India.

He presented the work entitled *Biogeochemical Investigation of Mangrove Ecosystem to Gauge Coastal Anoxia and Ecosystem Processes of the Last 7800 Cal. Year BP.* Not only did he presented the work, but also received the **Best Presentation (Poster) award at the International level** among 58 countries. In BSIP, he is registered for his PhD with Dr. Biswajeet Thakur (Scientist F). He is working on *Biogeochemical Investigation of Holocene sediment from inland and coastal wetlands of India: Processes, Variability, and Environmental Implications*.

Outreach Activity

INTERACTION with the tribal communities of Majuli Island, the world's largest river island on the Brahmaputra River, was conducted by Scientist-E, Dr. Swati Tripathi, along with research scholars Mrs. Arya Pandey and Mr. Ajay Kumar, during a field excursion in the Upper Brahmaputra Valley (January 4–11, 2026). The outreach engaged women and children to promote wetland conservation. The application of past climatic data, highlighting wetlands as natural flood buffers, biodiversity hotspots, and lifelines for fisheries and traditional livelihoods, was the centre of the discussion. Emphasis was placed on community-based conservation, traditional ecological knowledge, and adaptive wetland management to strengthen local resilience and ensure long-term sustainability amid recurrent flooding and severe riverbank erosion.

The INQUA Commission visit to Lucknow

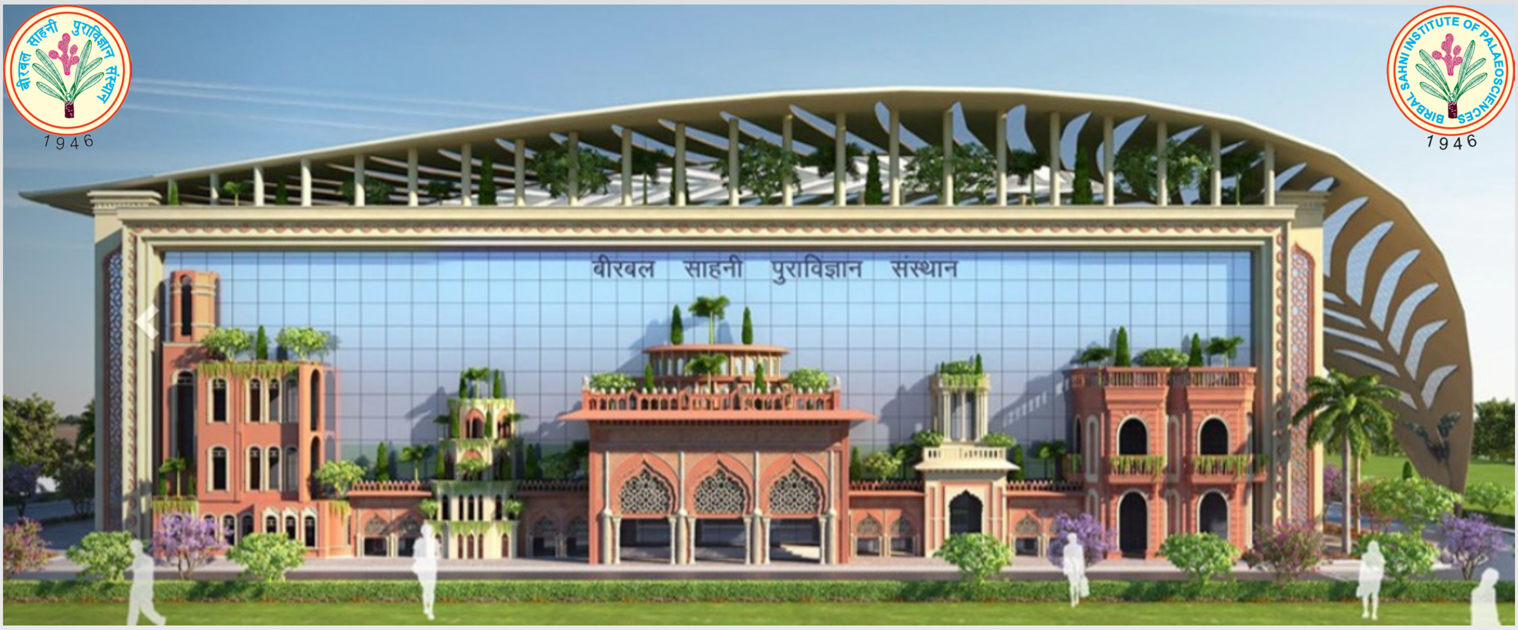
PROF. Mahesh G. Thakkar, Director, Birbal Sahni Institute of Palaeosciences, warmly welcomed the Executive Committee of the International Union for Quaternary Research (INQUA) and the Chairs of various INQUA Commissions during their visit to Lucknow. This significant engagement marks an important milestone as India prepares to host the prestigious INQUA Congress 2027 (January 28–February 03, 2027) in the vibrant city of Lucknow.

INQUA Delegation Visits Congress Venue

MEMBERS of the Executive Committee of the International Union for Quaternary Research (INQUA) and Chairs of various INQUA Commissions visit the Indira Gandhi Pratishthan Convention Centre in Lucknow, the venue for the XXII INQUA Congress 2027 (January 28–February 03, 2027). The visit marks an important milestone in preparations to welcome the global Quaternary research community to India for this landmark scientific gathering.

INQUA 2027

The International Union for Quaternary Research (INQUA) Congress is organized once in every four years. **INDIA** won the bid for the **XXII INQUA Congress 2027** while participating XXI INQUA Congress 2023, held during July 14-20, 2023 at the Sapienza University of Rome, Rome, Italy. The Congress will be organized jointly by the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow, National Centre for Polar and Ocean Research (NCPOR), Goa, and the Association of Quaternary Researchers (AoQR), BSIP, Lucknow, and hosted by INSA, MoES and DST, New Delhi, India. The XXII INQUA Congress 2027 has the theme **Quaternary Sciences as Societal Services**. It will take place in Lucknow (Uttar Pradesh), India, during January 28–February 3, 2027. Dr Pradeep Srivastava (IITR), Dr Rahul Mohan (NCPOR) and Dr Binita Phartiyal (BSIP) will be the President, Vice-President, and Secretary General (Organising Secretary), respectively, of XXII INQUA 2027 in India.



BIRBAL SAHNI INSTITUTE OF PALAEOSCIENCES (BSIP)

An Autonomous Institute under the Department of Science & Technology, Govt. of India
53, University Road, Lucknow - 226007

A premier DST institute pioneering research in Palaeosciences — from ancient life and climate to fossil fuels and human history — with cutting-edge laboratories, a presence spanning pan-India to the polar regions, including extra-terrestrial life and a renewed focus on creating modern facilities to achieve new scientific goals. Aligned with the vision of ***Viksit Bharat @2047***, BSIP is committed to contributing towards a self-reliant and scientifically empowered nation.

BSIP's Vision and Mission

Study of past life and climate—the drivers, impacts, and processes to provide models that are different in today's world to understand evolutionary processes and climate with special reference to climate change, palaeo-biodiversity, palaeo-environment, past civilizations in order to increase the credibility of future environmental projections.

For consultancy services related to the National Analytical Facilities at the BSIP, please visit www.bsip.res.in or write to us at director@bsip.res.in

Call for Authors – Palaeoscience Today

Quarterly Popular Science Magazine of the BSIP, Lucknow

Palaeoscience Today is published every quarter in the month of March, June, September and December. The Editorial Board of ***Palaeoscience Today*** invites contributions for the forthcoming issues. The magazine serves as a platform to bring palaeoscience research closer to society, highlighting the wonders of Earth's ancient past and their relevance to our present and future.

We are especially looking for popular science articles that communicate palaeoscience in a simple, engaging, and story-like manner. Articles should avoid technical jargon and be written with a wide audience in mind, including college students, young learners, educators, and the science-curious public.

What We Are Looking For

- **Feature Articles (1000–1500 words):** Well-researched, narrative-style explorations of discoveries, methods, or themes in palaeoscience.
- **Research spotlight/Columns (700–900 words):** Thematic write-ups under recurring sections such as *Fossil Story*, *Digging Through Time*, or *Palaeoscience & Policy*.
- **Science Shorts (500–700 words):** Quick insights into recent findings, innovations, or ideas.
- **Interviews & Q&A:** Conversations with scientists, students, or educators.
- **Photo Essays / Infographics / Visual Features:** Image-led stories, timelines, or creative visualizations.
- **Student Corner:** Contributions from research scholars and college students with guidance from mentors.
- **Accolades:** Recognitions received during the said time
- **Meetings and Workshops**
- **Field Notes and Insights**
- **Research Shorts**

Suggested Themes

- Evolution of Earth
- Discoveries in Palaeosciences
- Geology and Climate: Earth's Changing Landscapes
- Stories from Fossils
- Ancient Climates, Modern Lessons
- Heritage Rocks: Geosites & Conservation
- Tech and Tools in Palaeoscience
- Meet the Scientist | Ask a Palaeoscientist

Author Guidelines

1. **Audience First:** Write for non-specialists. Avoid jargon; where unavoidable, explain in simple terms.
2. **Narrative Style:**
   - Begin with a strong hook (a question, fact, or anecdote).
   - Use storytelling, analogies, and real-world connections.
   - Keep paragraphs short and flow logical (Introduction → Main Idea → Relevance → Conclusion).
3. **Scientific Accuracy:** Ensure correctness of facts. Provide informal references or hyperlinks (no formal citations required).
4. **Tone and Language:** Conversational yet professional. Use active voice. Avoid overly academic style.
5. **Visuals:** Authors are encouraged to provide high-quality images, diagrams, or sketches (with proper captions and credits).
6. **Relevance:** Link the subject to education, environment, culture, or daily life. Highlight India's contributions wherever possible.
7. **Originality:** Only original and unpublished articles will be accepted. Plagiarism check will be applied.

Submission Details – Where to Send Your Contribution

- **Deadline:** One month before every publishing quarter.
- **Format:** MS Word (.docx), Times New Roman, 12 pt or Open Document Format (ODF)
- **Email submissions to:** palaeosciencetoday@bsip.res.in
- **Subject line:** *Submission – [Article Title] – [Author Name]*
- Along with the article, please include:
  - A short biodata (about 50 words)
  - A high-resolution author's photograph

For queries and collaboration, please contact: palaeosciencetoday@bsip.res.in

Dr Nimish Kapoor
Coordinating Editor
Palaeoscience Today

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