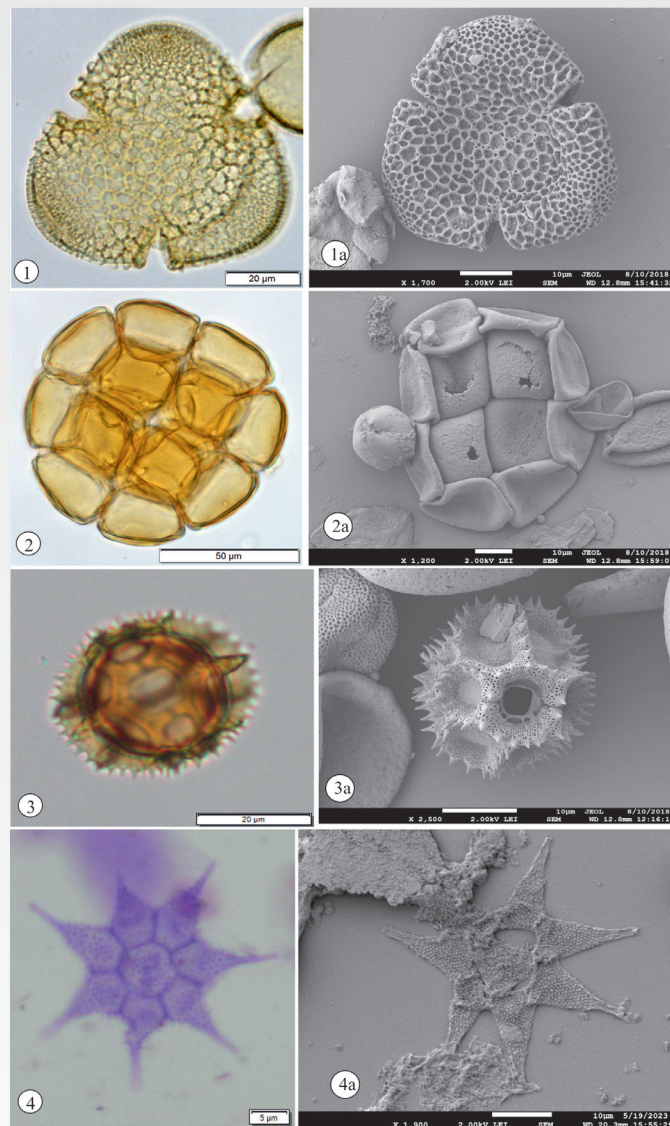


PALAEOSCIENCE TODAY

TRACING TIME, TELLING STORIES

Volume 2 Issue 2 2026



Birbal Sahni Institute of Palaeosciences

53 University Road, Lucknow 226 007, U.P., India

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Cover Page: 1. *Bombax ceiba* (LM), 1a. *Bombax ceiba* (FESEM), 2. *Acacia nilotica* (LM), 2a. *Acacia nilotica* (FESEM), 3. Cichorioideae (LM), 3a. Cichorioideae (FESEM), 4. *Pediastrum* spp. (LM), 4a. *Pediastrum* spp. (FESEM) (Photo courtesy: Mohammad Firoze Quamar)

Back Page: Intermorainal lakes with Leh city and the Tethyan Himalayan snow covered range (Photo courtesy: Binita Phartiyal)

From the Chief Editor's Desk

WHEN THE EARTH SPEAKS TWICE: LESSONS FROM THE 2026 VENEZUELA SEISMIC DOUBLET

ON 24th June 2026, northern Venezuela witnessed one of the most extraordinary and devastating seismic events of recent decades. Within an interval of only 39 seconds, two major earthquakes of moment magnitudes Mw 7.2 and Mw 7.5 ruptured adjacent segments of an active fault system along the boundary between the Caribbean Plate and the South American Plate. Rather than a conventional mainshock–aftershock sequence, this rare phenomenon represents what seismologists describe as a **seismic**

doublet - two large earthquakes of comparable magnitude occurring almost simultaneously in the same tectonic region (See Figure on next page).

From a geological perspective, the earthquake was a classic example of shallow strike-slip faulting associated with the eastward movement of the Caribbean Plate relative to the South American Plate. The plate boundary across northern Venezuela is dominated by a complex network of transform faults, including the San Sebastián, La Victoria and El Pilar fault systems, which together accommodate nearly 20 mm of relative plate motion each year. These faults have accumulated tectonic strain over centuries and have repeatedly generated destructive earthquakes throughout historical time.

The occurrence of two large earthquakes only seconds apart made this event exceptionally destructive. The first rupture weakened countless structures, while the second, stronger shock caused many already-damaged buildings to collapse. The



sequence also severely complicated emergency response, as rescue operations were interrupted by continued intense ground shaking and hundreds of aftershocks. This cascading failure illustrates why seismic doublets are among the most hazardous earthquake phenomena recognised in modern seismology.

The humanitarian consequences have been heartbreaking. Thousands of lives have been lost, many more people remain injured or missing, and millions have experienced displacement or

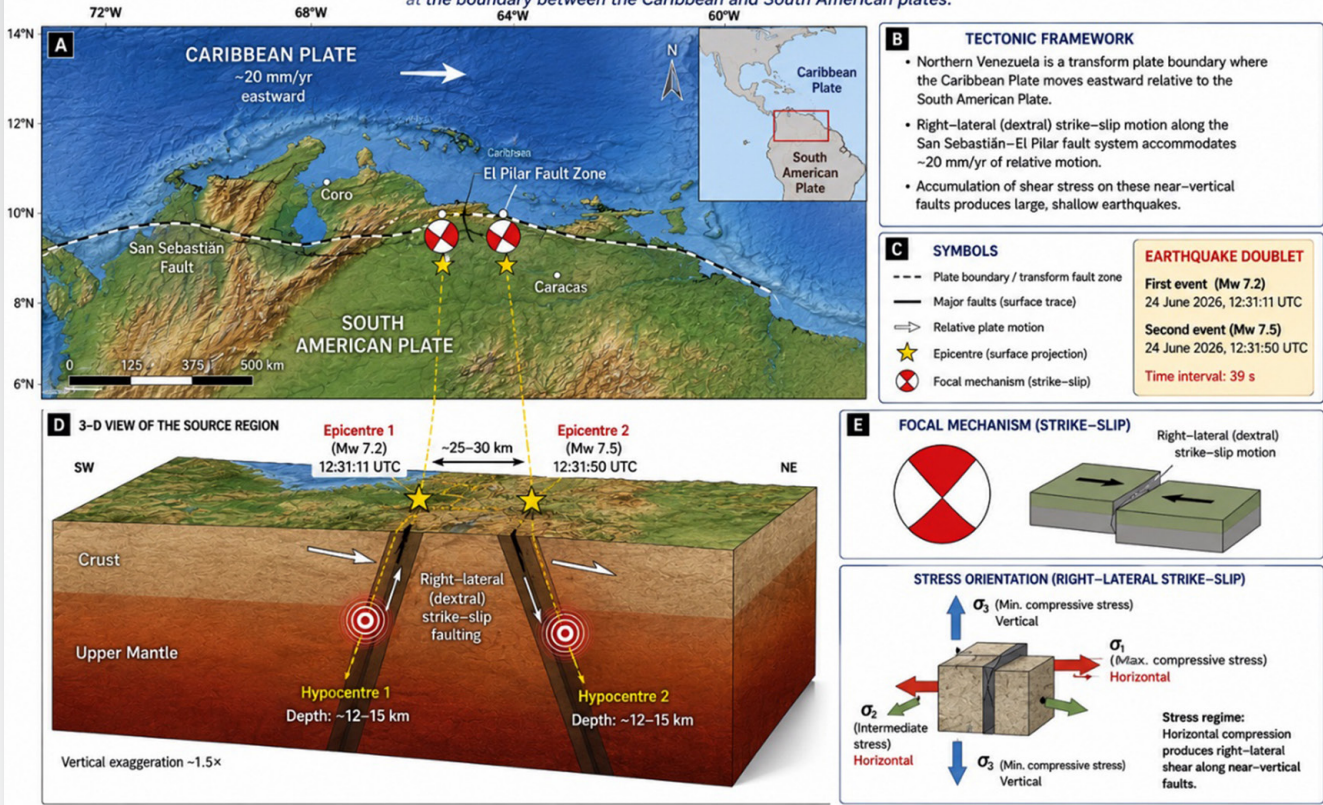
disruption of essential services. Homes, hospitals, schools, bridges, highways and public utilities suffered extensive damage, leaving entire communities struggling to recover. Beyond the immediate loss of life, the earthquake has imposed enormous economic and psychological burdens that will persist for years.

Although the 2026 earthquake was exceptional, it was not unexpected from a geological standpoint. Northern Venezuela has experienced repeated destructive earthquakes, including the catastrophic Caracas earthquake of 1812, the 1900 San Narciso earthquake, the 1967 Caracas earthquake and several damaging twentieth-century events. Geological investigations and modern geodetic observations have consistently demonstrated that the Caribbean–South American plate boundary remains tectonically active and capable of generating large earthquakes.

For Earth scientists, this tragedy is also a reminder that the processes shaping our planet operate continuously across geological and human timescales.

Plate-tectonic Setting and source of the 24 June 2026 Venezuela Seismic doublet

Two major strike-slip earthquakes (Mw 7.2 and Mw 7.5) occurred 39 s apart along a major transform fault at the boundary between the Caribbean and South American plates.

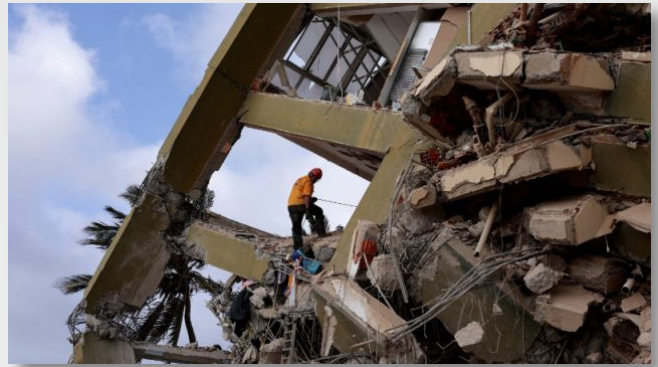


The same plate motions that have built mountain belts, displaced sedimentary basins and controlled landscape evolution over millions of years continue to accumulate elastic strain that is released suddenly as earthquakes. Understanding these processes through geology, palaeoseismology, geochronology, geomorphology and geophysics is fundamental to reducing future seismic risk.

The Venezuela seismic doublet, therefore, carries a message that extends far beyond the Caribbean region. It reminds us that the forces driving plate tectonics are universal, and that no tectonically active nation can afford contentment. For India, this event is particularly instructive. Large segments of our country lie within active seismic belts, including the Himalayan collision zone, the Kachchh Rift Basin of western India, the Indo-Burmese and Andaman - Sumatra subduction system, and several intraplate regions where damaging earthquakes have repeatedly occurred. The 2001 Bhuj earthquake, 1999 Uttarkashi

earthquake, the 1905 Kangra earthquake, the 1934 Bihar–Nepal earthquake, the 1950 Assam earthquake, the 1819 Allah Bund earthquake, and numerous Himalayan earthquakes serve as enduring reminders that seismic risk remains an integral part of the Indian landscape.

One of the most significant lessons from the Venezuela earthquake is that devastating earthquakes may occur in rapid succession, producing cumulative damage that overwhelms both infrastructure and emergency response systems. Such complex earthquake sequences highlight the importance of not only engineering resilience, but also a deeper geological understanding of active fault systems, earthquake recurrence intervals, and the long-term evolution of tectonic landscapes. These are precisely the domains in which palaeoseismology, neotectonics, geomorphology, geochronology, and allied geosciences make indispensable contributions.



As *Palaeoscience Today* accelerates its journey as a forum for Earth system research, this tragedy reminds us that understanding the geological past is fundamental to protecting the future. The sedimentary archives, displaced landforms, active faults, tree rings, cave deposits, and other geological records preserved in nature are not merely witnesses to Earth's history; they are repositories of knowledge that help us decipher the frequency, magnitude, and behaviour of past earthquakes, thereby improving assessments of future seismic hazards. The challenge before the scientific community is to translate this knowledge

into resilient infrastructure, informed land-use planning, effective public policy, and greater societal preparedness. In doing so, palaeoscience transcends its traditional role of reconstructing Earth's past and becomes a vital discipline for safeguarding human lives in an increasingly dynamic and vulnerable world.

Warm regards

Mahesh G. Thakkar
Chief Editor

Editorial

WHY THE PAST MATTERS MORE THAN EVER: PALAEOCLIMATE INSIGHTS FOR A WARMING WORLD

PALAEOSCIENCE is no longer a discipline confined to archives of deep time; it is central to understanding present and future climate risks as well. Modern climate change is unfolding over decades to centuries, but the Earth's climate system operates over millennia. Without long-term baselines, we risk mistaking natural variability for anthropogenic signals (or vice versa). Instrumental records (~150 years) are simply too short to capture the full spectrum of climate dynamics, especially for systems like the Indian Summer Monsoon (ISM), El-Niño and Southern Oscillation (ENSO), or ecosystem resilience thresholds. Palaeoclimate archives, such as sediments, ice cores, speleothems, tree rings, and marine records, are, therefore, not just complementary; but they are indispensable. They provide the only empirical evidence of how climate and ecosystems behaved under boundary conditions very different from today.

In an era defined by accelerating climate change, our understanding of the future depends fundamentally on how well we understand the past. Modern instrumental records, extending back little more than a century and a half, capture only a narrow window of Earth's climatic variability. Yet the climate system operates across vastly longer timescales, such as centuries, millennia, and beyond. To contextualize present-day changes and anticipate future trajectories, scientists must turn to the only archives that preserve this deep-time perspective: natural proxies embedded in sediments, speleothems, marine records, etc. These palaeoclimate archives constitute the Earth's memory. Lake and peat sediments preserve



layered histories of hydrological shifts, fire regimes, and biological productivity. Fossil pollen records encode past vegetation dynamics, offering sensitive indicators of monsoon strength, temperature, and precipitation regimes. Stable isotopes, such as oxygen ($\delta^{18}\text{O}$) and carbon ($\delta^{13}\text{C}$) provide powerful tracers of hydrological cycles and ecosystem processes, while speleothems, cave formations dated with remarkable precision, deliver high-resolution reconstructions of past rainfall

variability. Marine sediment cores extend this perspective further, linking terrestrial climate to ocean circulation and global teleconnections. Together, these archives reveal a climate system that is neither static nor linear. Instead, it is characterized by abrupt transitions, threshold responses, and complex feedbacks. Events, such as the Younger Dryas (YD) cooling or the 4.2 ka megadrought, widely implicated in societal transformations including the decline of the Harappan Civilization, underscore the capacity of the climate system to reorganize rapidly. These phenomena are entirely invisible in instrumental records, yet they are critical for understanding the full range of natural





variability against which current anthropogenic changes must be assessed.

The growing integration of palaeodata into climate science marks a paradigm shift. Climate models, once evaluated primarily against modern observations, are now rigorously tested against past climates through initiatives, such as the Paleoclimate Modelling Intercomparison Project (PMIP). The ability of models to reproduce Holocene monsoon

variability, glacial-interglacial transitions, or abrupt climate events has become a benchmark for their credibility in projecting future scenarios. In this sense, the past serves as a proving ground for the future.

This integration is also evident in global assessments. The Intergovernmental Panel on Climate Change (IPCC) relies extensively on multiproxy reconstructions to conclude that recent warming is unprecedented in at least the last two millennia. IPCC

suggested that the rate of CO₂ rise exceeds natural variability (IPCC AR-2021). Also, the current warming is faster than past deglacial transitions. Palaeoclimate data demonstrate not only the magnitude, but also the rate of current change, far exceeding natural variability observed in pre-industrial times. Such conclusions would be unattainable without long-term records derived from natural archives.

The relevance of palaeodata is more pronounced in monsoon-dominated regions, such as South Asia. The ISM, a lifeline for nearly a billion people, exhibits pronounced variability across timescales. Palaeorecords from lake sediments, speleothems, and marine cores reveal that the monsoon has undergone abrupt weakening and strengthening phases, often linked to shifts in the North Atlantic, solar variability, or changes in the Intertropical Convergence Zone (ITCZ). These findings challenge the notion of a smoothly varying monsoon system and instead highlight its sensitivity to thresholds and teleconnections.

Equally important is the insight palaeodata provides into ecosystem resilience. Vegetation records demonstrate that ecosystems do not always respond proportionally to climatic forcing. Gradual drying, for instance, can culminate in sudden forest-to-grassland transitions, while recovery from such shifts may take centuries. These thresholds and tipping points are not theoretical constructs, they are documented realities preserved in palaeoarchives. Understanding them is essential for predicting biodiversity responses, managing land use, and designing climate adaptation strategies. The role of palaeoclimate science is poised to expand further. Advances in proxy system modeling, data assimilation, and machine learning are enabling more precise integration of palaeodata into Earth system models. High-resolution regional reconstructions are improving our understanding of spatial heterogeneity, particularly in climatically sensitive regions, such as the Core Indian (Summer) Monsoon Zone or Core Monsoon Zone (CMZ), India. These developments are bridging the gap between past, present, and future in unprecedented ways. Thus, the past is not merely a record of what has been, rather it is a guide to what is possible. It reveals the boundaries

of natural variability, the mechanisms of abrupt change, and the resilience or fragility of ecosystems and societies. In the face of rapid anthropogenic warming, ignoring this deep-time perspective would be a profound oversight. To understand the future, we must first listen to the archives of the past. They remain our most reliable witnesses, and our most instructive teachers, in a rapidly changing world.

From a policy perspective, historical awareness is indispensable. Development strategies that ignore historical land use, settlement patterns, and ecological thresholds risk repeating past mistakes. Conversely, policies grounded in historical understanding are more likely to be adaptive, equitable, and sustainable. For policymakers and planners, moreover, this implies that future monsoon behavior under anthropogenic forcing may not be gradual, but potentially abrupt and disruptive.

Summing up, it can be said that without palaeodata, we cannot (i) define what is ‘normal’ climate variability, (ii) validate climate models and anticipate extreme events or tipping points. However, with palaeodata, we (i) gain deep-time perspective, (ii) improve predictive skills and (iii) strengthen climate resilience strategies as well.

Thus, the past matters the most and more than ever as well because it equips us with the knowledge, perspective, and wisdom necessary to face contemporary challenges. It is not a distant country to be admired from afar, but a living resource, one that must be studied, understood, and integrated into our collective decision-making. As we stand at critical crossroads, environmental, social, and technological, the lessons of the past may well determine the trajectory of our future. With the following key message

The Past Is The Only Laboratory For Testing The Future

I, as of now, conclude the discussion on the aforesaid aspect.

Best wishes.....

Md. Firoze Quamar
Editor

From the Coordinating Editor's Desk

PRITHVI 2026: WHEN SCIENCE FINDS ITS VOICE THROUGH CINEMA

“Nothing in science has any value to society if it is not communicated.”
- Anne Roe, *The Making of a Scientist* (1953)

MORE than seven decades ago, a psychologist and researcher Anne Roe articulated a truth that has only grown stronger with time: science that remains confined to laboratories, journals, and conferences fails its ultimate purpose. Knowledge acquires meaning only when it reaches society, shapes understanding, and informs action. Today, in an era marked by climate change, environmental degradation, misinformation, and shrinking attention spans, this responsibility of scientists to communicate has become not just relevant, but urgent.

It is in this context that **PRITHVI 2026 – The Palaeoscience Film Festival of India** emerges as a timely and transformative national initiative. For the first time in India, a dedicated palaeoscience institute has not only conceptualised, but is organising a science film festival that places Earth's deep past, fragile present, and uncertain future at the heart of public discourse through the powerful medium of cinema. The first edition of **PRITHVI 2026**, along with a **National Workshop on Earth Science Communication**, is scheduled to be held from July 23–25, 2026.

Organised by the Birbal Sahni Institute of Palaeosciences (BSIP), an autonomous organisation under the Department of Science & Technology, Government of India, New Delhi, India, **PRITHVI** is far more than a film festival. It is a movement: a call to



students, research scholars, scientists, and filmmakers to step beyond disciplinary silos and reconnect science with society.

This pioneering initiative has been made possible under the visionary leadership of Prof. Mahesh G. Thakkar (Director, BSIP), who has consistently emphasised the centrality of science communication and public engagement as integral components of contemporary scientific practice.

WHY PALAEOSCIENCE NEEDS PUBLIC STORYTELLING

Palaeosciences, encompassing palaeontology, sedimentology, stratigraphy, palaeobotany, geophysics, volcanology, palaeoclimatology, oceanography, archaeology, and even astrobiology, form the backbone of our understanding of Earth systems. They explain how continents moved, climates shifted, species evolved, and extinctions reshaped life. Yet, despite their foundational role in understanding climate change, geoheritage, natural hazards, and sustainability, these disciplines often remain invisible to the public.

WHY DOES THIS GAP PERSIST?

One reason is language. Research papers are written for peers, not people. Another is format. Data tables, stratigraphic charts, and isotope graphs rarely



PRITHVI
The Palaeoscience Film Festival of India

PRITHVI 2026

THE PALAEOSCIENCE FILM FESTIVAL OF INDIA
& NATIONAL WORKSHOP ON EARTH SCIENCE COMMUNICATION



23-25 JULY 2026



BIRBAL SAHNI INSTITUTE OF PALAEOSCIENCES
LUCKNOW, INDIA

(x)



Hon'ble Governor Announces PRITHVI 2026, Unveils Brochure for India's First-Ever Palaeoscience Film Festival

stir emotion or imagination. As a result, the stories locked within rocks, fossils, sediments, and ancient climates seldom reach classrooms, communities, or policymakers in a form that resonates.

Along with the **Palaeoscience Today**, **PRITHVI** addresses this challenge head-on by recognising cinema as a universal language, one that can translate complex science into compelling visual narratives without diluting its rigour.

CINEMA AS A BRIDGE BETWEEN SCIENCE AND SOCIETY

Cinema possesses an extraordinary ability to communicate science in ways that textbooks and classroom lectures often cannot. Through its visual language and narrative power, film can visualise geological and biological time scales spanning millions of years, humanise abstract scientific processes, and create emotional connections with landscapes, fossils,

and data. Most importantly, it has the capacity to inspire curiosity, wonder, and a sense of responsibility towards the Earth and its systems.

A well-crafted documentary on fossil plants can often explain the realities of climate change more effectively than a thousand charts and graphs. A short film on geoheritage can ignite pride and conservation ethics within local communities. An animated film can make complex concepts, such as plate tectonics intuitive and accessible for school students. Likewise, a science fiction narrative rooted in Earth sciences can provoke critical debate on possible future scenarios of our planet.

Recognising this immense potential, **PRITHVI** seeks to institutionalise cinema as a powerful tool of science communication by creating a national platform where scientific rigour and creative filmmaking converge, enabling meaningful dialogue between scientists, filmmakers, and society at large.

PRITHVI: A VISION ROOTED IN PUBLIC ENGAGEMENT

PRITHVI is an integral component of BSIP's **Science Communication for Public Engagement & Partnership (SCoPE)** initiative. Its vision is clear and ambitious. It seeks to foster a culture in which scientists do not merely generate knowledge, but also translate it meaningfully for society.

The festival is envisioned as a dynamic confluence of scientists and researchers, science communicators and educators, documentary makers and filmmakers, students and research scholars, as well as policymakers and informed citizens. By bringing these diverse groups together, **PRITHVI** creates a shared space for dialogue, collaboration, and creative exchange.

Through this collective engagement, **PRITHVI** aims to bridge the long-standing gap between scientists and the public. It strives to make palaeosciences and Earth sciences more relatable and engaging, empower citizens with scientific understanding, and contribute meaningfully to the national vision of **Viksit Bharat 2047**.

This vision resonates deeply with **Article 51A(h) of the Indian Constitution**, which enshrines the duty of every citizen to develop a scientific temper, humanism, and the spirit of inquiry and reform.

A FESTIVAL DESIGNED FOR DIVERSE SCIENTIFIC VOICES

PRITHVI 2026 welcomes a wide spectrum of creative and scientific expression through carefully curated categories:

- Documentary Films on palaeosciences, geology, botany, Earth sciences
- Short Films that creatively convey scientific ideas
- Animation Films simplifying complex concepts for all age groups
- Science Fiction Films exploring speculative Earth futures
- Films on Climate Change, focusing on causes, impacts, and solutions
- Films on Geoheritage and Geotourism, linking conservation and culture

- Student and Research Scholar Films, encouraging emerging voices

This inclusive structure ensures that a PhD scholar with a smartphone, a professional filmmaker collaborating with scientists, or an animation student passionate about climate can all find a place at **PRITHVI**.

WHY STUDENTS AND RESEARCH SCHOLARS MATTER MOST

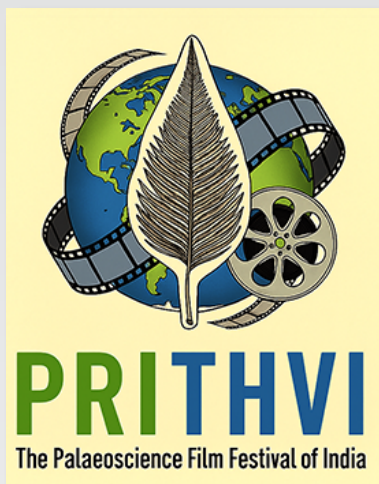
Perhaps the most important stakeholders in **PRITHVI** are students and research scholars. They represent the future of science, not only as researchers, but also as communicators, educators, and leaders who will define how scientific knowledge engages with society.

PRITHVI invites young scientists to step beyond journals and laboratories. It offers a platform to translate theses, datasets, and fieldwork into stories the public can understand—stories that inform, stories that engage, and stories that truly matter. In doing so, it repositions research as a shared societal resource, rather than a closed academic pursuit.

Participation in **PRITHVI** opens new possibilities. Interdisciplinary collaboration becomes natural. Workshops and masterclasses strengthen science communication skills. Interactions with filmmakers and professional communicators broaden perspectives. Importantly, scientific work gains visibility and recognition beyond conventional academic metrics.

At this point, a research scholar may pause and ask a practical question: **What do I gain by engaging in science communication or making a science film, when my primary responsibility is research?** The answer is neither abstract nor ornamental.

Science communication does not dilute research; it deepens it. Translating research into a film or public narrative sharpens conceptual clarity, strengthens critical thinking, and forces the researcher to identify what truly matters in the data. It builds skills that journals do not teach—storytelling, audience awareness, visual reasoning, and ethical framing of science.



Equally important, science films expand a researcher's professional horizon. They create visibility beyond citations, open pathways to interdisciplinary collaboration, and position young scientists as credible public voices at a time when society urgently seeks trustworthy interpreters of science. In an increasingly competitive academic ecosystem, the ability to communicate research effectively is no longer optional—it is a valuable intellectual and professional asset.

More fundamentally, **PRITHVI** challenges every emerging researcher to ask a critical question: *If my research matters, how can I make it matter to society?* This question lies at the core of responsible and relevant scientific practice.

The words of Anne Roe remind us that scientific excellence alone is not enough. The true social obligation of a scientist lies in sharing, explaining, and contextualising knowledge—especially in a democracy, where informed citizens shape collective futures.

FROM KNOWLEDGE PRODUCTION TO KNOWLEDGE PARTICIPATION

PRITHVI marks a significant shift in the way science communication is envisioned and practiced. It moves away from one-way dissemination of scientific information towards a more participatory, dialogic approach. The films screened at the festival are not intended to be endpoints or passive viewing experiences, rather they serve as conversation starters that invite reflection and discussion on pressing themes, such as climate resilience, environmental ethics, heritage conservation, and sustainable development.

The impact of **PRITHVI** also extends well beyond the festival itself. Selected films will be developed as public educational resources, enabling their use in schools, colleges, and academic institutions across the country. In doing so, **PRITHVI** ensures that science communication does not remain event-bound or episodic, but evolves into a sustained and accessible

public resource that continues to inform and engage diverse audiences.

A CALL TO JOIN THE PRITHVI MOVEMENT

PRITHVI is not merely about awards, screenings, or accolades. At its core, it is about reclaiming science as a shared cultural enterprise. It seeks to ensure that Earth's stories—written in rocks, fossils, ice cores, and sediments—are heard beyond laboratories, journals, and conference halls.

By placing palaeosciences at the heart of India's science communication ecosystem, **PRITHVI** weaves together scientific inquiry, environmental stewardship, visual storytelling, and public engagement. For students and research scholars, this represents an invitation to step forward, not only as producers of knowledge, but as storytellers of the planet who can connect research with lived realities.

GIVING SCIENCE ITS SOCIAL VOICE

In a world increasingly shaped by climate anxiety, ecological loss, and the rapid spread of misinformation, silence is no longer an option for science. As Anne Roe cautioned decades ago, scientific knowledge that is not communicated holds little value for society. The responsibility of scientists today extends beyond discovery to dialogue.

PRITHVI 2026 responds to this challenge with imagination, inclusivity, and intent. It asks us to view science not only as a body of knowledge, but as a narrative responsibility to society. By embracing cinema as a partner in science communication, **PRITHVI** encourages us to translate data into stories and stories into understanding—reconnecting science with society in meaningful and lasting ways.

Be part of **PRITHVI** – Bringing Earth's Stories to Life, Inspiring a Sustainable Tomorrow.

Warm regards

Nimish Kapoor
Coordinating Editor

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Tracing Early Life in Ancient Rocks: Decoding the Precambrian Fossil Puzzle

Yogmaya Shukla, Anshika Pandey and Shakshi Pal

DURING the Precambrian era, just after the formation of the Earth, it was very different from today. There was no oxygen in the atmosphere, and the planet was mostly covered by oceans filled with simple chemicals and gases. The world was quiet and empty, with no plants or animals. Yet, in these harsh conditions, life may have begun. How life first started is still one of the biggest mysteries in science.

Scientists believe that the earliest life appeared billions of years ago during the Precambrian era. The Precambrian era (4.56 Ga to 439 Ma), constitutes almost 88% of the Earth's history. The first living organisms were tiny microorganisms that lived in ancient oceans. Although they were very simple, they slowly changed the planet in important ways. Over time, they altered the chemistry of the oceans and the

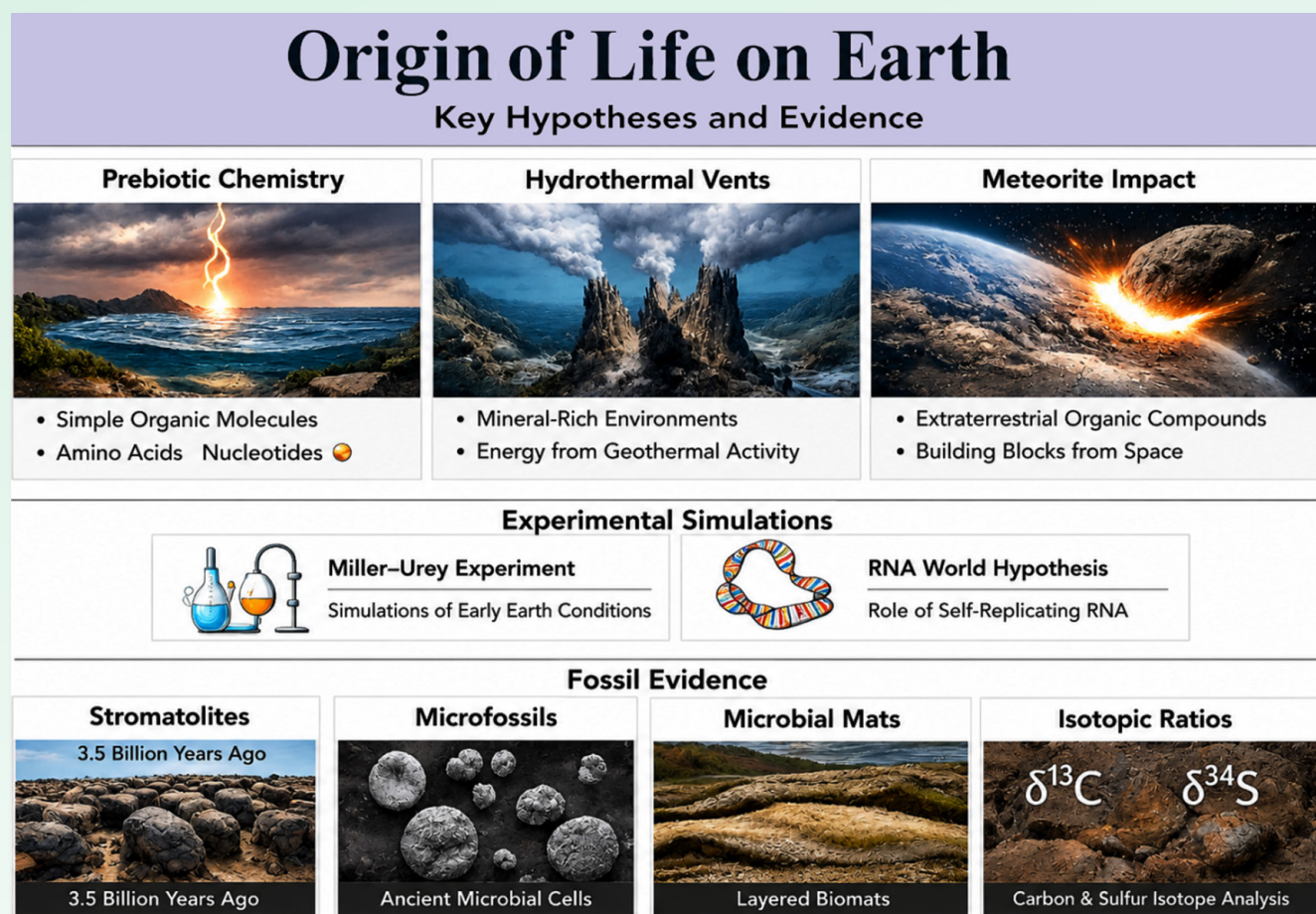


Figure 1. Schematic representation of the major hypotheses and supporting evidence for the origin of life on Earth

atmosphere, preparing the Earth for the evolution of more complex life.

One of the most important changes was the development of photosynthesis. This process allowed some microorganisms to use sunlight to make energy. As a result, oxygen was gradually released into the atmosphere. This major change is known as the Great Oxidation Event. The rise of oxygen transformed the environment of the Earth, which, in turn, enabled more complex forms of life to develop. However, even though these early organisms had such a huge impact on the planet, finding direct evidence of them in ancient rocks has been very difficult. The absence of very old fossils remains an important scientific challenge and raises key questions about how and when life first appeared on the Earth.

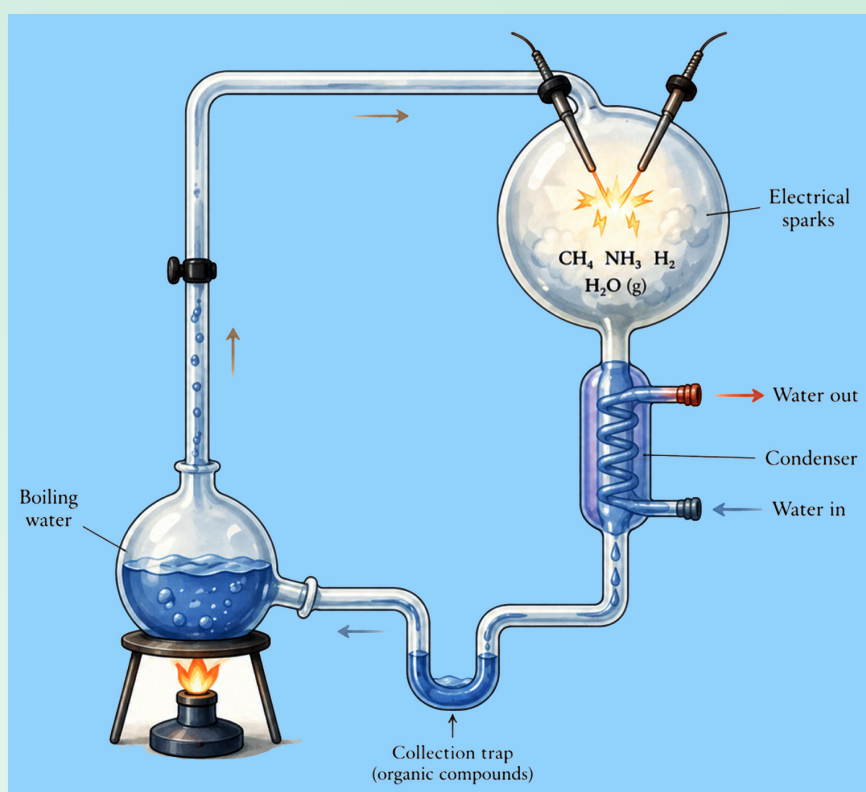
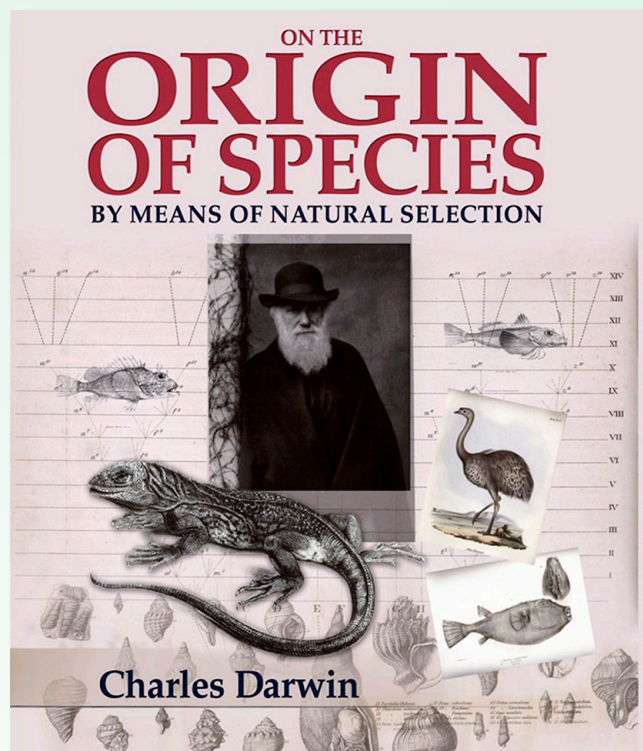
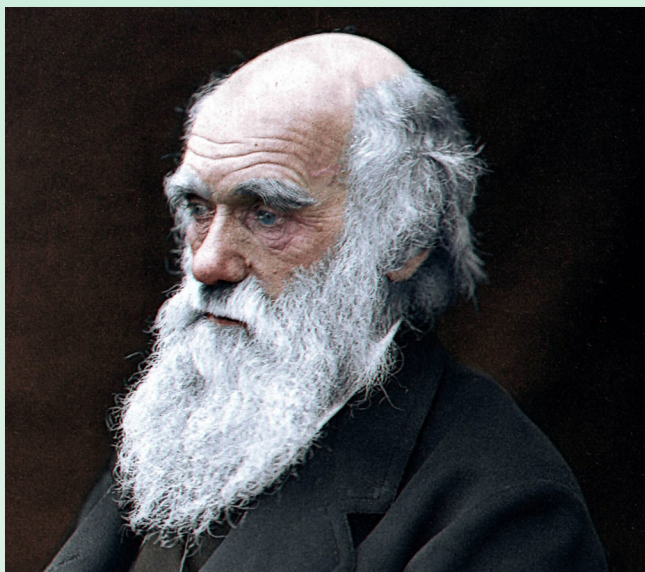


Figure 2. Schematic illustration of the classic Miller–Urey experiment demonstrating the abiotic synthesis of organic compounds under simulated early Earth conditions

THE PUZZLE OF THE MISSING FOSSILS

In 1859, Charles Darwin published his famous book *On the Origin of Species*. In this work, he explained the theory of evolution by natural selection. Darwin also recognized a major problem in the geological record. As his theory stated evolution happens slowly over long periods of time, then life must have existed long before the Cambrian period. However, scientists found very few fossils in rocks older than the Cambrian. This lack of ancient fossils puzzled Darwin and raised important questions about the early history of life on the Earth that make it difficult to explain the history of life. This problem later became known as the Precambrian fossil record problem, which refers to the mismatch between the long history of life and the limited fossil record from the Archaean and Proterozoic eons.





Sir Charles Darwin

DARWIN DAY

Each year, Darwin Day is celebrated on February 12th, commemorating his contributions to science and promoting public education about science and human progress.



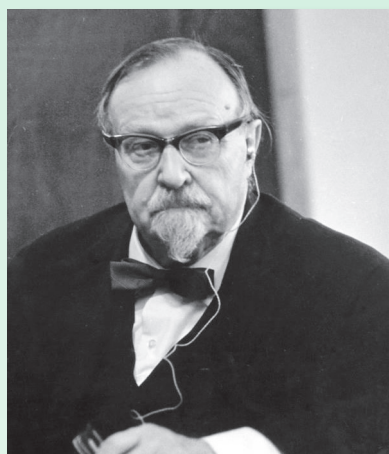
Prof. Louis Pasteur

EXPERIMENTS ON THE ORIGIN OF LIFE

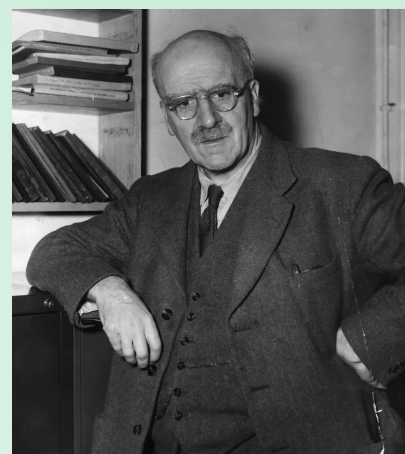
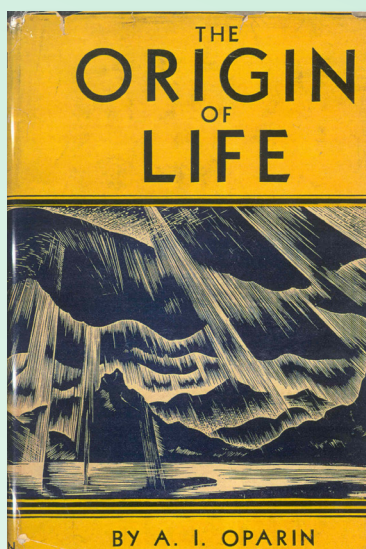
For centuries, people widely accepted the concept of spontaneous generation, which says that living organisms could originate from non-living matter. For example, it was thought that maggots appeared spontaneously in rotting meat or that mice could form from piles of old rags. This belief in the absence of scientific understanding has remained widely accepted for a long time. In the 19th century, parallel to the work of Charles Darwin, Louis Pasteur, through his swan-neck flask experiment (1859), made important contributions to our understanding of life. His work showed that life does not arise spontaneously, but comes from pre-existing life, thus, disproved spontaneous generation and helped establish germ theory. However, it did not explain how life first originated, while Darwin's work focused on how life evolved after it began.

Two major approaches helped scientists address Darwin's problem about the early history of life. One approach is that origin-of-life experiments showed that organic molecules could form naturally on the early Earth. The other one is tracing the signatures of early microbial life existed billions of years before the Cambrian period.

Researchers have used two main ways to understand how life began, and both ideas go back to Charles Darwin. The first approach is experimental, based on Darwin's idea of a "warm little pond," where life might have started. In this method, scientists try to recreate early Earth conditions in the laboratory



Alexander I. Oparin



J. B. S. Haldane

to see how life could form step by step. Alexander Ivanovich Oparin (1924), in his book *The Origin of Life*, and J. B. S. Haldane (1929) independently proposed the idea that life began in a **primordial soup** of chemicals on the early Earth. Their hypothesis, the **Oparin–Haldane primordial soup hypothesis**, later gained wider recognition and support. This idea gained support from the famous experiment by Stanley Miller and Harold Urey (1953), which showed that amino acids could form naturally under the early Earth–like conditions. In their experiment, a special apparatus was designed to imitate the presumed reducing atmosphere of the early Earth in a closed system, consisting of methane (CH_4), ammonia (NH_3), hydrogen (H_2), and water vapour. Electrical discharges were introduced to mimic lightning. Later, Joan Oró demonstrated that adenine, an important component of DNA, could also form in the absence of life. "RNA world," the phrase coined by Walter Gilbert in 1986, suggests that early life was based on RNA. The RNA-based system was said to be working before DNA and proteins evolved. This is further supported by the work of Sidney Altman and Thomas Cech, who argued that early life may have relied on RNA, which can both store information and catalyze chemical reactions. Both received the Nobel Prize in Chemistry in 1989. Over the time, scientists expanded these studies to include environments, such as hydrothermal systems. Günter Wächtershäuser,

proposed in a series of publications that life may have started through chemical reactions on mineral surfaces, particularly iron–sulfur minerals like pyrite. The connection between hydrothermal vents and the origin of life was strongly developed by Michael J. Russell (1994, 1997, 2003). According to him, life may have begun in alkaline hydrothermal vent systems on the ocean floor. The Lost City Hydrothermal Field is widely regarded as the most representative modern analogue of the environment proposed by him for the origin of life.

TRACING THE EARLIEST LIFE SIGNATURES

The second approach comes from studying rocks and fossils and is linked to Darwin's question in "On the Origin of Species" about why very ancient fossils were missing. This curiosity led scientists to search for early evidence of life in old rocks. In 1953, Stanley A. Tyler and Elso S. Barghoorn discovered tiny fossils in ancient rocks in Canada, opening the door to the field of Precambrian paleobiology. By the early 1960s, the field grew rapidly and attracted researchers, such as Preston Cloud and Martin Glaessner, solving the conundrum of the sudden rise of complex life at the start of the Phanerozoic Eon.

From 1970s, scientists found new evidence of early life. They discovered stromatolites, microfossils,

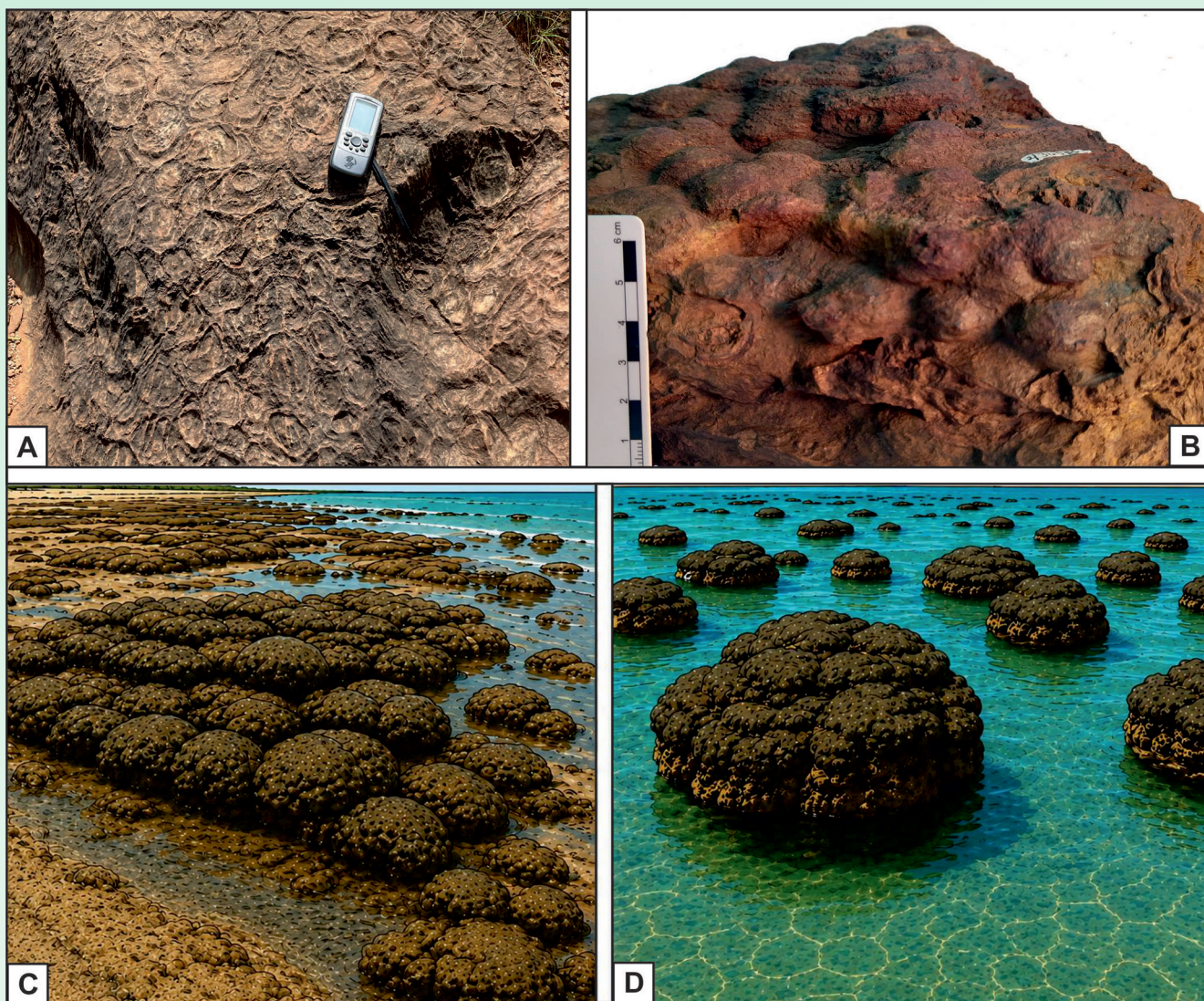


Figure 3. Representative examples of Archaean Stromatolites (A–B) and modern (C–D) stromatolites showing characteristic laminated and domal morphologies formed by microbial activity. (Original Ref: Figure A; Kumar et al., 2023; Figure B; Shukla and Sharma, 2020; C–D: AI-generated illustrations)

and chemical signs in ancient rocks. These were found in places like the Pilbara Craton and the Barberton Greenstone Belt. Similar evidence was also found in Indian region. Scientists also found microbial mats and chemical signatures in rocks. These discoveries suggest that life existed about 3.5 billion years ago.

Evidence of these early life forms is preserved in some of the oldest rocks on the Earth. In India, regions, such as the Dharwar, Singhbhum, and Bundelkhand cratons contain ancient geological formations, which act like windows into the distant past. These rocks contain important clues called

biosignatures. They help scientists find traces of the early life. With modern techniques, scientists can study early life more clearly by using advance microscopy and chemical analysis. This helps them examine tiny fossils and chemical signals in rocks. These tools also help them distinguish between real-life remains and non-living structures. Because of this, evidence that was once unclear is now understood with greater confidence.

Stromatolites: Among the most significant biosignatures are stromatolites. These are the layered organo-sedimentary structures formed by

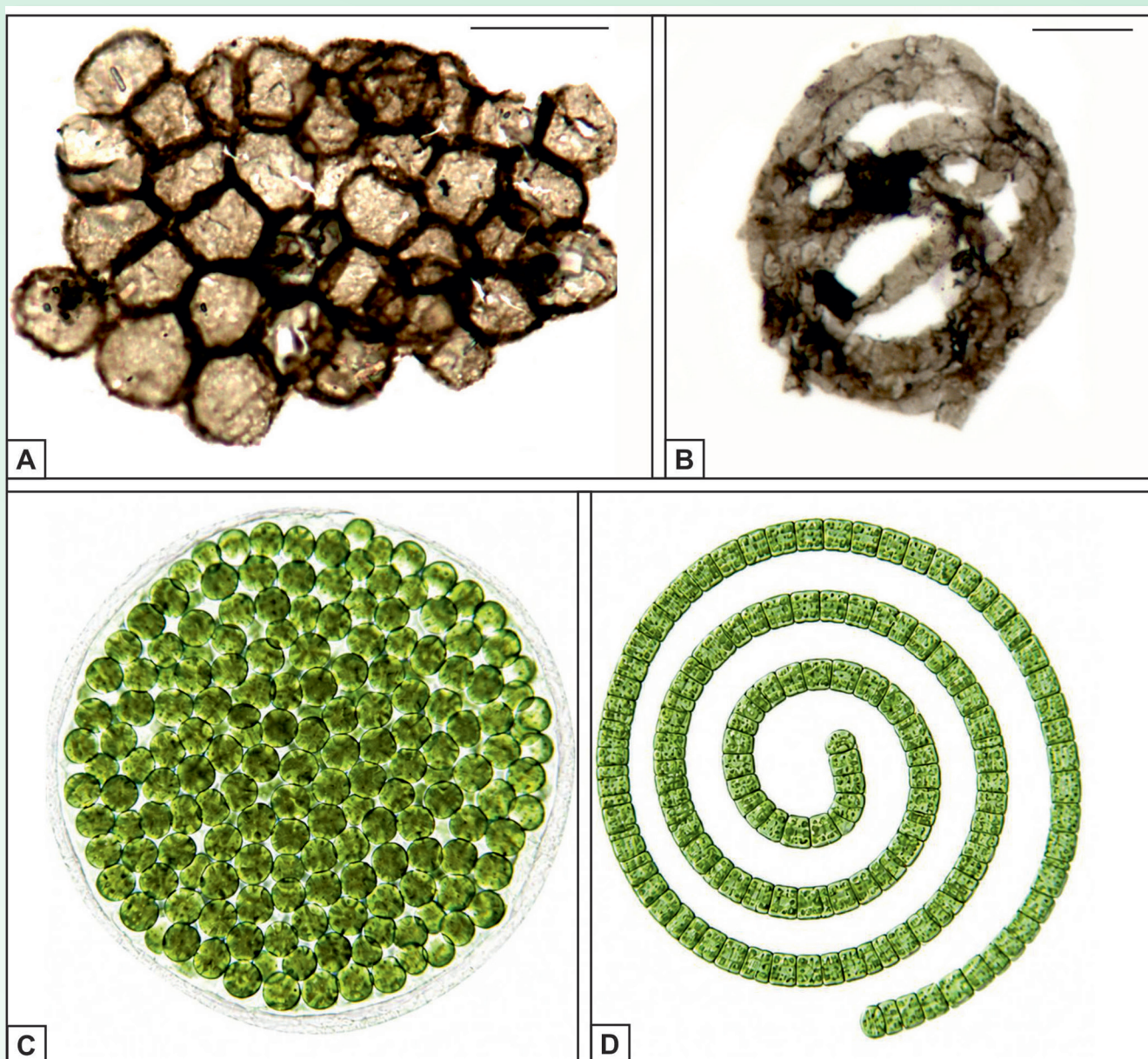


Figure 4. Precambrian microfossils (A–B) and modern cyanobacteria (C–D) showing morphological similarities. (A) Colonial coccoidal forms resembling modern chroococcalean cyanobacteria (C); (B) spiral microstructure comparable to *Arthrospira* (D). Scale bar 20 μm for Figure A and B, Ref: Shukla et al., 2020) (C–D) AI Generated Illustration based on modern forms.

the trapping and binding of sediments by microbial mats, reported from carbonate successions, such as the BIF-associated sequences of the Dharwar and Singhbhum cratons. Stromatolites are considered biogenic structures formed by predominantly photosynthetic cyanobacteria in the Proterozoic. For the Archaean succession, the biogenic nature is the matter of debate. These microorganisms grow

as thin, cohesive biofilms that trap and bind fine sedimentary particles. Over time, microbial mats grow repeatedly and trap sediments. This leads to the formation of thin, layered, hard structures. These layers in stromatolites show repeated cycles of growth and sediment trapping. They create clear patterns at both large and small scales.



The stromatolites are not restricted to the geological past. They continue to form in modern environments, such as Shark Bay (Australia), the Exuma Cays (Bahamas), the Cuatro Ciénegas Basin (Mexico), and Pavilion Lake (Canada) by the activities of living organisms. Modern and Precambrian stromatolites are very similar. They have similar shapes, internal layers, and growth patterns. In cross-section, both show fine layering formed by microbial mats. The stromatolites studies provide valuable analogues for interpreting ancient examples.

Microfossils: Scientists have also recorded microfossils from Precambrian sedimentary successions. These are very small remains of ancient life preserved in the sedimentary rocks, such as shale and chert. They often look like simple filaments or small, spheroidal or coccoidal shapes. These microfossils resemble modern bacteria, cyanobacteria, and acritarchs. Studying microfossils is not always easy. Scientists must carefully check if they are truly biological. When studied in their rock setting (syngeneticity) and chemical signals (biogenicity), they provide useful information. These microfossils help scientists understand early microbial life in ancient oceans. When combined with sediment and chemical data, these fossils provide strong evidence of early life on the Earth.

Isotopic ratios: Another important evidence of life comes from geochemistry, especially organic carbon isotopes. Living organisms prefer lighter carbon. This leaves a clear chemical signature in rocks. This is called carbon isotopic fractionation. It often shows low $\delta^{13}\text{C}$ values in ancient rocks. These signals suggest that biological processes, such as carbon fixation, were occurring. Because of this, they are considered one of the strong evidence for the existence of early life on the Earth.

INDIAN PRECAMBRIAN FOSSILS AND THE ORIGIN OF EARLY LIFE

Ancient rocks of India give important evidence of the early life. The Dharwar Craton, Singhbhum Craton, and Bundelkhand Craton are very important in this regard. These regions contain less metamorphosed

sedimentary rocks, and well-preserved stromatolites and microfossils. They show that microbial life existed billions of years ago. However, there are some challenges. Rocks may be altered over time, and some non-living structures can appear to be fossils. Even with these problems, every new finding is improving our understanding of early life on the Earth.

Early evidence of Precambrian life in India were reported in the 19th century by William King Jr., who described “dark spotted circular structures” from the Owk Shales of the Kurnool Group as possible cycloid fish scales (King, 1872, p. 69). These remains were later re-examined by S. T. Rajurkar (1963), who compared them with *Fermoria*, now regarded as a junior synonym of *Chuaria circularis*. Similar carbonaceous discs were also reported by T. R. Jones (1909) from the Suket Shales of the Vindhyan Supergroup.

The biological affinity of these structures remained debated until the mid-20th century. These circular structures are now widely accepted as fossils of *Chuaria circularis* (Ford and Breed, 1973; Vidal and Ford, 1985). Their recognition marked a turning point, heralding the beginning of systematic Precambrian palaeobiology in India.

The earliest report of stromatolite-like structures from India dates back to John McClelland, who described ring-like features (McClelland, 1834). Later, William King Jr. documented similar structures from the limestones of the Cuddapah Supergroup. He referred to them as “laminated and segregated in a peculiar way” (King, 1872, pp. 189–190). In the Vindhyan Basin, spheroidal bodies preserved in limestone were reported by J. B. Auden (1933, pl. 7, fig. 2).

The taxonomy, evolutionary significance, and biostratigraphic utility of these stromatolite-like structures remained poorly understood until the 1960s. Their roles in evolution and biostratigraphy were also unclear. After the 1960s, scientists made major progress. Simultaneous studies by different researchers showed that stromatolites are found in many Precambrian basins across India. These structures became important as evidence of early life. They also helped in dating Precambrian rocks



(biostratigraphy). This marked the beginning of detailed research on stromatolites in Indian Precambrian rocks (Sharma et al., 2012).

The macrofossils, microfossils, and acritarchs, as well as Pre-Ediacaran and Ediacaran fossils, have been widely reported from several Precambrian sedimentary basins of India. These evidences of life were reported from the peninsular India successions, such as Vindhyan, Chattisgarh, Marwar, Cuddapah, Bhima, and Kurnool successions, and in the Himalayas. These fossil assemblages have substantially enriched the record of early life in the Indian subcontinent. They also provide crucial evidence that diverse microbial and early eukaryotic organisms existed well before the Cambrian. In this context, the Indian Precambrian fossil record helps address the problem highlighted by Charles Darwin regarding the apparent absence of pre-Cambrian life.

The Indian fossil record shows that this apparent gap was mainly caused by poor preservation and the difficulty of identifying very old fossils, rather than an actual absence of life. In reality, many kinds of microorganisms and early eukaryotic life were already living and thriving long before the Phanerozoic era.

A STORY STILL UNFOLDING

The scientists have found evidence of life dating back at least 3.5 billion years. Life may have started

even earlier that we are not able to assess due to poor preservation of rocks of that time. Darwin's theory explained how life evolves and becomes diverse. Yet, it does not explain how life first began. The origin and evolution of life is not a single, abrupt event in history, but a gradual, complex process involving chemistry, environment, and time. From simple molecules to microscopic organisms, and eventually to complex ecosystems, life's journey began in the Earth's ancient oceans. The study of ancient rocks, especially in regions, such as India, continues to provide new clues about the earliest life on the Earth. These findings not only help us to understand our own origins, but also guide the search for life beyond Earth.

Though many questions remain unanswered, **each discovery brings us closer to understanding how life emerged from a lifeless world** and how it came to shape the planet we live on today.

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When Flowers Learned to Paint the Earth

Pragya Gautam

FLOWERING PLANTS AND THEIR ORIGIN

IN the beautiful world of plants that surround us, nearly eighty percent are flowering plants, known as angiosperms. They represent the largest, most successful, and most influential group in the plant kingdom. **Of all plant species found on the Earth, nearly eighty to ninety percent belong solely to angiosperms.** From the perspective of biodiversity, around 350,000 species of these plants have been discovered across the globe, classified into approximately 400 plant families and more than 13,000 genera. Except for the vast frozen expanse of Antarctica's main ice-covered landmass, these plants have spread to almost every corner of the world. Humanity, as a primary source of food and sustenance, relies heavily upon these plants.

The most remarkable characteristic of these plants is the evolution of flowers as their reproductive structures. A flower consists of four distinct whorls: the calyx, the corolla, the androecium, and the gynoecium. Among these, the calyx and corolla are sterile whorls, while the androecium serves as the male reproductive organ and the gynoecium as the female reproductive organ. Since the seeds remain enclosed within carpels inside the ovary, these plants are known as angiosperms, meaning “enclosed seeds.” In due course, the ovary develops into a fruit, completing one of nature's most elegant processes of growth and reproduction.

The emergence of a flower-like structure was a beneficial genetic transformation that proved instrumental in ensuring the expansion, survival, and continued success of these plants. Since fertilization



and embryonic development take place within the ovary, the developing structures receive protection from various environmental hazards. Over time, flowering plants established a remarkable harmony with animal pollinators and, in turn, played a significant role in their evolution as well. Animals benefited from these plants by utilizing their seeds and fruits as sources of nourishment. In return, they became important partners in the widespread dispersal and global expansion of angiosperms. Beneficial genetic changes have always paved the way for evolutionary progress, and the flower stands as one of nature's most exquisite examples of evolutionary innovation.

This naturally raises an intriguing question: how did such a novel structure as the flower first come into existence? Who were the ancestors of flowering plants? The evolution of the flower remains one of the most complex mysteries in botany—a mystery so profound that Charles Darwin famously described it as an “abominable mystery.”

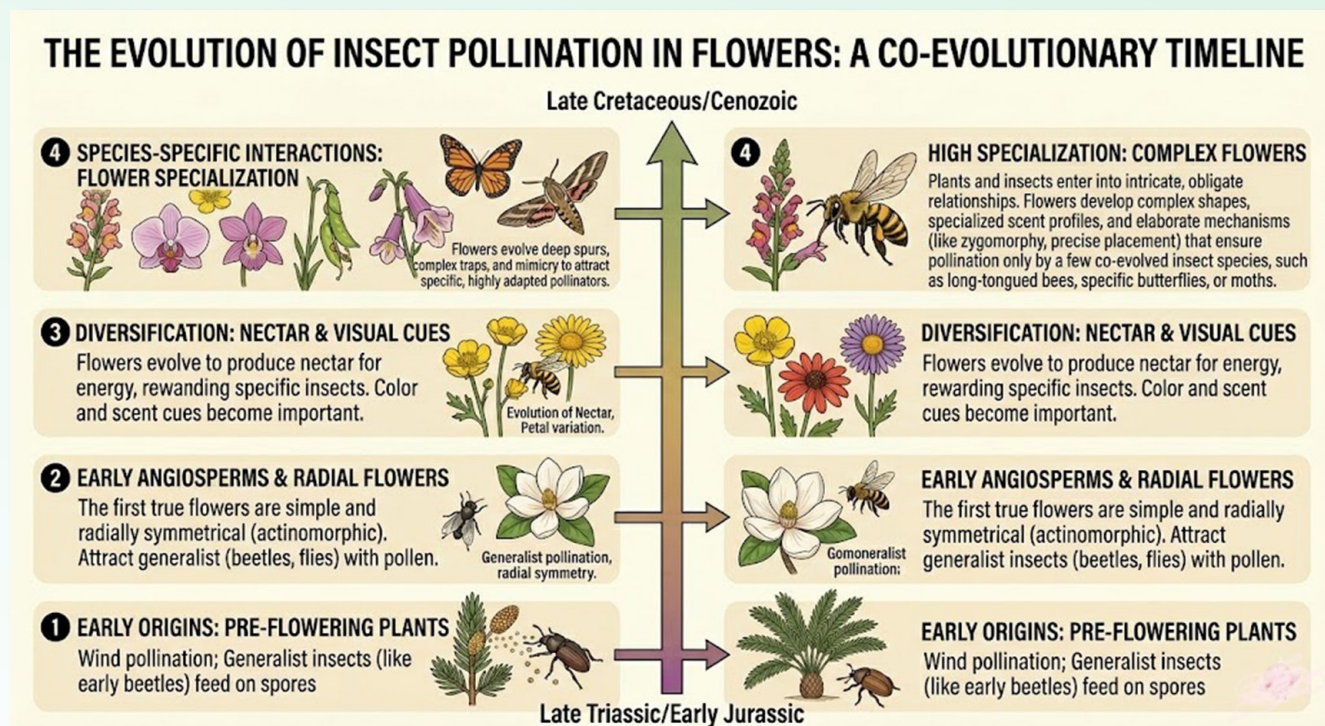
To address these questions, three complementary approaches have been proposed. The first involves the

study of fossil records to identify the closest relatives of angiosperms. The second approach focuses on a comparative analysis of the reproductive structures of living angiosperms and gymnosperms. The third relies on advanced analytical methods supported by vast datasets and modern computational techniques.

Floral structures exhibit an extraordinary degree of diversity. This diversity may be reflected in the loss of certain floral whorls or the emergence of additional structures, in radial versus bilateral symmetry, and in the spiral or cyclic arrangement of floral parts. Furthermore, variations are also observed in the colour, arrangement, number, and size of floral organs. Fossil records provide valuable insights into understanding their broad emergence and the remarkable process of diversification through evolutionary history.

FOSSILS CAN REVEAL DEEP SECRETS

To understand the origin and diversification of flowering plants, we must cast our gaze far back into the depths of the past. Ancient plants, preserved through the ages as fossils can offer valuable glimpses into what the earliest flowering plants may have



looked like and how they were related to their ancestral lineages. Fossil records alone possess the power to reveal where these plants first emerged and what circumstances may have led to their appearance on the Earth.

For a long time, it was generally believed that flowering plants, or angiosperms, first appeared during the Early Cretaceous Period, around 145 to 100.5 million years ago. However, certain fossil discoveries from the Triassic Period and Jurassic Period astonished the scientific community and challenged this long-held assumption.

In 2013, researchers in Switzerland discovered pollen grains resembling those of flowering plants. These fossilized pollen grains were traced back to the Middle Triassic Period, approximately 247.2 to 242

million years ago. This remarkable discovery pushed the timeline of flowering plant origins back by tens of millions of years, suggesting that the emergence of flowering plants on the Earth may have occurred far earlier than previously imagined, reaching into a past even older than our expectations.

The fossil *Nanjinganthus*, estimated to be nearly 174 million years old, was discovered in 2016 in the Nanjing region of China. It displayed a cup-like structure that appeared to completely enclose the ovules, a feature strikingly reminiscent of a flower. However, for many years this fossil remained the subject of considerable debate. Several scientists argued that it was not a true flower, but rather a highly advanced gymnosperm.



To resolve this uncertainty, researchers employed micro-CT scanning technology in 2023. This technique made it possible to examine the fossil's internal structures without damaging it. The scans clearly revealed enclosed ovules within the fossil, lending strong support to the original claim of its discoverers and strengthening the argument that it represented an early flowering structure.

In 2021, another remarkable macrofossil, *Florigerminis jurassica*, approximately 164 million years old, was discovered in the Jiulongshan Formation of Inner Mongolia, China. This fossil preserved a stem, leaves, fruits, and a flower bud all connected as part of a single structure. Its discovery sent waves of excitement through the scientific community, as it seemed to provide an extraordinary glimpse into the early evolution of flowering plants. Nevertheless, some researchers consider it more closely related to the gymnosperm *Ephedra*. As a result, scientific debate surrounding its true identity continues even today.

As is well known, fossilized pollen grains of angiosperms have been found in great abundance

from the Early Cretaceous Period. The various parts of a flower are delicate in nature and tend to decay rapidly, whereas pollen grains possess an extraordinary ability to withstand the passage of time and are often preserved remarkably well in the fossil record. Their outer layer, made of sporopollenin, is exceptionally strong and highly resistant biopolymer, remaining largely unaffected by heat and even by acids.

The pollen grains of the earliest flowering plants possessed only a single aperture or opening. In contrast, modern pollen grains are generally tricolpate, bearing three apertures, a feature that reflects an important stage in their evolutionary advancement.

Most fossilized angiosperm leaves and flowers discovered to date belong to the Early Cretaceous Period. Between 1996 and 1998, the fossil *Archaeofructus* was unearthed from the Yixian Formation in China. Estimated to be nearly 125 million years old, it represented an ancient aquatic plant. Remarkably, sepals and petals were entirely absent in this fossil. Instead, the reproductive organs, the stamens and



carpels, were arranged along an elongated axis, with the male structures positioned below and the female structures above.

This discovery offered an intriguing insight into the earliest stages of floral evolution. It suggested that reproductive organs may have evolved first, while protective structures, such as sepals and visually attractive floral components like petals, designed to entice pollinating insects, appeared later in the course of evolution.

In 2015, scientists reexamined the fossils of an aquatic plant known as *Montsechia vidalii*, dating back nearly 130–125 million years, which had been discovered in Spain. Their renewed analysis revealed that it represented one of the most primitive flowering plants known from the Cretaceous Period. Unearthed from limestone quarries in Spain, this fossil belonged to an aquatic weed-like plant that lived completely submerged beneath the water's surface. Like several of the earliest flowering forms, it possessed no petals. Its enclosed fruit contained only a single seed, offering a

fascinating glimpse into the simplicity of early floral evolution.

Remarkable fossil discoveries from the Cretaceous Period have also been found preserved in amber deposits in Myanmar. These specimens have retained the three-dimensional structure of flowers in extraordinary detail. Such exceptional preservation allows scientists to investigate the intricate architecture of pollen grains and even study the internal structures of stamens through micro-CT scanning, opening a rare window into the hidden details of ancient plant life.

Taken together, these fossil records suggest that the origin of flowering plants had already begun during the Jurassic Period, although it was during the Cretaceous Period that they began to establish a widespread and abundant presence across the Earth. The earliest fossil representatives of angiosperms were predominantly herbaceous or shrub-like plants, modest in form yet destined to become one of the



most successful groups in the history of life on our planet.

Thus, a broad analysis of fossil evidence led scientists to several significant conclusions. In the earliest fossils, floral organs appeared loosely arranged or organized in spiral patterns. Gradually, over the course of evolution, these structures became more compact and transformed into well-defined floral whorls. Primitive flowers possessed separate petals and carpels, but later fossil records reveal a tendency toward the fusion of floral organs. Petals began to unite, forming tubular structures that facilitated more efficient insect pollination.

The earliest fossil flowers were generally circular and exhibited radial symmetry. However, by the Middle and Late Cretaceous Period, flowers resembling orchids began to display bilateral symmetry. This transition is believed to reflect a remarkable story of co-evolution between flowering plants and their insect pollinators, where each influenced and shaped the evolutionary path of the other.

Amborella trichopoda is considered the most ancient living flowering plant known today. It is a small evergreen shrub native to New Caledonia in the South Pacific Ocean. Scientists believe that it diverged from all other flowering plant lineages nearly 130 million years ago. Its vascular tissues retain primitive characteristics resembling those of gymnosperms. Its floral organs are arranged in a spiral pattern, and their numbers are not fixed. The carpels remain free and are not entirely enclosed, while its pollen grains possess a single aperture, features that preserve echoes of an ancient evolutionary past and offer a living glimpse into the earliest stages of floral evolution.

CO-EVOLUTION OF EARLY FLOWERING FAMILIES AND INSECTS

The fossil remains of most early flowering plants closely resemble members of the Chloranthaceae, Ceratophyllaceae, and Ranunculaceae families. The diversification of flowering plants is believed to have



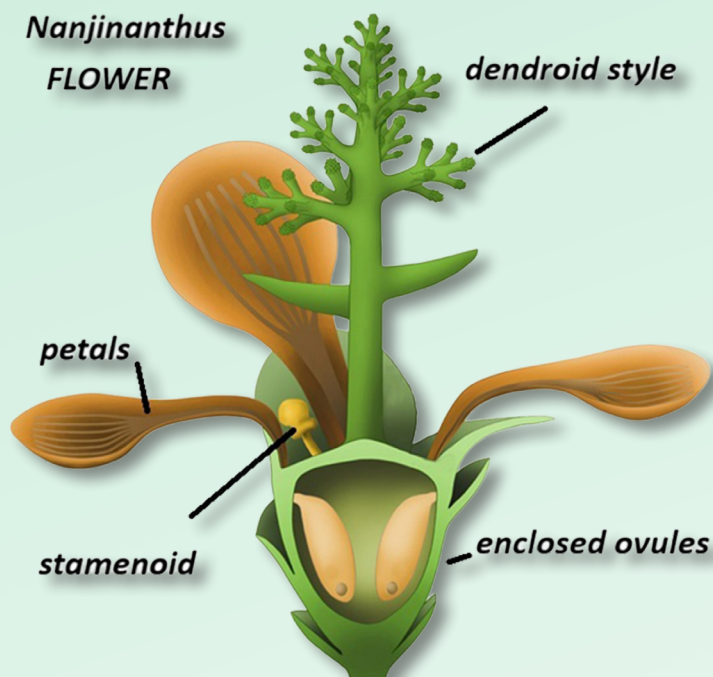
begun approximately 113 to 100.5 million years ago. During this remarkable period, magnolia-like arboreal plants emerged upon the Earth, while the water lily family also made its appearance. It is widely believed that the oldest and most diverse angiosperms first evolved in regions of Africa near the equator and gradually spread outward toward the poles.

As floral structures became increasingly diverse, their pollinating insects evolved alongside them in a remarkable journey of mutual adaptation. Scientists suggest that insect pollination had already originated much earlier in now-extinct seed ferns, whose large pollen grains made wind pollination impractical. Similar evidence is also found in the extinct Cycadeoidophyta and in present-day cycads.

Among angiosperms, most insect-pollinated flowers were bisexual in nature. By the Cenomanian age, flowers had already established themselves as a novel and distinctive reproductive structure. They had become adorned with large petals, abundant small pollen grains, and nectar-bearing glands that attracted pollinating visitors. As insect pollination continued to evolve, flowers also developed sophisticated mechanisms to prevent self-pollination, including incompatibility systems and pollen-tube competition. Thus, nature wove an intricate evolutionary partnership between flowers and insects, one that enriched the living world with greater diversity, beauty, and ecological harmony.

As floral structures gradually diversified, their pollinating insects evolved alongside them in an extraordinary tale of mutual adaptation. It is believed that insect pollination had already begun in the now-extinct seed ferns, whose pollen grains were too large for effective wind dispersal, making insect-mediated

***Nanjinanthus* FLOWER**



transfer a more likely mechanism. Similar indications are also found in the extinct Cycadeoidophyta, as well as in present-day cycads. Among angiosperms, the majority of insect-pollinated flowers were bisexual in nature.

By the Cenomanian age (100.5 to 93.9 million years), flowers had firmly established themselves as a novel

and distinctive reproductive organ. They had become adorned with large and attractive petals, abundant small pollen grains, and nectar-producing glands that served as invitations to their pollinating visitors. As insect pollination became increasingly refined, flowers also evolved sophisticated strategies to prevent self-pollination, including incompatibility mechanisms and pollen-tube competition, ensuring greater genetic diversity and reproductive success.

The earliest angiosperms that emerged during the Cretaceous Period are known as basal angiosperms. These primitive flowering plants possessed spirally arranged floral organs and pollen grains with a single aperture. They exhibited a fascinating blend of characteristics shared by both monocotyledonous and dicotyledonous plants. From these basal ancestors, a distinct evolutionary branch later arose, known as the eudicots, characterized by pollen grains with three apertures.

In the primitive angiosperms of the Cretaceous Period, the task of pollination was not performed by the modern flies and butterflies familiar to us today. Instead, this role was carried out by beetles and thrips, the earliest companions in the story of floral evolution. Their mouthparts were adapted for

chewing rather than sipping, shaping the nature of their interaction with flowers.

The earliest flowers resembled shallow, flattened dishes, with thick and sturdy petals. Such structures were ideally suited for the landing, biting, and chewing habits of beetles. In the beginning, fragrance evolved as one of the earliest floral attractions, for beetles possessed limited visual abilities, but an exceptionally keen sense of smell. Scent became nature's first invitation, guiding these ancient pollinators toward their floral hosts.

As time unfolded, changes in floral architecture were accompanied by corresponding transformations in the anatomy of insects, their body structures became more specialized, their vision sharper, and their powers of flight increasingly refined. Through this gradual and delicate process of co-evolution, flowers and insects shaped one another across countless ages.

Even today, one can witness the enduring legacy of this ancient partnership, where many flowers and their pollinating insects remain bound together in a profound and inseparable relationship, an elegant testimony to nature's timeless artistry.

MODERN GENETIC TECHNIQUES (PHYLOGENOMIC) AND THE VALIDATION OF FOSSIL EVIDENCE

The stories revealed by fossils are now examined and verified in laboratories through DNA sequencing and molecular analysis. Three major approaches have contributed to this understanding: the molecular

clock theory, ancestral genome reconstruction, and the study of MADS-box genes.

The molecular clock theory measures the rate of mutations occurring within plant DNA. Since mutation rates are relatively consistent over time, computer-based models can trace evolutionary history backward and estimate the point at which two species diverged from a common ancestor. In this way, time itself becomes a silent recorder of life's evolutionary journey.

The reconstruction of ancestral genomes has also offered remarkable insights. Under the *eFlower Project*, data from thousands of living and fossil plants were analyzed using powerful supercomputers. The results led to a fascinating conclusion: the very first flower on the Earth was most likely bisexual in nature.

MADS-box genes are responsible for the formation and development of floral organs. Studies through genetic engineering have revealed that these genes are also present in gymnosperms, where they give rise to leaf-like structures. This discovery strengthens the long-standing view that a flower is, in essence, a modified shoot transformed by evolution into a specialized reproductive structure.

While palaeontology tells us *when* and *where* flowers evolved, modern genetic technologies answer the equally profound question of *how* this evolution unfolded. The beautiful flowers that have painted the Earth with colour and elegance have travelled through a long and extraordinary evolutionary journey. And throughout this grand voyage, enchanting insects have remained their steadfast companions, sharing in the story of life's unfolding wonder.

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.

After India's Final Goodbye to Gondwana: When it Sailed Alone

Poonam Verma

Western India's basins, from rift valleys and lava plateaus to lignite corridors, chronicle the breakup of a supercontinent and the emergence of a drifting India.

IMAGINE if the rocks in western India could explain how a supercontinent split up and give us clues about what our climate could be like in a much warmer world.

Under today's sand and scrub, there is a series of hidden basins that captured India's final separation from Gondwana, when the subcontinent broke away from its southern neighbours and moved north toward Asia. These basins hold the marks of that split in their faults and lava flows, as well as peat

from ancient wetlands that once covered Gujarat, Rajasthan, and parts of Pakistan.

WHEN INDIA STARTED TO RUN

For much of the Earth's history, India was not its own subcontinent, but part of **Gondwana**, a southern supercontinent that included Africa, Madagascar, Antarctica, and Australia. Geological studies show India was attached to Gondwana's



Continental drift of India from Gondwana to Asia, highlighting key timelines and tectonic collision

eastern edge until the Late Jurassic, when it began to break away. By about 80 million years ago, India had become a separate plate, moving north across the ocean much faster than most plates today—up to 15 to 20 centimetres per year, while most move only a few centimetres. The research suggests that this was because it was simultaneously pushed from behind by active underwater volcanic ridges and pulled from the front by a heavy, sinking ocean floor. When a tectonic plate speeds up and changes direction, the edges feel the stress first. On India's western side, this stress reactivated old weak zones in the crust, called the Dharwar, Aravalli–Delhi, and Satpura trends. These are like seams in the continent. As India moved away from Gondwana and from Africa, Madagascar, and Seychelles, these seams became the places where the crust started to tear. This tearing created long, narrow rift basins, troughs bordered by faults where blocks of crust sank lower than their neighbours. Today, these basins show up as:

- Kachchh and Saurashtra along the Gujarat coast,
- the Cambay Basin running from north of Patan down past Bharuch,

- further inland, the Barmer–Santhor, Bikaner–Nagaur and Jaisalmer basins in western Rajasthan,
- and, across the border, the Indus–Thar rift system in Pakistan.

Each of these basins formed at different times and in different ways, but they all share the same story: India's west and northwest were pulled apart as the plate separated from Gondwana and moved toward Asia.

WHEN THE EARTH TORE APART AND FIRE FLOODED WESTERN INDIA

As India drifted away from Gondwana, stretching along its western margin pulled the crust apart, creating a series of rift basins. Although each basin evolved differently, they shared the same broad pattern of faulting and subsidence. The Kachchh Basin preserves some of the earliest evidence of this rifting, while similar structures developed farther south in the Cambay Basin and inland in the Barmer–Santhor, Bikaner–Nagaur, and Jaisalmer basins. Together with



Paleoart of the Deccan trap during the Late Cretaceous (By Leonardo HerSan)

the Indus–Thar region across present-day Pakistan, they record the progressive breakup of India's western margin.

Among these basins, Cambay provides one of the clearest examples of tectonic evolution. It developed as a long fault-bounded depression that subsided in stages, eventually becoming divided into several smaller sub-basins by repeated fault movements. Meanwhile, Saurashtra remained relatively elevated, forming a structural high between Kachchh and Cambay.

While these basins were evolving, western India experienced one of the largest volcanic events in Earth's history. Between 66.4 and 65.6 million years ago, enormous eruptions produced the Deccan Traps, covering much of western and central India with flood basalts. Saurashtra became buried beneath these lava flows, forming the lava plateau seen today, while thick basalt layers accumulated beneath the Cambay Basin and extended into Rajasthan.

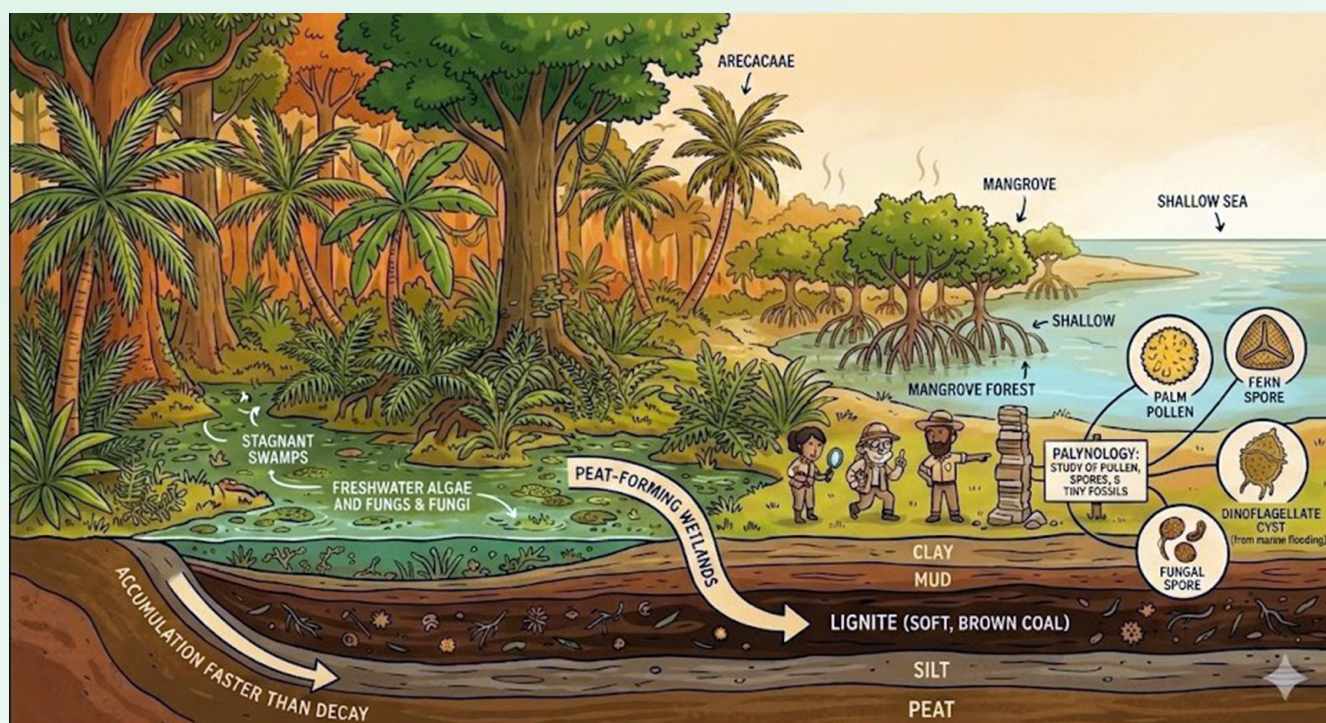
These eruptions did far more than create plateaus and black soils. The heat and weight of the lava

weakened the crust, altered drainage patterns, and promoted continued subsidence in many of the basins. By the time volcanic activity waned, western India had acquired a landscape of faulted depressions and low-lying areas, conditions that would later favour the development of rivers, lakes, and the extensive peat-forming wetlands that flourished during the Early Paleogene greenhouse world.

GREENHOUSE WORLD AND EXTENSIVE PEATLANDS

By the late Paleocene and early Eocene, India had moved close to the equator. At the same time, the world's climate experienced periods of extreme warmth, such as the Paleocene–Eocene Thermal Maximum (PETM) and the Early Eocene Climatic Optimum (EECO), when there was little polar ice and many mid-latitude areas had subtropical or tropical climates.

The new and reactivated western basins, located at low latitudes and near sea level, became ideal places



Conceptual sketch of Early Eocene landscape of the Indian subcontinent, illustrating a highly diverse megathermal ecosystem. Peat-forming wetlands, stagnant swamps, and mangrove forests thrived under a warm, wet climate, flanked by a shallow epicontinental sea.

for peat-forming wetlands like swamps and marshes. Where the land sank slowly and the water table stayed high, plant material built up faster than it decayed, creating thick deposits. Over time, this peat turned into lignite, a soft, brown coal that still holds much of its original plant material and chemistry. The main early Paleogene lignite corridor is found in Rajasthan's Bikaner–Nagaur and Barmer basins, and in Gujarat's Cambay, Saurashtra, and Kutch basins along the northwestern edge of the Indian Plate.

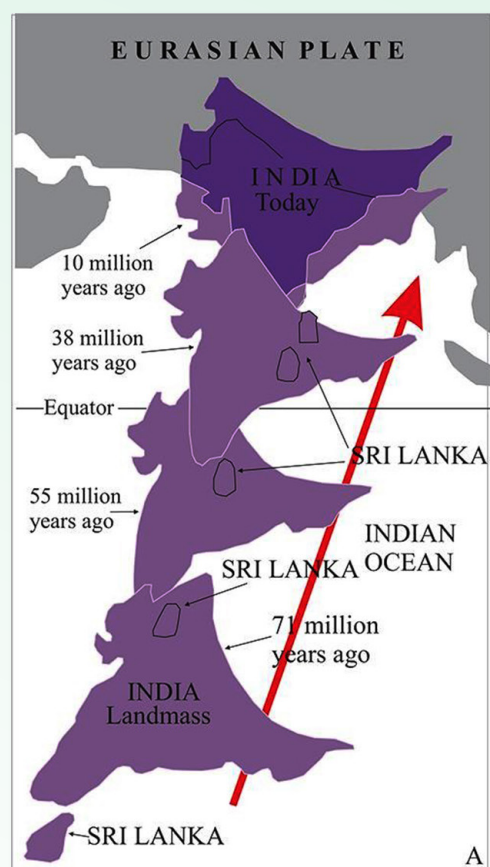
READING PEATLANDS: PAST ENVIRONMENTAL STORIES LOCKED IN LIGNITIC ROCKS

Today, much of the western India is characterized by deserts, scrublands, and semi-arid landscapes. Fifty million years ago, however, the same region was warm, wet, and covered by luxuriant vegetation. The lignites

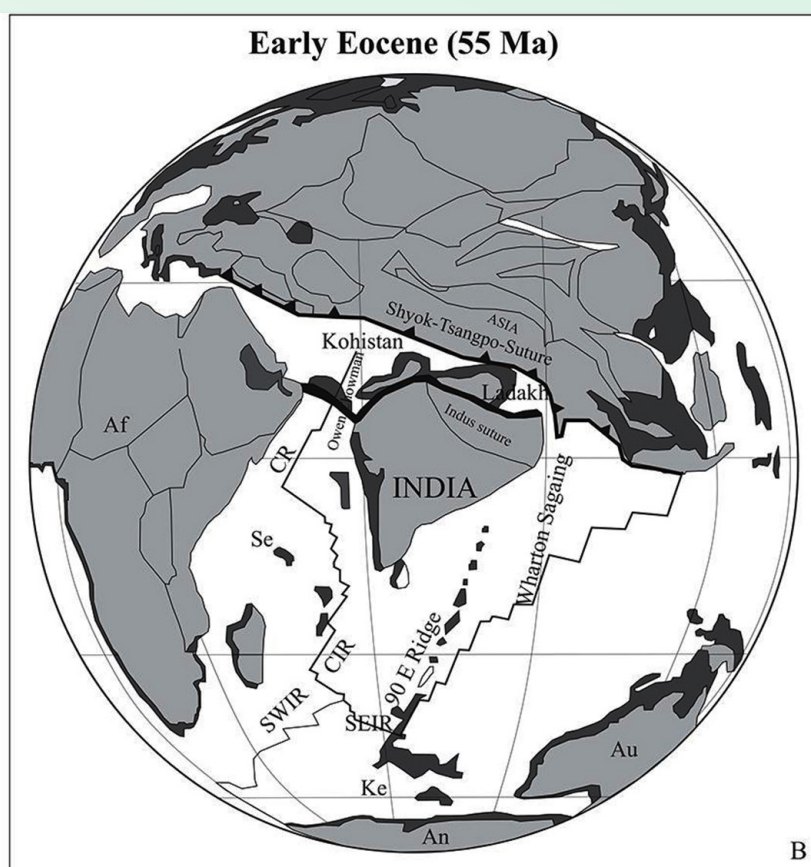
hidden beneath these modern landscapes preserve traces of those lost ecosystems. To reconstruct them, scientists turn to palynology, the study of pollen, spores, and other microscopic fossils preserved in sediments.

Early Eocene lignites from western India contain abundant angiosperm pollen, especially palms (family Arecaceae), together with fern spores, freshwater algae, and fungi. Many of the palm pollen grains belong to mangrove plants, showing that coastal swamps and mangrove forests once occupied areas that are now dry and sparsely vegetated.

Far from today's thorny scrub and desert plains, India then supported diverse equatorial rainforests, known as megathermal vegetation, dominated by broad-leaved evergreen trees adapted to year-round warmth and abundant rainfall. Fossil pollen from Paleogene lignites along western and northeastern India suggests that a nearly continuous belt of tropical



A



B

A. Shifting of the Indian plate during the last 71 million years; B. location of India during the Eocene period (adopted from Singh et al. 2019)



rainforest and swamp forest once stretched across much of the subcontinent during the Late Paleocene–Early Eocene greenhouse world.

Evidence from marine microfossils further reveals that these ancient wetlands often lay close to shallow seas and estuaries. At the Vastan mine in the Cambay Basin, Early Eocene lignites are interbedded with dark marine shales containing marine palynomorphs and microfossils, recording a bay–marsh environment repeatedly affected by coastal flooding and marine incursions. Similar mixed terrestrial and marine assemblages in Kachchh indicate humid nearshore settings during the Early Eocene Climatic Optimum (EECO).

Likewise, palynological and organic petrographic studies from the Bikaner–Nagaur and Barmer basins reveal low-lying swamp forests and floodplain marshes rich in angiosperm pollen, spores, fungal remains, and freshwater algae. Comparable records from the Thar and Lakhra coalfields of Pakistan show that these tropical peatlands extended far beyond modern political boundaries, forming an extensive wetland belt across the northwestern Indian Plate.

In short, each thin layer of lignite preserves a snapshot of a vanished world. Beneath today's deserts and scrublands lie the remains of tropical rainforests, mangrove swamps, freshwater marshes, and shallow coastal seas that flourished as India raced northward through one of Earth's great greenhouse intervals.

WHY THIS DEEP-TIME STORY MATTERS NOW

When India first separated from Gondwana and moved into equatorial latitudes, the new rift basins along its western margin filled with Paleocene–Eocene peats beneath hot, humid megathermal rainforests

and mangrove swamps. These peats quietly recorded global greenhouse events like the PETM and EECO in their pollen, spores, marine microfossils, and organic layers, capturing not just climate, but also a moment when equatorial rainforests and early mammals used the drifting Indian plate as both a refuge and a bridge between Gondwana and Asia.

Today, those same deposits are central to western India's energy and resources. They have become lignites that power parts of Gujarat and Rajasthan, source rocks and reservoirs in hydrocarbon-rich rifts like Cambay and Barmer, and aquifers and sediment layers that control groundwater and hazards across a corridor from Kachchh, Cambay, Barmer, and Bikaner into Thar and the Indus Basin. Because they formed under CO₂-rich, very warm conditions similar to some future climate scenarios, they also serve as a natural experiment for testing models of monsoon response, sea-level change, and tropical wetland resilience, using real rocks instead of just simulations. This is a distinctly Indian contribution to Earth science: Indian palynologists, stratigraphers, and coal petrologists have played a key role in connecting these local basins to global hyperthermals and biotic dispersals, turning western India's lignites into both a record of how India left Gondwana and a quiet warning about the climates and coastal risks we may face again.

Today, deserts and scrublands stretch across much of western India, but beneath them lie the remains of rainforests, mangrove swamps, and peatlands that flourished during one of the Earth's great greenhouse worlds. Their silent record carries a message from deep time: the climates of the future may not be entirely unfamiliar—they may echo worlds that our planet has experienced before.

About author



Dr Poonam Verma is Scientist at BSIP, Lucknow with expertise in studies of organic-walled microfossils. She specialises in biostratigraphy and the reconstruction of Cenozoic depositional environments. Her current research interest is in exploring Cenozoic hyperthermal events and the associated vegetational and climatic interactions.

Decoding Ancient Environments: Expanded Insights from Palynofacies Analysis in Gondwana Deposits

Neha Aggarwal, Roshan Kumar and Kanchan Awasthi

Reconstruction of palaeoenvironments and palaeoclimate is the primary goal of palaeosciences, especially to study the ancient environmental development, and the formation of resources on Earth.

One of the many methods that can be used, palynofacies analysis, the study of dispersed organic matter/sedimentary organic matter preserved in the sediments, has become one of the potential and most versatile methods of interpreting palaeoenvironmental and palaeodepositional environments.

The sedimentary organic matter comprises a variety of microscopic components, which include spores and pollen grains, plant tissues, woody fragments, cuticles, algae, degraded organic matter, opaque phytoclasts, amorphous organic matter and other organic debris.

The components of dispersed organic matter are indicators of the formation and transport of plant-produced materials in sedimentary deposits. The distributions and composition of these particulate organic matters are regulated by various factors like the vegetation type, sediment supply, hydrodynamic energy, the availability of oxygen, and the post-deposition diagenetic processes.

As a result, dispersed organic matter studies have become a crucial tool for reconstructing palaeoenvironmental conditions, depositional setting and basin evolution in both marine as well as continental successions.

Consequently, all their composition, morphology, and preservation state can give useful information regarding the source vegetation, deposition processes, transportation mechanisms, and post-depositional

changes. Both palynofacies research and petroleum exploration were originally restricted to marine successions. Nevertheless, their usage in the last decades has spread considerably into the continental environment like fluvial, lacustrine and coal-forming environments.

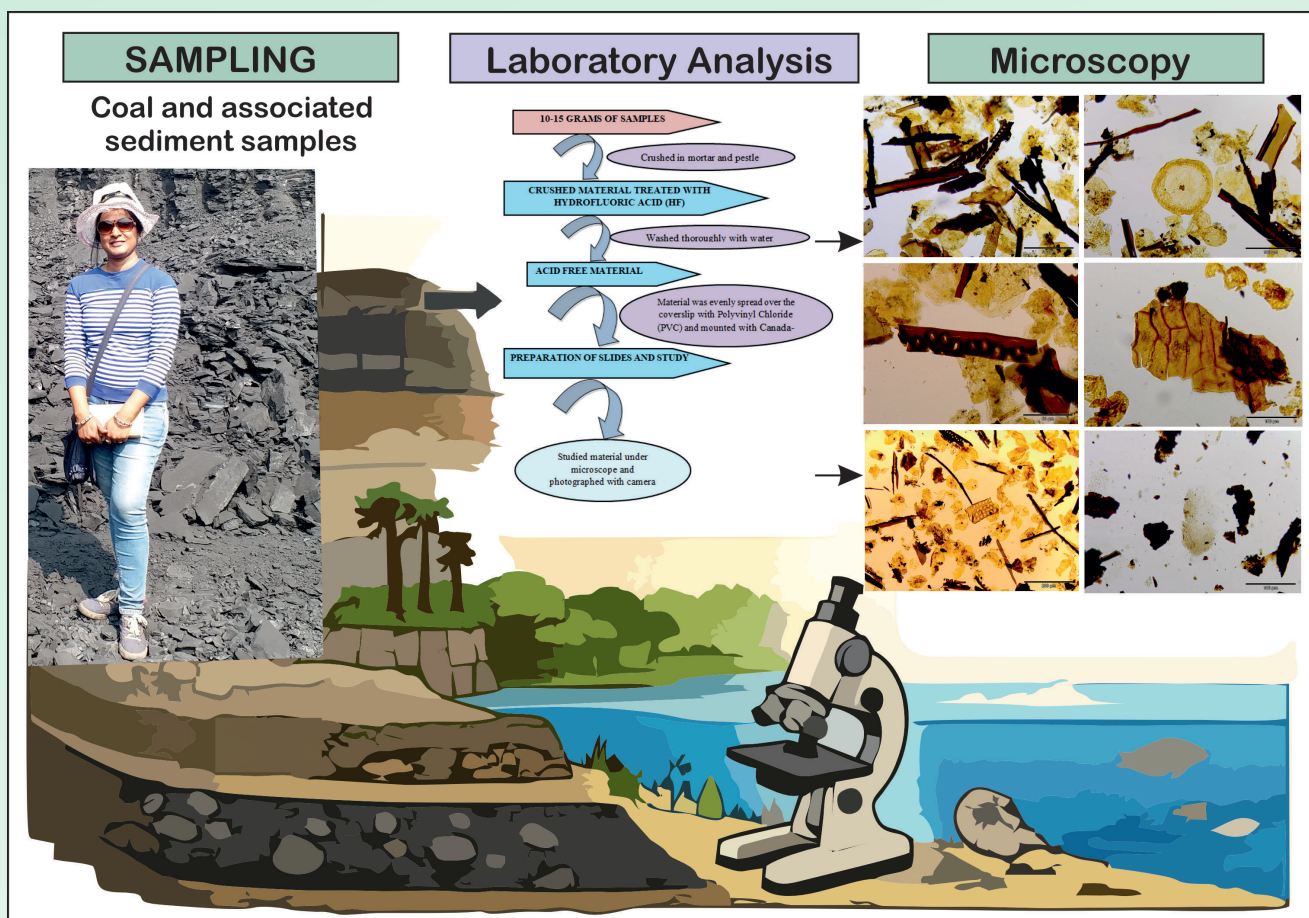
The shift has been significant especially to Gondwana deposits in which palynofacies analysis has been playing a vital role in determining the genesis of coal, basin history, and palaeoclimatic history. The broadest group of palynofacies analysis categorizes sedimentary organic material into four major groups namely palynomorphs, structured phytoclasts, opaque phytoclasts and degraded organic matter.

The groups have different environmental indicators and can be used to interpret palaeoenvironment differently. The palynomorphs (SP) that include spores, pollen grains, phytoplankton and other microfossils are also important characteristics of biological origin and deposition environment.

The preponderance of terrestrial palynomorphs, including the spores (of pteridophytes), and pollen grains of the gymnosperms are usually indicators of closeness to vegetated landmasses.

On the other hand, marine palynomorphs, such as dinoflagellate cysts and foraminiferal test linings, are indications of marine influence and assist in determining transgressive periods.

Structured phytoclasts (ST) that can be identified as structures of plants like woody tissues, cuticles, and plant cells make up the structured phytoclasts. These are the elements that are helpful especially in explaining transport dynamics and depositional energy. Lath shaped (phytoclasts that are elongated,



Graphical representation of the palynofacies analysis in the Gondwana deposits.

narrow, and rectangular (slat-like) fragments) phytoclasts are usually coarse and well preserved and, thus, suggest minimal transport and deposition in the proximity environment, but equidimensional phytoclasts (phytoclasts in which length, width, and thickness are approximately equal) tend to be related to the distal environment and extensive transport.

Besides, their state of preservation indicates the intensity of oxidation and deposits. Opaque phytoclasts, usually black, structureless or weakly structured, are usually linked to oxidizing conditions or thermal modification of organic matter. They can be of natural sedimentary origin due to long-term exposure to oxygen during transportation or combustion, and their abundance can give information about the environment and sedimentary reworking.

Recently Aggarwal et al., 2025 have introduced two forms of opaque phytoclasts (CH): palaeofire-induced opaque phytoclasts/charcoal (PAL-CH) and oxidized opaque phytoclasts/charcoal (OX-CH). PAL-CH is characterized by lines, crevices, or impressions on the opaque phytoclasts, with equidimensional or lath shapes and sub-rounded or corroded margins. In contrast, OX-CH is defined by opaque phytoclasts without lines, crevices, or impressions, exhibiting equidimensional or lath shapes with mostly angular or regular margins. The degraded organic matter (DOM) is an altered biologically material, mostly changed by microorganisms.

A major part of this group is amorphous organic matter (AOM) and is the structureless, spongy masses seen through a microscope. AOM is especially significant as far as the detection of the conditions of



dysoxic to anoxic is concerned because it develops in low-oxygen conditions when organic matter is not fully decomposed.

It can also be determined in a way that it had terrestrial or aquatic origins by variations in its texture and composition.

Palynofacies analysis methodology consists of systematic sampling and then laboratory work. To eliminate the carbonates and silicates in the sediment or coal samples, they are treated using acids and leave the organic residues. These residues are sieved and placed on slides and studied under transmitted light microscopy. A minimum number of five hundred organic matter particles per sample are usually counted in order to be statistically reliable. The resulting dataset which includes qualitative identification of organic components and quantitative distribution of organic components is then employed to define palynofacies assemblages and interpret depositional environments.

Palynofacies analysis has been effective especially in reconstructions of palaeodepositional environment in the coal-bearing sequences of Gondwana origin.

The proportion of palynomorphs, phytoclasts, and degraded organic matter allow the determination of the changes in between fluvial channels, floodplains, lacustrine systems and peat-forming swamps. To illustrate, since assemblages that contain structured phytoclasts and terrestrial palynomorphs are usually an indicator of peat deposition in swampy setting, and a larger proportion of degraded organic matter and amorphous organic matter is an indicator of stagnant and low-oxygen water.

Additionally, it can be pointed out that alterations in palynofacies assemblages can be attributed to climate and hydrology changes. Higher inflows of the terrestrial material can indicate humid conditions and increase in vegetation cover and runoff, whereas higher percentages of the oxidized or degraded material can indicate drier conditions or changing water levels. These interpretations help a great deal in the palaeoclimatic evolution in the period of deposition of Gondwana sediments.

A significant quantitative measure in the analysis of palynofacies is the ternary diagram that gives a

graph of the relative abundance of various types of sedimentary organic matter. The diagrams are common to explain depositional setting through plotting of three important components at the corners of a triangle and assessing the relative distribution of these components in samples.

The ternary diagrams usually include the combinations of palynomorphs, phytoclasts, and amorphous organic matter (AOM) in the palynofacies studies. Their relative abundance indicates the differences in the source of organic matter, the processes of its transport, and the conditions of deposition, thus, permitting the separation of the continental and marine environment.

Ternary plots in a continental environment, i.e. fluvial, lacustrine, and swamp habitats, are typically represented by phytoclasts and terrestrial palynomorphs. A high proportion of structured phytoclasts (woody debris, plant tissues) indicates proximity to vegetation sources and limited transport. Similarly, the dominance of spores and pollen grains reflects strong terrestrial input. In such diagrams, data points cluster toward the phytoclast–palynomorph axes, indicating sediment deposition in land-dominated systems with minimal marine influence.

Marine environments, in contrast, are usually defined by a higher proportion of amorphous organic matter (AOM) and marine palynomorphs (e.g. dinoflagellate cysts, prasinophytes, etc.). AOM forms predominantly under low-oxygen conditions in deeper or more distal marine environments, where organic matter is preserved in a structureless form. As a result, samples from marine settings tend to plot toward the AOM apex of the ternary diagram, reflecting reduced terrestrial input and enhanced preservation of the organic matter.

In the ternary diagram intermediate environments are commonly transitional environments with a deltaic or marginal marine environment, where both land and sea influences are present. Mixed phytoclasts, palynomorphs, and AOM in these instances also show varying conditions of deposition including sea level variations, sediment supply, and hydrodynamic energy.

These diagrams are further interpreted with the addition of sedimentological and geochemical data to provide more strength to the interpretation. As an example, variations in data clustering in the diagram can be compared to transgressive-regressive cycles, changes in the oxygen concentration, and variations in depositional energy. In such a way, ternary plots can be considered as a good visual summary of the organic matter composition and as an effective tool to rebuild the palaeoenvironmental gradients.

These diagrams have also been found to be of use in Gondwana coal-bearing sequences, helping to determine the differences between peat-forming swamp environments and either lacustrine or marginal marine environments. The prevalence of phytoclasts and terrestrial palynomorphs favour the in situ vegetation build, but higher AOM is also possible and might represent waterlogged stagnant environments or intermittent marine intrusion.

In general, ternary diagrams provide an easy, but useful, model of transferring complex palynofacies data to useful environmental interpretations between microscopic observations and depositional models.

In addition to palaeoenvironmental reconstruction, palynofacies analysis has significant implications to applied geosciences. It finds broad application in

basin analysis to assess the properties of source rocks (e.g. organic matter type, preservation and potential to generate hydrocarbons). Palynofacies is an important addition to geochemical and sedimentological data when it comes to the evaluation of petroleum systems and enhancing exploration strategies. The fact that Gondwana deposits are found globally in India, Africa, Australia, South America and Antarctica only confirms the increased importance of palynofacies studies. A comparative study of assemblages of organic matter in these basins allows reconstructing the palaeogeographic patterns on a large scale and environmental changes, which provides clues on the evolution of the Gondwana supercontinent.

To sum up, **palynofacies analysis is an effective method of interpreting the past environments on the Earth using the microscopic organic fossils discovered in sediments.** Its use in Gondwana deposits not only increase our knowledge about ancient ecosystems, deposition processes and climatic processes, but also contributes to resource exploration and basin modelling.

Further incorporation with sophisticated analytical methods is likely to enhance the interpretation and increase its contribution in the current geoscientific studies.

About authors



Dr. Neha Aggarwal is Scientist at BSIP, Lucknow. She specializes in Gondwana Palynology and palynofacies. Her study areas are on floristic characteristics, depositional environments, palaeoenvironmental settings palaeowildfires, event stratigraphy, etc. in the Gondwana deposits.



Mr. Roshan Kumar is M.Sc. student of Maharishi University of Information Technology (MUIT) Lucknow. He is perusing his Masters Dissertation program at Birbal Sahni Institute of Palaeosciences, Lucknow.



Dr. Kanchan Awasthi is an accomplished academician currently serving as Associate Professor in the Department of Botany and Deputy Dean of the Maharshi School of Sciences. She has dedicated her academic career to study plant toxicity, particularly the effects of heavy metals on plant systems. Her research interests focus on understanding plant responses to environmental stress and developing sustainable approaches.

Can South Asian Legumes Survive in a Warming World?

Harshita Bhatia and Gaurav Srivastava

LEGUMES, those tiny, humble seeds tucked away in pods, have quietly sustained human civilization for millennia. Think of lentils in your daal, chickpeas in chana masala, or peanuts in your snack bowl. These unassuming powerhouses are packed with protein, fiber, and essential minerals. But, legumes don't just feed people, they also feed the soil, thanks to their extraordinary ability to fix nitrogen, enriching the land they grow on.

India, the world's largest producer and consumer of pulses, is deeply intertwined with these crops, economically, nutritionally, and agriculturally. From ancient farmlands to modern export markets, legumes are everywhere. But, as the Earth warms and climate

patterns grow chaotic, a pressing question emerges: Can legumes, the backbone of Indian cuisine and agriculture, survive in tomorrow's hotter world?

To answer this question, scientists turned to the past—far past. Fossils, the time capsules of ancient ecosystems, hold stories of plant survival across dramatic shifts in Earth's climate. Legumes, it turns out, have a long evolutionary history etched in sediments. The oldest known legume fossil was discovered in Colorado, USA, and dates back over 65 million years. But, could legumes have existed in India back then too? Or did they arrive here from somewhere else?

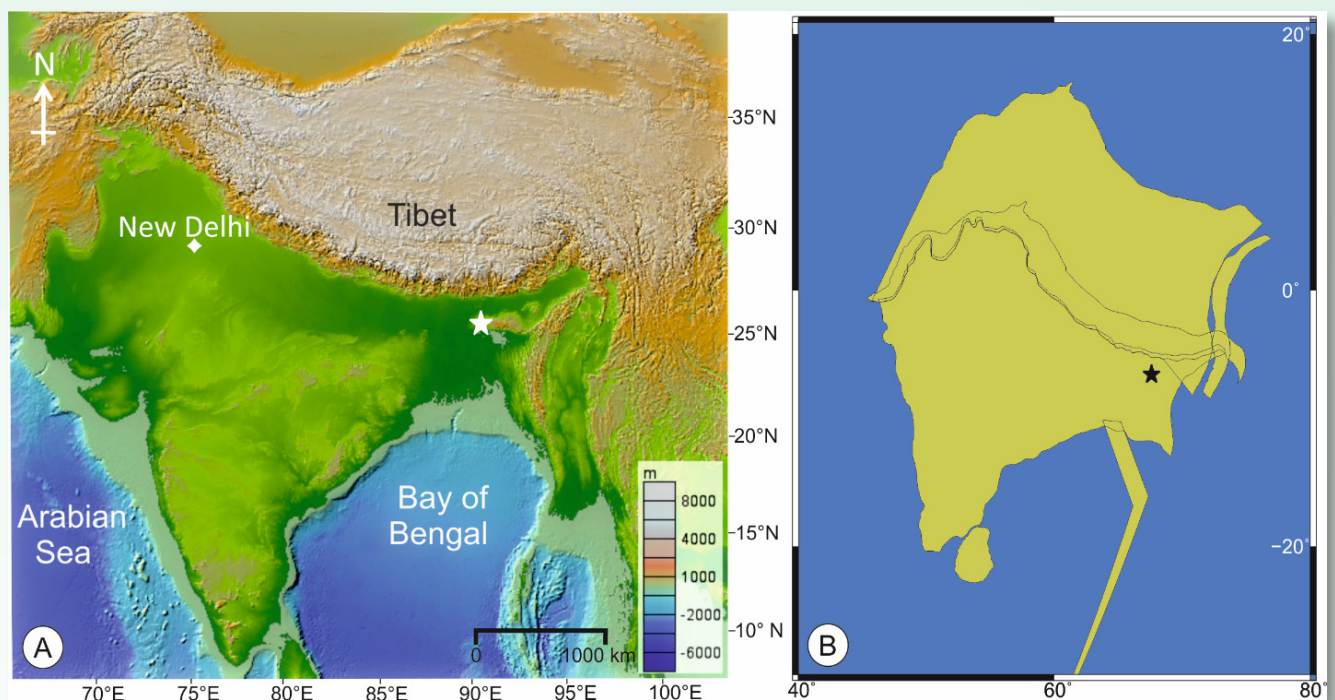


Figure 1: A) Location of the fossil locality in Meghalaya, northeast India (white star). B) Map showing location of the India and the fossil locality at around 56 Ma.

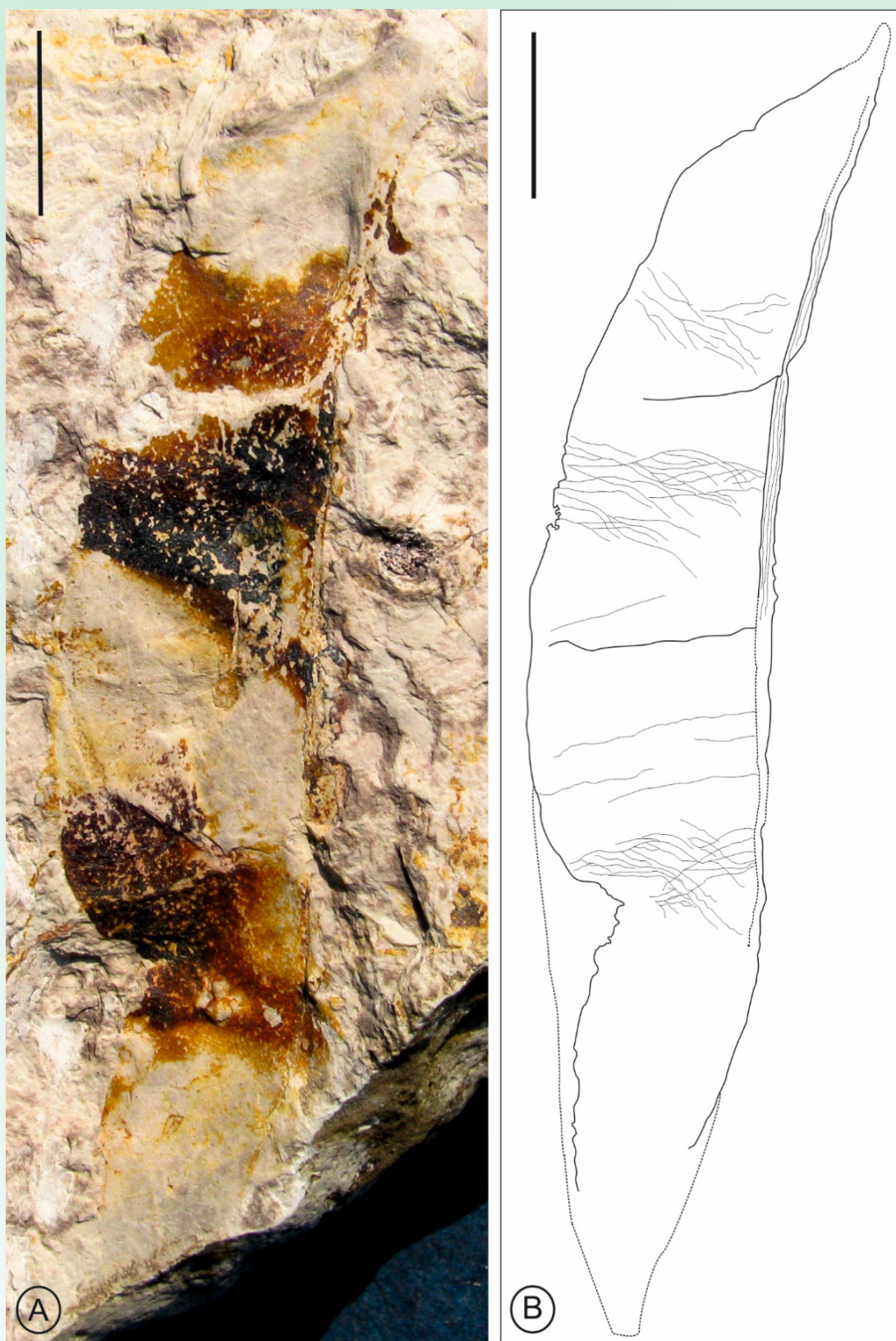


Figure 2: A) A 56 Ma old legume fossil fruit discovered from India and B) Text diagram of the fossil fruit (after Bhatia et al., 2023).

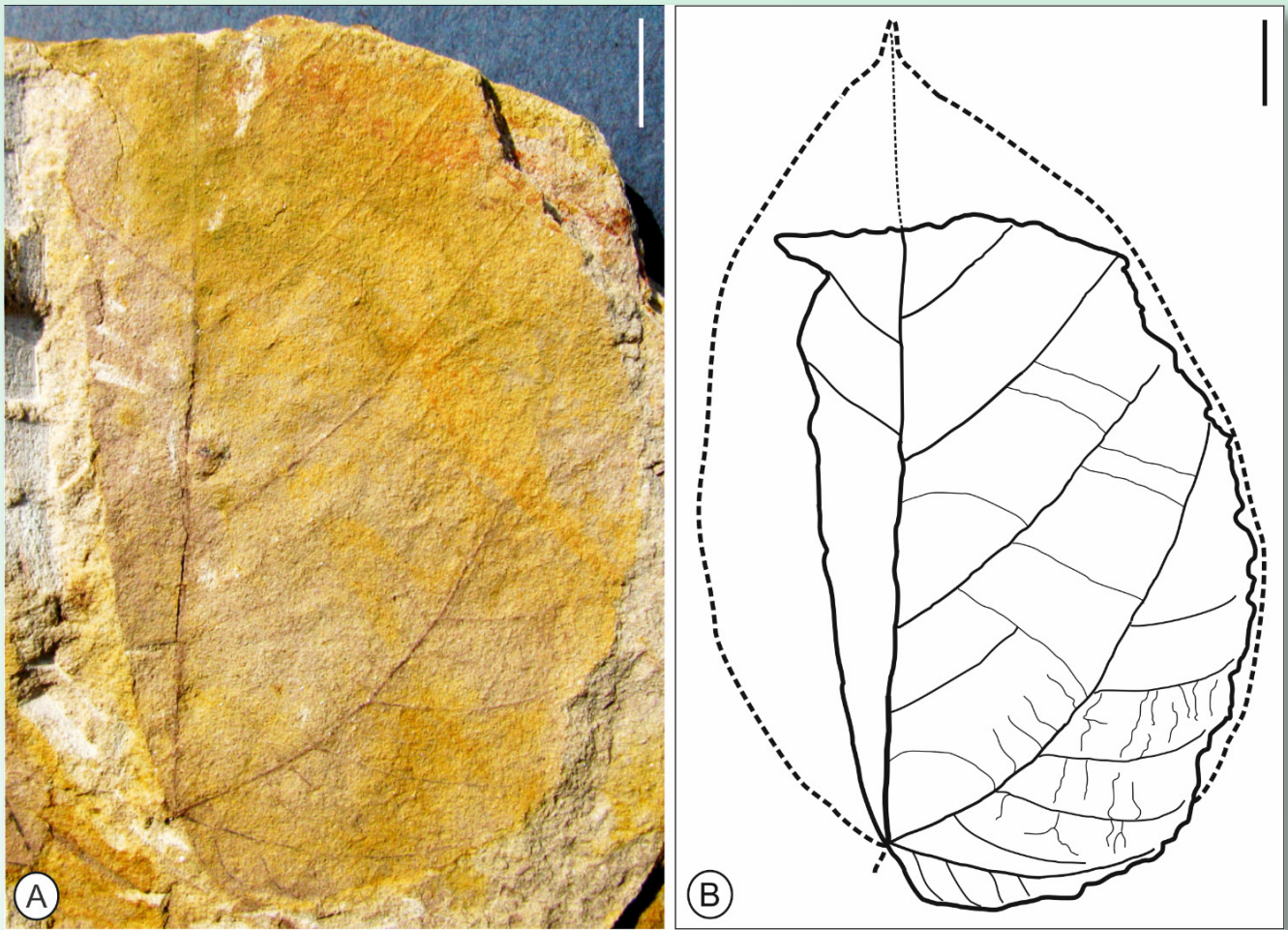


Figure 3: A) A 56 Ma old legume fossil leaf discovered from India and B) Text diagram of the fossil leaf (after Bhatia et al., 2023).

The discovery of fossilized legume fruit and leaf in Meghalaya, northeastern India, may provide the answer. These ancient remains, named *Leguminocarpum meghalayensis* and *Parvileguminophyllum damalgiriensis*, are approximately 56 million years old. They place legumes firmly in Indian territory during the Paleocene epoch (56 million years ago). Here's where it gets fascinating: 56 million years ago, India wasn't where it is today. Back then, the subcontinent sat near the equator in the Southern Hemisphere, slowly drifting northward after breaking away from the ancient supercontinent: Gondwana. Positioned close to Africa and connected by a land bridge, India likely received its early legumes as botanical migrants from African lands.

These ancient legumes flourished in a lush, tropical environment with intense monsoonal rains. The fossil site itself reveals a warm, humid climate, a perfect habitat for many legumes. And what's more compelling? The world back then was far warmer than today, with CO₂ levels soaring above 1000 ppm, conditions that eerily resemble projections for Earth's near future.

So, what do these fossilized fruit and leaf tell us? Simply put: legumes have survived worse. If they could thrive 56 million years ago in a sweltering, carbon-rich world, there's a chance they might endure future climate shifts as well. These ancient plants weren't just surviving, they were thriving, scattered

across continents from India and Argentina to the United States and the UK.

Their story is one of resilience. As global warming threatens crop yields and food security, legumes may offer hope. They are not just climate-smart in terms of nutrition and farming practices, they're also evolutionarily battle-tested.

The fossil record of legumes from northeast India offers more than just historical intrigue, it offers a glimmer of hope. These plants, deeply rooted in India's soil and culture, have endured global upheavals

before. Their legacy tells us that nature has ways of surviving, even thriving, through extreme change. So, next time you savor your lentils, remember: they are more than just a superfood, they are survivors from an ancient, warming world.

Reference:

Bhatia H., Srivastava G., Mehrotra R.C., 2023. Legumes from the Paleocene sediments of India and their ecological significance. *Plant Diversity* 45, 199–210.

About authors



Dr Harshita Bhatia is working as a Birbal Sahni Research Associate (BSRA) at the Cenozoic Palaeofloristics Lab., BSIP, Lucknow. Her research focuses on understanding how Indian vegetation and climate have interacted and evolved throughout the Cenozoic Era.



Dr Gaurav Srivastava is a Senior Scientist at BSIP, with expertise in paleobotany and climate evolution. His current research explores hyperthermal events and hydrological changes in South Asia from the Late Cretaceous through the Cenozoic.

Quaternary Palynology in India: Initiation and Implications

Mohammad Firoze Quamar

THE Quaternary Period, spanning the last 2.6 million years of the Earth's history, has shown dramatic changes in global climate with fluctuations between glacials and interglacials (Cane 1998; Clement et al. 1999). The late Quaternary climate has been suggested variously to be stable (Jouzel et al. 1987; Von Grafenstein et al. 1999), unstable with periodic fluctuations (Dansgaard et al. 1993; O'Brien et al. 1995) or subject to rapid changes (Bond et al. 1997; Stager and Mayewski 1997; Wohlfarth et al. 2004). Within the late Quaternary, the Holocene (11,700 yr to present) climate has been found to be even more variable (Mayewski et al. 2004). Global climate change, considered to be a serious threat to the environment and to humans, has been at the centre of scientific and political debates in recent years. The Earth is currently experiencing an unusual degree of climate warming. Potentially rapid environmental/climate changes could pose major challenges for human habitation. Understanding the causes and patterns of climate change is the major objective and challenge of Quaternary palaeoclimatic studies. Moreover, any pattern of cyclicity in the past may provide insight as to how the climate may behave in the future. In the Indian context, such studies are important for an understanding of the dynamics of Indian Summer Monsoon (ISM) precipitation and the effect of Western Disturbances (winter precipitation), which have a great impact on the agrarian economy.

Various geological, biological, historical and archaeological proxies provide evidence for ways in which the Earth's climate has changed and may do so in the future. Of these, palynology has proved to be one of the most potent biological tools for the reconstruction of vegetation-based past climatic

changes. Palynology is the study of microscopic organic structures (especially the pollen grains and spores), which are resistant to treatments with Hydrofluoric acid (HF). The term 'Palynology' was coined by two Britons, Harold Hyde and David Williams (1944). Carl von Linnaeus (1663) first used the term "Pollen" in 1750 and stated that the male 'seed dust' is necessary for seed development. In other words, Linnaeus (1751) stated that pollen grains are microspores of seed plants (Silvia et al., 2018). Göppert (1837, 1848) and Ehrenberg (1838) first described the fossil pollen grains and spores. Pollen is found from the Late Ordovician (445-458 Ma; millennium years ago) to the Holocene (11.7 ka; thousand years ago).

Three terms are commonly used in palynology, i) *Palynomorphs* (Tschudy, 1961), which include, other than pollen grains and spores, acritarchs, dinoflagellate cysts and scolecodonts, ii) *Palynofacies* (Combaz, 1964), which is the assemblage of phytoclasts (plant-derived, more or less resistant-walled particles occurring in a sediment). e.g. palynomorphs, wood fragments, cuticle and iii) *Palydebris* (Manum, 1976), which is nothing but the palynofacies minus palynomorphs, i.e. all palynomorph-sized particle in a sediment excluding those that actually are palynomorphs, but include wood fragments, cuticle and some animal remains. The advantage of palynomorphs over other fossils is their ubiquitous distribution, i.e. they can be found in terrestrial, freshwater or estuarine sources of sedimentation (Figure 1).

Palynology is broadly categorised as A) *Basic Palynology* or *Actuopalynology*, which deals with the study of pollen grains and spores of extant plants. It

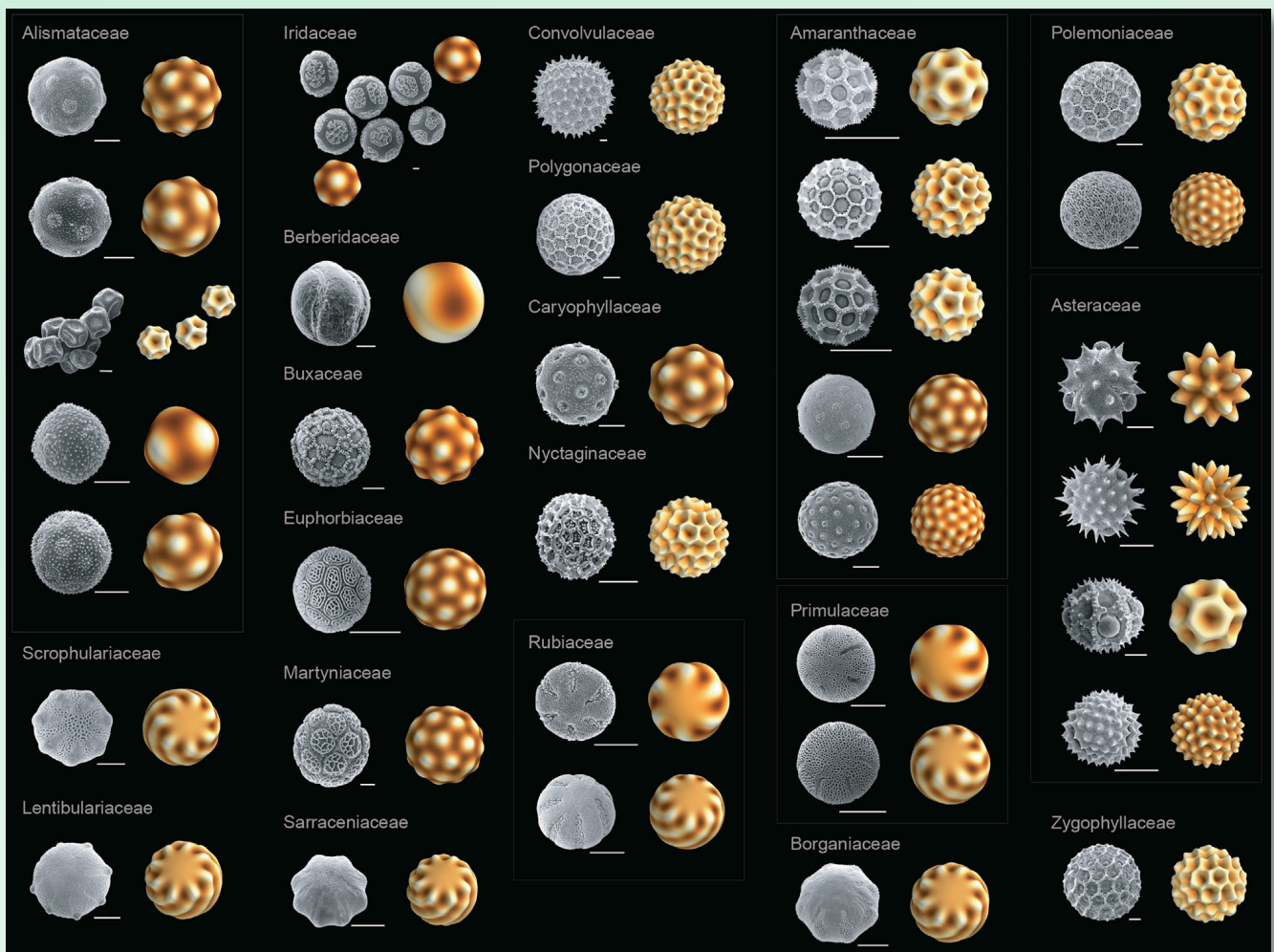


Figure 1. Pollen patterns generated by Theory at Equilibrium (Rajda et al., 2019)

is also known as *Neopalynology*. This study is used in taxonomy to understand the affinities of the modern plant groups/families as well as in ascertaining the precise status of plant species in various taxonomic groups, and B) *Applied Palynology*, which deals with the use of pollen-based information in understanding the other aspects of science, particularly relevant to the human society. It is further divided into i) *Aeropalynology*: Study of pollen/spore content of the air in relation to allergy, ii) *Melissopalynology*: Study of pollen of honey, which provides information regarding the botanical provenance of honey, its purity and seasonality, iii) *Forensic palynology*: Study of pollen in detecting crimes and nabbing criminals, iv) *Archaeopalynology*: Study of pollen of settlement sites, which furnish the data related to inception

of agriculture, anthropogenic impact on natural resources and cultural shifts owing to climate change and v) *Palaeopalynology*: Study of fossil pollen grains and spores, which help in the reconstruction of past vegetation and climate, phylogeny of various plant groups, etc. in terms of geological time scale (Nayer, 1990). However, advances in microscopy have enhanced its application potential to the extent of various botanical and geological sciences as below. 1. *Entomopalynology*- deals with the study of pollen found on the body and/or in the gut of insects, 2. *Pharmacopalynology*- deals with the study of the role of pollen in the production of drugs, 3. *Copropalynology*-deals with the study of pollen and spores in excretory material with the object of understanding the dietary pattern of humans and animals, and 4.



Lennart von Post



Gunnar Erdtman



Prof. Birbal Sahni, FRS

Palynotaxonomy- deals with the study of palynology in relation to taxonomy and systematics, as well as to the evolutionary aspect (Wodehouse, 1935; Agashe, 2009).

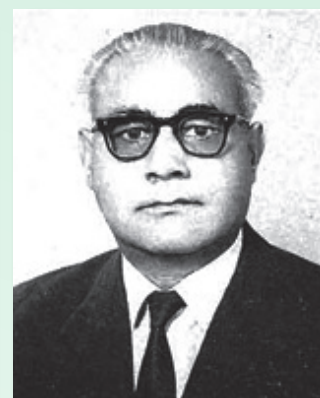
Reinsch (1884) established the palaeopalynology through publishing first photomicrographs of fossil pollen and spores of Russian coals. Moreover, Ernst Jakob Lennart von Post (1916) published the first pollen diagram using exclusively the arboreal pollen from Sweden. Lennart von Post (1916) is regarded as the “father of Quaternary pollen analysis” and Otto Gunnar Elias Erdtman (1952) is known as “father of pollen morphology” (Gaillard et al., 2018; Birks and Berglund, 2018).

Prof. Birbal Sahni, FRS, is known as the “father of Indian palaeobotany”. Dr. P.K.K. Nair had contributed a lot on the Indian palynology and is known as the “father of Indian palynology” (Garg, 2015). However, Dr. Vishnu-Mittre initiated Quaternary Palynological work at the Birbal Sahni Institute of Palaeobotany, Lucknow, and coordinated various research programmes in diverse disciplines, such as Actinopalynology, Quaternary biogeography, Climatology, Forestry, Archaeobiology, Aerobiology, etc. in 1960s (Gupta, 1993).

Palaeoclimate studies not only aim at reconstructing the response of the atmosphere, but also of all different spheres (atmosphere, cryosphere, hydrosphere, lithosphere, biosphere), as well as their interactions and related feedback mechanisms modulating climate change. The concept of climate



Dr. P.K.K. Nair



Dr. Vishnu-Mittre

on the Earth is as a system, in fact, where the different spheres respond to external forcings, such as astronomical and anthropogenic forcings (Ruddiman, 2001).

Quaternary palynological studies in India were initiated in the early part of the twentieth century, when Huntington (1906) undertook pollen analysis of the sediments from the Pangong Lake (Ladakh), situated at an altitude of 4250 m a.m.s.l., in the north-western Himalaya. Based on pollen evidence, it was inferred that the lake sediments were of an interglacial period. Such studies were resumed by studying the Upper and Lower Karewa deposits of Kashmir, which highlighted the depositional environment that was essentially equivalent to what is prevalent Today (Wodehouse and de Terra, 1935). Subsequently, the pollen spectra from the Pangong Lake in Ladakh were described and the climatic conditions were



Figure 2. Birbal Sahni Institute of (Palaeobotany) Palaeosciences (BSIP), Lucknow, India

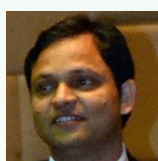
inferred to the second interglacial Period (Deevy, 1937). Quaternary palaeoclimatic studies in India, with reference to palynology, continued until the 1940s. A watershed in palynological research in the country occurred in the late 1940s, primarily with the inception of the Birbal Sahni Institute of Palaeobotany (now Birbal Sahni Institute of Palaeosciences) (Figure 2). Since then, other academic centres and universities have also steadily contributed in augmenting palynological research in India. Preliminary studies, though seemingly rudimentary, nonetheless helped in the expansion of the palynological database for the country. The pioneering workers, in spite of limited resources, did a creditable job in undertaking palynological studies across a vast territory. Dr. Vishnu-Mittre established and organized the Department for Quaternary Palynology at the Birbal Sahni Institute of Palaeobotany, and coordinated various research programmes in diverse disciplines, such as Actinopalynology, Quaternary biogeography, Climatology, Forestry, Archaeobiology, Aerobiology, etc. (Gupta, 1993). Vishnu-Mittre joined the Institute in 1951 and devoted himself to the research in Indian Mesozoic Palaeobotany and also awarded Ph.D. degree by Lucknow University in 1957. His work on the Jurassic Pteridophytes, Conifers, and Pteridophytes has stood the test of time. He was deputed by the Institute for higher studies abroad. He joined the Emmanuel College, Cambridge University, U.K. and obtained Ph.D. degree in 1960. While in Cambridge, he specialized in the field of Quaternary palynology and was ably guided by Sir Harry Godwin. Returning to India in early 1960, then, he, in fact, established the Department of Quaternary Palynology at the BSIP. Earlier studies were limited to local data generation; however, recent research has featured stronger global

contextualization. This includes the Last Glacial Maximum (LGM; ~21,000 calendar years ago), Bølling-Allerød (B/A; ~14,690–12,890 yr BP), Older Dryas (~14,000 to 13,600 years ago), Younger Dryas (YD; ~13,000–11,700 yr BP), Holocene Climatic Optimum (HCO; 7000 to 4000 yr BP), Minnoan Warm Period (MWP; 3400 to 3250 yr BP), Roman Warm Period (RWP; 2500–1450 yr BP), Dark Ages Cold Period (DACP; 1450–1050 yr BP), Medieval Climate Anomaly (MCA; 1050–650 yr BP), Little Ice Age (LIA; 650–100 yr BP) and Current Warm Period (CWP; 100 yr BP–present).

Meher-Homji and Gupta (1999) provided a critical appraisal of vegetation and climatic changes during the Quaternary Period in India. Mehrotra et al. (2014) reviewed the Late Pleistocene–Holocene palaeoclimate records from northeast India, based on pollen proxy data. Kar and Quamar (2019) provided an overview of recent advances in pollen-based Quaternary palaeoclimatic studies in India. Kar and Quamar (2020) also provided a palynological perspective of the Late Pleistocene–Holocene vegetation and climate change from the Western and Eastern Himalaya, India. Quamar et al. (2024) provided an overview of the pollen-based hydroclimatic changes in the Core Monsoon Zone of India since the LGM, and correlation with the marine and continental records.

Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow; Department of Botany, University of Kolkata, Kolkata; and French Institute of Pondicherry (FPI), Puducherry, are the major centers of Quaternary palynological studies in India. However, Vallabhbhai Patel (VP) Chest Institute (Delhi) serves as a nucleus for research on aerobiology and allergy in India.

About author



Dr Mohammad Firoze Quamar is Senior Scientist at 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.

Unravelling India's Weather Engine

Sadanand

INDIA'S climate system is considered one of the most complex and dynamic weather systems in the world. The country's agriculture, water resources, food security, energy production, biodiversity, and the daily lives of millions of people are directly or indirectly linked to weather and monsoon rainfall. This is why weather in India is more than a natural phenomenon; it underpins the country's agriculture, economy, water resources, and cultural traditions.

As summer begins, several scientific terms frequently appear in news reports, weather bulletins, and social media discussions — *Monsoon, Western Disturbance, El Niño, La Niña, Heatwave* and *Jet stream*. To many people these terms may sound highly technical, yet they represent natural climatic processes that directly influence our everyday lives. Sudden heavy rainfall, prolonged heat, weak monsoon seasons, severe droughts, or unusual cold spells are all connected to the Earth's intricate climate system.

Weather is not determined solely by local temperature or cloud cover. Rather, it emerges from complex interactions among the atmosphere, oceans, mountains, ocean currents, and wind systems. Consequently, changes occurring thousands of kilometres away in the Pacific Ocean can exert a profound influence on the Indian monsoon.

MONSOON: THE LIFELINE OF INDIA

According to the India Meteorological Department (IMD), nearly 70 percent of India's annual rainfall is received from the Southwest Monsoon. Since almost half of India's agricultural land is still rain-fed, the monsoon is often called the "lifeline" of the Indian economy. The term "monsoon" is derived from the Arabic word *mausim* (موسم),

meaning "season". It refers to a seasonal reversal of winds associated with marked changes in rainfall.

The Indian monsoon is influenced by several factors, including – Temperature contrast between land and sea, Moisture from the Indian Ocean, Equatorial low-pressure systems, The geographical position of the Himalaya, Ocean-atmosphere interactions such as El Niño and La Niña, Indian Ocean Dipole, Jet streams and global atmospheric circulation

SOUTHWEST MONSOON

The Southwest Monsoon, active from June to September, is India's most important rainfall system. During summer, the Indian landmass heats up rapidly and develops a low-pressure zone, while the Indian Ocean remains relatively cooler. As a result, moisture-laden winds move from the ocean toward the land, bringing widespread rainfall. The Southwest Monsoon has two major branches. The Arabian Sea branch brings rainfall to the Western Ghats, Konkan coast, Gujarat, and northern India, while the Bay of Bengal branch influences northeastern India, the Gangetic Plains, and the Himalayan foothills. Regions such as Mawsynram and Cherrapunji in Meghalaya receive some of the highest rainfall in the world mainly due to this branch.

NORTHEAST MONSOON: THE RAINFALL SYSTEM OF SOUTH INDIA

The Northeast Monsoon, often called the "retreating monsoon," is another important rainfall system for southern India. It remains active mainly from October to December. During this period,

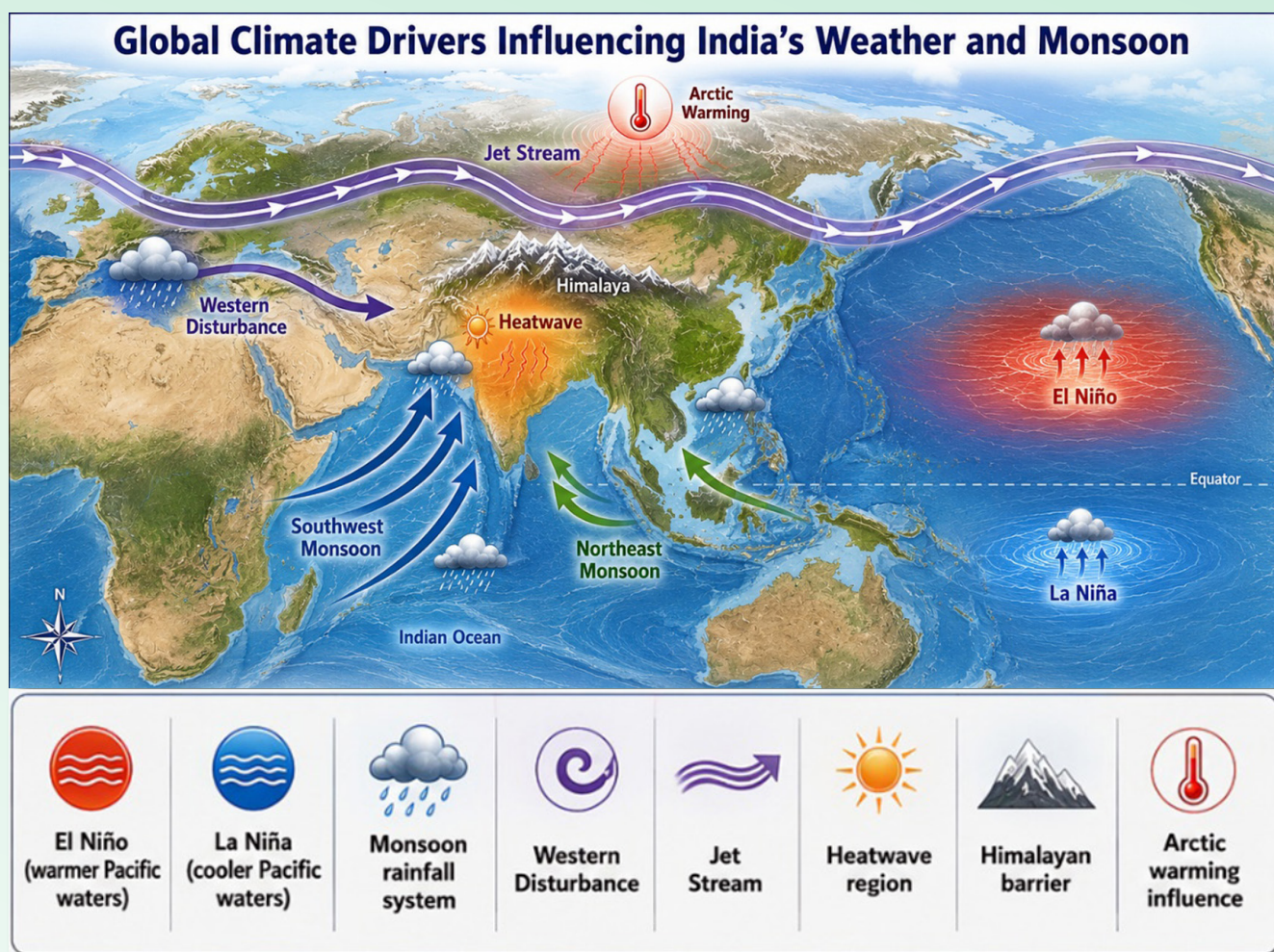


Figure: The schematic illustration shows the principal climate drivers that regulate seasonal weather pattern across the Indian subcontinent.

winds blow from the land toward the Bay of Bengal, absorb moisture, and return to the southeastern coast of India, producing rainfall. Tamil Nadu and Puducherry depend heavily on this monsoon, receiving nearly half or more of their annual rainfall from it. Coastal Andhra Pradesh, Rayalaseema, southern interior Karnataka, and parts of Kerala are also influenced by this system. From an agricultural perspective, the Northeast Monsoon is crucial for crops cultivation in southern India. It also plays a major role in replenishing reservoirs and groundwater levels. This season is frequently associated with low-pressure systems and tropical cyclones developing over the Bay of Bengal. These cyclones often bring strong winds and intense rainfall to coastal regions.

WESTERN DISTURBANCES: THE WINTER RAINFALL SYSTEM

India's weather is not controlled by the monsoon alone. During winter, rainfall and snowfall in northern India are strongly influenced by Western Disturbances. These are temperate low-pressure systems that generally originate over the Mediterranean region and West Asia. Moving from west to east, they reach the Himalayan region and bring rainfall and snowfall. Agriculture in Punjab, Haryana, Himachal Pradesh, Jammu & Kashmir, and Uttarakhand depends significantly on these winter rains. Rabi crops such as wheat receive much of their required



moisture from Western Disturbances. Recent studies suggest that climate change may be influencing the frequency, intensity, and spatial distribution of Western Disturbances. Sometimes they produce excessive rainfall, cloudbursts, and flash floods, while in other situations prolonged dry conditions may occur.

EL NIÑO AND LA NIÑA: GLOBAL OCEANIC PHENOMENA

The Indian monsoon is strongly affected by climatic events occurring in the Pacific Ocean. **El Niño** refers to the abnormal warming of sea surface temperatures in the central and eastern Pacific Ocean. Under normal conditions, trade winds push warm water westward, but during El Niño these winds weaken and ocean temperatures rise. For India, El Niño is often associated with weak monsoon conditions and drought-like situations. Reduced rainfall can affect agriculture, water availability, and food production. In severe years, it may also contribute to rising food prices and water scarcity. However, not every El Niño event produces the same impact. Some remain moderate, while others can intensify global warming trends, droughts, and extreme weather events worldwide. Although El Niño events are generally associated with weaker monsoons, their impacts vary and may be modulated by factors such as the Indian Ocean Dipole and intra-seasonal variability.

La Niña represents the opposite phase of El Niño. In this condition, sea surface temperatures in the Pacific Ocean become cooler than normal. Trade winds strengthen, often enhancing monsoon rainfall over India. Many La Niña years are associated with stronger monsoons, but excessive rainfall can also create serious problems such as floods, landslides, urban waterlogging, and crop damage. Scientists emphasize that the Indian monsoon is not controlled solely by El Niño or La Niña. Other factors such as the Indian Ocean Dipole, Madden-Julian Oscillation, Himalayan snow cover, and regional oceanic conditions also play important roles.

JET STREAM: FAST WINDS IN THE UPPER ATMOSPHERE

Jet streams are narrow bands of extremely fast-moving winds flowing in the upper layers of the atmosphere. These winds strongly influence the movement and direction of weather systems. The Subtropical Westerly Jet and Tropical Easterly Jet play important roles in controlling the movement and intensity of weather systems affecting India.. Scientists believe that rapid warming in the Arctic region is affecting jet stream behaviour, making weather patterns more unstable and extreme.

HEATWAVES: A GROWING CLIMATE THREAT

In recent years, heatwaves have become increasingly common across India. A heatwave occurs when temperatures remain significantly above normal for several consecutive days. According to climate scientists, global warming is increasing both the frequency and intensity of heatwaves. Their impact extends beyond human health and affects water availability, agriculture, energy demand, and labour productivity. Urban areas often experience the “Urban Heat Island” effect, where concrete structures and limited green spaces trap heat, making cities considerably warmer than surrounding rural regions. Recent decades have witnessed an increase in the frequency, duration, and intensity of heatwaves across India, consistent with global warming trends.

WEATHER FORECASTING AND THE ROLE OF IMD

The India Meteorological Department uses satellites, radars, oceanic observations, numerical models, and artificial intelligence-based systems for weather forecasting. Rainfall is classified into categories such as: Large Deficient, Deficient, Below Normal, Normal, Above Normal, Excess. Similarly, daily rainfall is categorized as light, moderate, heavy, very heavy, and extremely heavy rainfall. These

INDIA METEOROLOGICAL DEPARTMENT

India Meteorological Department was established in 1875. It is the National Meteorological Service of the country and the principal government agency in all matters relating to meteorology and allied subjects.

- To take meteorological observations and to provide current and forecast meteorological information for optimum operation of weather-sensitive activities like agriculture, irrigation, shipping, aviation, offshore oil explorations, etc.
- To warn against severe weather phenomena like tropical cyclones, norwesters, duststorms, heavy rains and snow, cold and heat waves, etc., which cause destruction of life and property.
- To provide meteorological statistics required for agriculture, water resource management, industries, oil exploration and other nation-building activities.
- To conduct and promote research in meteorology and allied disciplines.



classifications are extremely important for agriculture advisories, disaster management, and public warning systems.

CLIMATE CHANGE AND FUTURE CHALLENGES

Climate change is making weather systems and monsoon patterns increasingly unpredictable and extreme. Intense rainfall over short periods and prolonged dry spells are becoming more common. As a result, understanding Western Disturbances, El Niño, ocean temperatures, jet streams, and monsoon circulation through an integrated scientific approach has become more important than ever. These climatic processes are not merely scientific concepts; they are deeply connected to food security, water resources,

public health, agriculture, energy production, and economic stability. Farmers depend on the monsoon, cities rely on water availability, and mountainous regions depend on snowfall and seasonal rainfall. For this reason, scientists continuously study these climate systems to improve weather forecasts and reduce losses caused by natural disasters. In an era of rapid climate change, understanding these interconnected climate phenomena has become essential not only for scientists, but for society as a whole. From Western Disturbances and jet streams to El Niño and ocean-atmosphere interactions, India's weather is governed by a complex and interconnected climate system. Understanding these processes is essential for improving forecasts, ensuring food and water security, and building resilience against climate-related hazards in a warming world.

About author



Mr Sadanand is pursuing his PhD at BSIP, Lucknow. Working within the Cenozoic Palaeofloristics Lab, his research centres on uncovering the long-term relationship between Indian vegetation and climate during the Cenozoic Era.

Tracing Climate and Monsoon Variability on the World's Largest River Island

Arya Pandey and Swati Tripathi

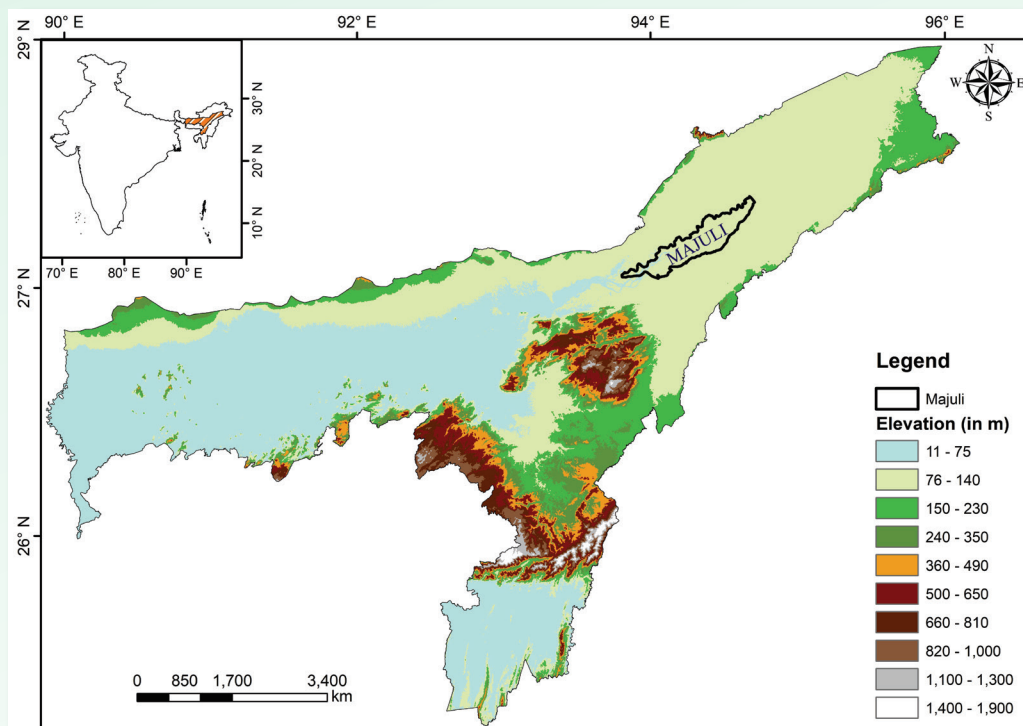
MAJULI Island in **Assam**, recognized as the world's largest inhabited river island, lies within the dynamic floodplains of the **Brahmaputra River** and forms part of the Indo-Burma biodiversity hotspot. Despite its ecological importance, the island is also one of the most erosion-prone landscapes in Northeast India. Continuous flooding and riverbank erosion have dramatically reduced Majuli's landmass, with more than half of its original area lost over the past decades.

A recent study presents the first detailed palaeoecological reconstruction of Majuli Island, revealing how climate, vegetation, and river dynamics have interacted over the last ~4000 years (Pandey et al., 2026). By analyzing fossil pollen and sediment characteristics from a wetland sequence, the study

provides a rare long-term perspective on the ecological evolution of this fragile river island. These palaeoenvironmental insights not only help scientists understand past monsoon variability and landscape transformation, but also offer valuable context for interpreting the island's present-day environmental challenges.

EMBRACING THE FLOODS: INDIGENOUS WISDOM FROM MAJULI ISLAND

While scientific records trace Majuli's environmental history across millennia, the island's inhabitants have long developed their own ways of understanding and adapting to the rhythms of



the Brahmaputra. For generations, the people of Majuli have lived with floods, not as an enemy to be defeated, but as a natural rhythm to be understood and embraced.

This deep relationship with the river is reflected in their architecture and lifestyle. Traditional homes, known as *chang ghars*, are built on bamboo stilts, raised high above the ground to withstand the seasonal swelling of the Brahmaputra's waters. These structures are more than simple dwellings; they represent a remarkable cultural adaptation, embodying a worldview in which nature is accommodated rather than resisted.

Even livestock are sheltered in elevated sheds, illustrating a holistic approach to living with floods that protects every member of the household, human and animal alike, within this dynamic riverine landscape. Together, these practices demonstrate how traditional knowledge and environmental adaptation

have enabled communities in Majuli to coexist with one of the most powerful river systems in the world.

FILLING A CRITICAL KNOWLEDGE GAP IN RIVER ISLAND ECOLOGY

Although Majuli has been studied extensively from geomorphological and geochemical perspectives, long-term palaeoclimatic and vegetation reconstructions were previously lacking. Understanding how ecosystems responded to past climatic shifts is essential for predicting future environmental change, particularly in regions influenced by strong monsoonal systems. To address this gap, the researchers analyzed biotic and abiotic proxies preserved within a 150 cm sediment profile retrieved from a wetland on Majuli Island. The region experiences strong influence from the Indian Summer Monsoon (ISM), which plays a critical role in shaping vegetation patterns,



Homes above the Water: Traditional Flood Adaptation in Majuli



river dynamics, and sediment deposition across the Brahmaputra floodplain. Using an integrated multiproxy approach combining pollen analysis and grain-size studies, we reconstructed approximately four millennia of hydroclimatic variability and vegetation dynamics.

FOSSIL POLLEN: TINY ARCHIVES OF ANCIENT ECOSYSTEMS

The backbone of the research lies in palynology, the study of pollen and spores preserved in sediments. Pollen grains are exceptionally durable because their outer walls are composed of sporopollenin, a highly resistant biopolymer that can survive for thousands or even millions of years. When plants release pollen, some grains settle into nearby lakes, wetlands, and soils, where they become incorporated into sediment layers. Over time, these layers accumulate, preserving a chronological archive of vegetation and climate history. By analysing pollen assemblages from different sediment depths and comparing them with 25 modern surface pollen samples, the researchers reconstructed changes in plant communities and climate conditions across time. Statistical approaches, such as the Coexistence Approach (CA) enabled estimation of Mean Annual Temperature (MAT) and Mean Annual Precipitation (MAP) from the fossil pollen assemblages. This method allowed us to divide the sediment sequence into five pollen zones, each representing a distinct ecological phase.

CLIMATE AND VEGETATION DURING THE LAST 4000 YEARS

The earliest phase of the record, dating from ~4040 to 2260 cal. years before present, reveals a warm and humid climate, with estimated mean annual temperatures around 30 °C and annual precipitation close to 3000 mm. Dense forest vegetation dominated the landscape during this time, indicating stable and favourable environmental conditions. Interestingly, this phase corresponds to the globally recognized 4.2 ka climatic event, which is generally associated with aridity in many parts of the world. However, the Majuli record suggests that the river island orography remained relatively resilient, maintaining humid conditions and forest cover during this period. Subsequent phases show fluctuations in

monsoon intensity and flood regimes. Around 1100-500 years before present, the island experienced relatively moist conditions that coincide with the Medieval Climatic Anomaly (MCA), a period of regional climatic variability documented across many parts of the world. The last ~500 years, however, reveal a noticeable shift. Pollen data indicate decreasing

temperature and precipitation, corresponding with the global Little Ice Age (LIA) cooling phase. During this period, vegetation gradually transitioned towards savanna-like landscapes, and signs of human influence began to accelerate in the pollen record.

MAJULI ISLAND IS A RIVER ISLAND IN THE BRAHMAPUTRA RIVER, ASSAM

IN 2016, MAJULI ISLAND BECAME THE FIRST ISLAND TO BE MADE A DISTRICT IN INDIA

MAJULI IS THE WORLD'S LARGEST RIVER ISLAND ACCORDING TO GUINNESS WORLD RECORD



Wetland and Riverine Environment with Surface Sampling Points in Majuli Island

TRACKING FLOOD DYNAMICS THROUGH SEDIMENT GRAIN SIZE

Because Majuli lies adjacent to the highly dynamic Brahmaputra River, pollen records alone cannot fully capture environmental changes. Flooding and strong river currents can transport, redeposit, or remove pollen grains, potentially complicating interpretations. To overcome this challenge, researchers incorporated

granulometric (grain-size) analysis, which examines the texture and size distribution of sediment particles. Grain size reflects the energy conditions of sediment transport: fine sediments typically accumulate under low-energy conditions, while coarser particles indicate stronger hydrodynamic activity. The sediment data reveal transitions between low-energy and high-energy depositional regimes, suggesting increasing hydrodynamic instability through time. These shifts highlight the role of flooding, sediment transport, and river dynamics in shaping Majuli's landscape over millennia.

SCIENTIFIC METHODS BEHIND THE RECONSTRUCTION

The study involved extensive field and laboratory work. Researchers extracted the sediment profile from the wetland and processed samples using the standard acetolysis method to isolate pollen grains. Radiocarbon dating of selected sediment layers established a reliable chronological framework for the sequence. Modern pollen samples from surrounding environments were also analysed to create a modern analogue dataset, enabling more accurate interpretation of fossil pollen assemblages. Statistical techniques such as **Principal Component Analysis (PCA)** and **Canonical Correspondence Analysis (CCA)** were used to examine relationships between pollen taxa and environmental variables, while CONISS cluster analysis helped identify major ecological phases within the sediment record. Together, these methods produced a robust multiproxy reconstruction of Majuli's environmental history.

LESSONS FOR CLIMATE ADAPTATION AND RIVER MANAGEMENT

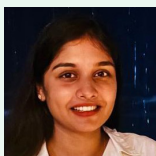
Beyond its scientific significance, the study has important implications for environmental management and climate resilience in the Brahmaputra basin. By reconstructing long-term patterns of vegetation change, monsoon variability,

and flood dynamics, the research helps distinguish natural climatic variability from recent human-driven environmental changes. Understanding these patterns is essential for designing effective strategies to mitigate erosion, flooding, and habitat loss on Majuli Island. The findings also provide valuable baseline data for biodiversity conservation, wetland restoration, and sustainable land-use planning in this fragile ecosystem. For communities living on Majuli, who face increasing threats from land loss and extreme flooding, the research offers critical insights into the environmental processes shaping their landscape.

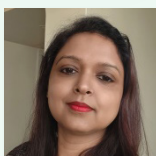
Reference

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- Assam: 4,000 years of monsoon history locked inside Majuli's wetlands, study finds: From ancient forests to modern erosion, sediment study maps the island's long climate and flood history. <https://nenow.in/north-east-news/assam/assam-4000-years-of-monsoon-history-locked-inside-majulis-wetlands-study-finds.html>

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Ms Arya Pandey is Senior Research Fellow (SRF), Quaternary Palaeoclimate Laboratory, BSIP, Lucknow. Her research focuses on Holocene climate variability, vegetation dynamics, and anthropogenic influences in the Upper Brahmaputra Valley of Assam, Northeast India, using a multi-proxy approach to reconstruct past environmental changes and human-environment interactions.



Dr Swati Tripathi is Senior Scientist in the Quaternary Palaeoclimate Laboratory, BSIP, Lucknow. Her work focuses on reconstructing Quaternary vegetation, climate, and depositional environments through a range of biotic and abiotic proxy analyses.

***Sporormiella*—a palynological proxy for detecting the presence and abundance of megaherbivores: Indian context**

Mohammad Firoze Quamar and Jyotsna Dubey

SPORORMIELLA is an obligate coprophilous Ascomycetes fungus, which is found exclusively on the dung of herbivores (Ahmed and Cane, 1972; Davis, 1987). It is common on the dung of both domestic herbivores and extant megaherbivores (e.g. elephants) (Ebersohn and Eicker, 1997), and is widespread across sub-boreal and temperate regions of the world (Davis and Shafer, 2006).

The spores of *Sporormiella* develop in sclerotia on the surface of dung and are passively dispersed onto nearby vegetation. These spores are then ingested by herbivores and later excreted, completing the fungal life cycle. Due to the low height of spore release, long-distance dispersal is inefficient, resulting in *Sporormiella* spores being present (and/or abundant) primarily in close proximity to herbivore dung accumulations. Additionally, the spore size of *Sporormiella* and other coprophilous fungi falls within the typical pollen grain size range [ca. (5)10–250 µm], which further limits their ability to disperse over long distances (Davies, 2019; Lee et al., 2022). The dispersal of coprophilous fungal spores is largely localized, typically occurring within tens of meters, though some studies have documented dispersal distances of up to 100 meters from the source (Davies, 2019). However, Baker et al. (2013) suggested that these spores are initially ejected over very short distances, generally no more than two meters.

Sporormiella spores are four-celled, measuring approximately 11–17 µm (size), and are characterized by a distinct S-shaped (sigmoid) germinal aperture, which facilitates their identification during palynological analysis (Figure 1) (Davis, 1977; Davis

and Shafer, 2006; Raper and Bush, 2009; van Geel et al., 2007). These spores are widely used as indicators of herbivore population densities across different regions and time periods (Davis, 1987; Davis et al., 1977; Davis and Turner, 1986). Other coprophilous fungal spores (CFS), also referred to spores of coprophilous fungi (SCF) or spores of dung fungi (SDF) (hereafter SCF), besides *Sporormiella* spp., were recorded as well (Figure 1). Some of the recorded SCF were also used to indicate the presence and/or abundance of large herbivores (megaherbivores) and grazing pressure in an area in a definite time frame (Figure 1).

Though pioneered in the Great Plains of the USA (Wildcat Lake, USA; Davis, 1987; Davis et al., 1977; Davis and Shafer, 2006), *Sporormiella* spores have been widely used as a palynological means to reconstruct the presence of extinct megafauna, including Moas in New Zealand (Wood et al., 2011), Giant tortoises in the Galápagos (Froyd et al., 2013), and Giant lemurs, elephants, birds, and the Pygmy Hippopotamus in Madagascar (Burney et al., 2003). Over the past two decades, a growing body of research has explored the role of *Sporormiella* spores in Quaternary sediments for detecting the presence, abundance, and extinction of megaherbivores (Burney et al., 2003; Robinson et al., 2005; Davis and Shafer, 2006; van Geel and Aptroot, 2006; Carrión, 2002a, 2002b; Carrión et al., 2001, 2005, 2006, 2007; Raper and Bush, 2009; Wood et al., 2011; Etienne et al., 2013; Gill et al., 2009, 2012, 2013; Froyd et al., 2013; Pokharia et al., 2022; Britzius and Sirocko, 2023; Quamar et al., 2021, 2024, 2025, and references cited therein). However, in India,

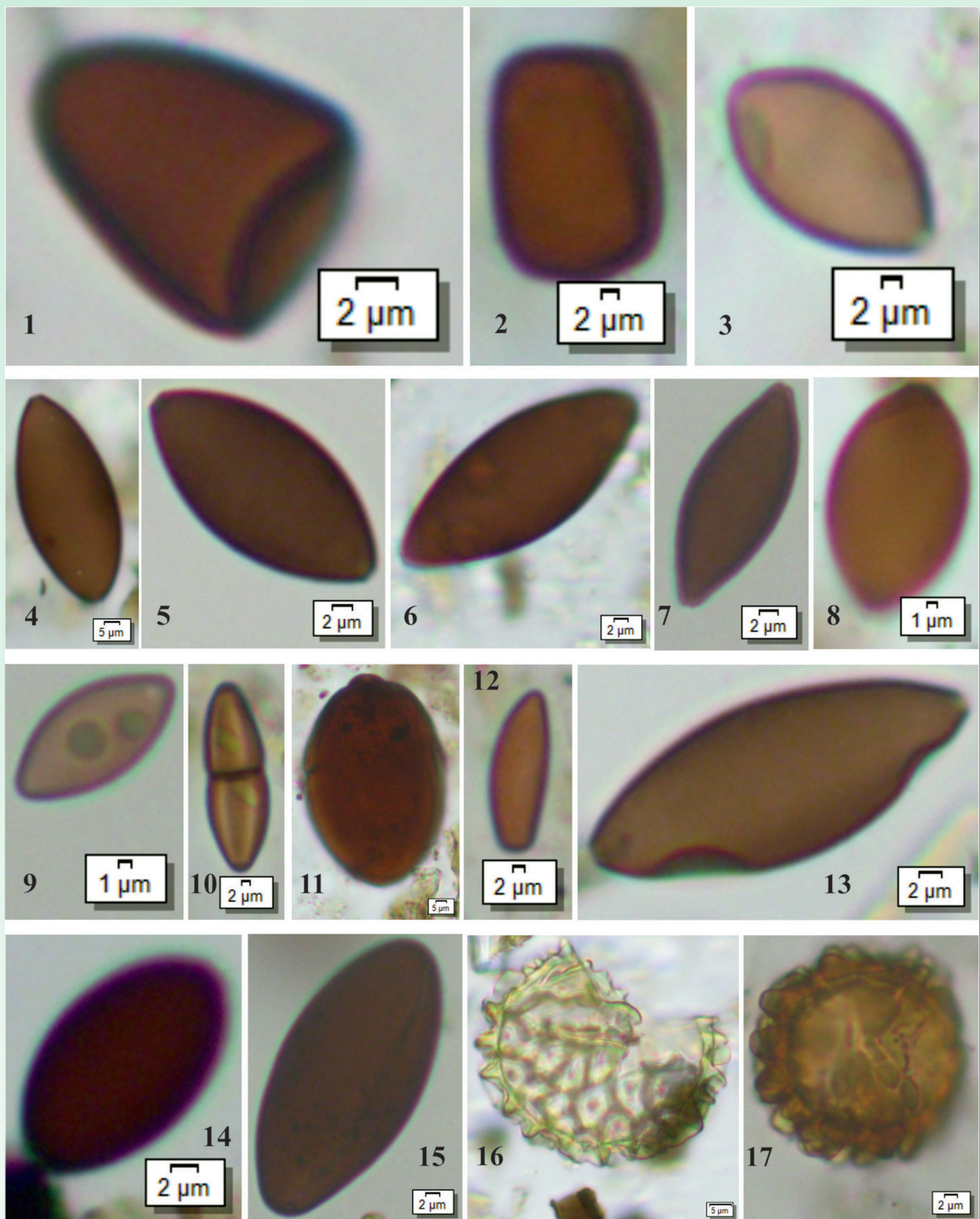


Figure 1. Photomicrographs of the most common coprophilous fungal spores (SCF). 1. Terminal segment of *Sporormiella*, 2. Medial segment of *Sporormiella*, 3-6. *Sordaria* and *Sordaria* spp. 7. Sordariaceous ascospore (HdV-55), 8. *Podospora* spp., 9. *Coniochaeta* spp., 10. *Delitschia* spp., 11. *Schizothecium conicum*, 12. *Cercophora* spp. (ascospore), 13. *Arnium*, 14 & 15. *Saccobolus* spp., 16 & 17. *Ascodesmis* spp.



research on the reliability of *Sporormiella* spores as a palynological proxy for detecting megaherbivore presence, estimating their abundance, and assessing their extinction in palaeoecological reconstructions remains in its early stages (Quamar et al., 2021, 2025, and references cited therein). Addressing this research gap requires further studies at spatio-temporal scales within the Indian context. The primary objective was to assess the potential of *Sporormiella* spores in reconstructing herbivore densities over time across different regions (Figure 2). The studies were primarily conducted to understand pollen deposition patterns and contribute to palaeoecological and palaeoclimatic reconstructions in India (Figure 2). The presence and distribution of *Sporormiella* spores (along with other key SCF) in both modern samples (surface soil, moss cushions, etc.) and Holocene lake sediment samples have been analyzed to explore their relationship with megaherbivore presence, potential abundance, and possible extinction. The study aims to enhance our understanding of past and present megaherbivore populations in modern landscapes and also during the late Pleistocene and Holocene in India. Furthermore, we aimed to address the following key scientific questions:

1. How reliable is *Sporormiella* as a proxy for detecting megaherbivore presence and/or abundance in different Indian ecosystems?
2. What are the taphonomic or preservation biases affecting *Sporormiella* in Indian sediments?
3. Can we differentiate between local vs. regional megaherbivore populations, based on spore concentration and distribution?
4. How do megaherbivore populations respond to Holocene climate variability in India?

In this context, International research has made significant strides in utilizing *Sporormiella* as a reliable proxy to reconstruct the presence and abundance of megaherbivores in past ecosystems. These studies were primarily focussed on the late Pleistocene and Holocene epochs of the Quaternary Period, offering insights into megafaunal dynamics and extinction events (Carrión, 2002a, 2002b; Carrión et al., 2001, 2005, 2006, 2007; Burney et al., 2003; Robinson et al., 2005; Davis and Shafer, 2006; van Geel and

Aptroot, 2006; Raper and Bush, 2009; Wood et al., 2011; Etienne et al., 2013; Gill et al., 2009, 2012, 2013; Froyd et al., 2013; Johnson et al., 2015; Britzius and Sirocko, 2023, and references cited therein). In the Qinghai-Tibetan Plateau also, near the Himalayas (India), some research has been done on the reliability of *Sporormiella* spores as a palynological proxy for detecting megaherbivore presence, pastoralism, and grazing intensity change in palaeoecological reconstructions (Wei et al., 2020; Huang et al., 2020; Li et al., 2024; Zhang et al., 2021, 2022, 2025a, and references cited therein). Additionally, research work on ecology, diversity, niche partitioning, and changes in the relative abundance of the past herbaceous species in a region, as well as pastoral and other human activities have also been completed (Davis, 1987; Van Geel et al., 2003; Velázquez and Burry, 2012; Kamberling et al., 2017).

PRINCIPLE, BACKGROUND AND METHODOLOGICAL APPROACH

The principle underpinning the use of *Sporormiella* (and other SCF) in past ecosystem reconstructions is that these fungi predominantly grow on herbivore feces (Ahmed and Cane, 1972; Bell, 1983; Davis, 1987; Ebersohn and Eicker, 1992; Richardson, 2001; Burney et al., 2003; Robinson et al., 2005; Davis and Shafer, 2006; Gauthier et al., 2010; van Asperen et al., 2021). As a result, when herbivores are removed from an ecosystem, the number of SCF declines significantly (Davis and Shafer, 2006; Wood and Wilmhurst, 2013). Following this principle, SCF preserved in sedimentary records have been widely used as indicators of past herbivore presence, absence, and shifts in their population dynamics over time (van Asperen et al., 2021; Richardson, 2001; Johnson et al., 2015; Pino et al., 2020).

The efficacy of the spores of coprophilous fungus *Sporormiella* spp. (and/or other SCF together) in understanding modern herbivory and reconstructing past herbivore populations across regions has been tested over the past two decades (Davis and Shafer, 2006; Van Geel and Aptroot, 2006; Raper and Bush, 2009; Van Asperen et al., 2016; Baker et al., 2013,

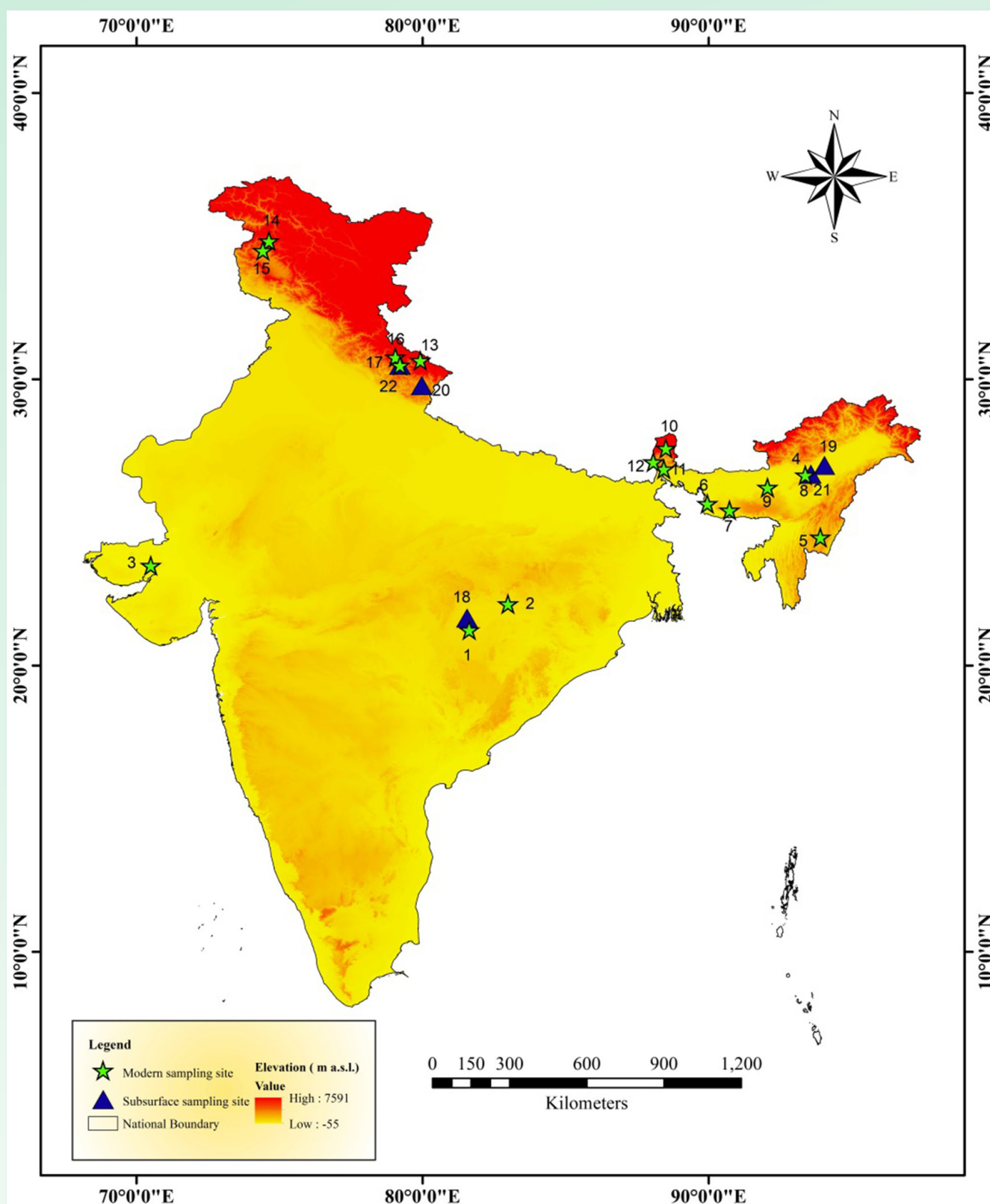


Figure 2. Shuttle Radar Topographic Mission (SRTM) and Digital Elevation Model (DEM) of India showing the site of investigation for surface samples (★), as well as lake/swamp/wetland profile sediment samples (▲) in India. (Quamar et al., 2026).

2016; Davies et al., 2022; Quamar et al., 2025, and references cited therein). Since Davis (1987) first utilized *Sporormiella* frequencies in sedimentary sequences to infer herbivore densities and extinctions in North America, numerous researchers have expanded upon this work (Wood et al., 2011; Froyd et al., 2011; Burney et al., 2003; Robinson et al., 2005; Davis and Shafer, 2006; Van Geel and Aptroot, 2006; Carrión, 2002a, 2002b, Carrión et al., 2001, 2005, 2006, 2007; Raper and Bush, 2009; Wood et al., 2011; Etienne et al., 2013; Gill et al., 2009, 2012, 2013; Froyd et al., 2013; Pokharia et al., 2022; Britzius and Sirocko, 2023; Quamar et al., 2025, and references cited therein). However, the very research in India has not been given due attention primarily due to the lack of taxonomic expertise, reference collections to name, but a few for examining “extra” microfossils on palynological slides. Until around 2000, the absence of internet facilities in many research institutes and universities further hindered access to necessary resources. As a result, apart from a few studies (see Kar et al., 2022; Quamar et al., 2021, 2024, 2025, and references cited therein), extensive research on SCF in relation to herbivore populations, including their presence, abundance, decline, and potential extinction, was lacking.

Meanwhile with the availability of relevant research materials and/or atlases on the NPPs, in general, and the SCF, in particular, recent researchers, especially at the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow, India, accepted this daunting task despite existing limitations, and initiated the research work on NPPs, in general, and on the SCF, in particular, although preliminary, at the BSIP, Lucknow, India (Quamar et al., 2015; Ghosh et al., 2017; Tripathi et al., 2019; Kar et al., 2022; Basumatary et al., 2024; Vaish et al., 2024; Quamar et al., 2021, 2024, 2025, and references cited therein). The onus is now on the present and future Quaternary Palynologists of the BSIP to continue advancing this research, and reach the zenith. Detailed research is, therefore, further required to be carried out, using multiple proxies, for studying various aspects of the SCF (e.g. morphology and identification, dispersal, deposition, preservation and taphonomy)

in sedimentary profiles and cores. Such studies will be crucial for assessing megaherbivore populations over time and across regions in India, ultimately contributing to conservation policies and wildlife management strategies.

The relative abundance of *Sporormiella* and other SCF has been calculated with reference to the total number of pollen (TLP) count in most of the studies except Quamar et al. (2025) wherein the relative abundance of *Sporormiella* and other SCF has been calculated with reference to the total number of fungal spores as it purely deals with the fungal spores and other Non-Pollen Palynomorphs (NPPs), especially the SCF. The threshold value of *Sporormiella* spp. is $\geq 2\%$ for indicating the presence of large herbivores (megaherbivores) on the landscape, whereas $> 5\%$ suggests abundant local populations of megaherbivore, and $< 2\%$ or a consistent decline to near absence is often interpreted as reflecting megafaunal decline or local extinction signal (Davis and Shafer, 2006; Gill et al., 2009; Raper and Bush 2009; Baker et al. 2013). Furthermore, Wood et al. (2011) and Perrotti and van Asperen (2019) suggested that if the threshold value and abundance metrics is $> 10\%$, then very high megaherbivore densities, often associated with open landscapes/pastures, could be indicated. Davis (1987), Davis and Shafer (2006) and Gill et al. (2009) also suggested accumulation rates as < 50 spores $\text{cm}^{-2} \text{yr}^{-1}$ for indicating the presence of small herbivores, $50\text{--}200$ spores $\text{cm}^{-2} \text{yr}^{-1}$ for the presence of megaherbivores, and $>200\text{--}300$ spores $\text{cm}^{-2} \text{yr}^{-1}$ for indicating the high abundance and strong local populations on the landscape in an area. The suggested threshold value and abundance metrics have been tested in Indian scenario, but since the gridded sampling were not carried out in all the studies in India for calculating the accumulation rates; therefore, this aspect has not been discussed here.

In Indian context, following conclusions have been drawn, based on the studies conducted so far on the very aspect:

- Herbivory is suggested in present times in Central India, Western India, as well as in the Eastern and the Western Himalayas, based on the records of the SCF in modern (contemporary) samples.

- Western Himalaya has comparatively more abundant herbivores, and, thus, intensive herbivore grazing can be suggested except some study, wherein almost consistent decline or near absence of large herbivores can be suggested. However, in Northeast India, local herbivore presence and, thus, the local grazing pressure can be suggested.
- Intensified local herbivore grazing (pastoralism) has been suggested between ca. 8041 and 7406 cal yr BP in the Kumaun Himalaya (Western Himalaya). However, between 8327 and 8041 cal yr BP, local herbivore grazing initiated, which increased between 7406 and 6999 cal yr BP.
- Intensified herbivory grazing has been suggested between 1100 and 500 cal yrs BP around Sakali wetland in Majuli Island, Assam. However, herbivory comparatively declined during 1460 to 1100 cal yrs BP, during 2260 to 1460 cal yrs BP and since 500 cal yrs BP onwards. However, no herbivory can be suggested at all during 4040 to 2260 cal yrs around the study area in Assam.
- Herbivore grazing has been suggested to initiate during 3290 and 1700 yrs BP around the Sohola Swamp of the Kaziranga National Park (KNP), Assam. The grazing activity and herbivory increased between 1700 and 640 yrs BP, which further increased since 640 yrs BP to the present around the KNP, Assam. Moreover, very high abundant local populations of megaherbivores densities can be suggested during 1700 to 640 yrs BP and since 640 yrs BP to the present in and around the KNP, Assam.
- In central India, localized herbivore grazing and varying degrees of human pressure can be suggested during ca. 3000–1800 cal yr BP. However, between ca. 3000 and 2600 cal yr BP and also between ca. 2200 and 2000 cal yr BP, the increased intensity of the local herbivore grazing and human pressure as well can also be suggested, but, only the presence of large herbivores can be suggested, between ca. 2000 and 1800 cal yr BP in central India.
- In the Chopta-Tungnath region of the Rudrapur District, Uttarakhand State

(Western Himalaya), it was suggested that the herbivores appeared around ca. 900 yrs BP, hence, local livestock grazing has been suggested since ca. 900 yrs BP, which intensified in present times when humans started to visit the place.

Herbivory plays a crucial role in regulating many modern terrestrial plant ecosystems (Raper and Bush, 2009; van Asperen et al., 2016; Baker et al., 2013; Davies et al., 2022, and references cited therein). Moreover, large herbivores act as key drivers of biodiversity change and in ecosystem resilience (Gill, 2014; Bakker et al., 2016; Jeffers et al., 2018; Kunes et al., 2019; Davies et al., 2022, and references cited therein). However, tracking changes in herbivores abundance over time remains a major challenge in long-term ecological studies (Bradshaw et al., 2003). Also, understanding historical fluctuations in herbivore populations is essential for effective wildlife management, as it requires long-term data on herbivore abundance and its interactions with vegetation, climate, and disturbances (Ekblom and Gillson, 2010). Spores specific to herbivore dung offer a potential source of information for reconstructing past herbivore abundances. *Sporormiella* spores grow on dung of herbivores (SCF), and the study of *Sporormiella* spores, despite limitations, hold significant taxonomic values.

Accurate identification (high-resolution) of *Sporormiella* spores in sedimentary records is crucial, as inconsistencies due to factors such as swelling, shrinkage, or variations in methodological approaches can lead to misinterpretations of palaeoecological data. Through such studies, estimates of herbivore biomass density and the presence of megaherbivores in a given landscape can be inferred (Parker and Williams, 2012). In fact, a strong correlation exists between herbivory and vegetation composition (and/or dynamics), highlighting the role of herbivores in shaping vegetation structure. This is based on two key assumptions: (i) herbivore assemblages fluctuate between browsers and grazers, but overall herbivore abundance remains relatively stable, and (ii) megaherbivores play a dominant role in influencing tree abundance, though their impact may be masked by changes in the broader herbivore community

when using fungal spore proxies. These insights are particularly relevant given the ongoing ecological and socio-economic concerns regarding the decline of large herbivore populations in some regions and overpopulation in others (Cote et al., 2004; Ripple et al., 2015). Large herbivores significantly impact the structure, diversity and functioning of terrestrial ecosystems (Eklblom and Gillson, 2010). Furthermore, such study may provide critical insights into the initiation and intensification of herbivore grazing (pastoralism) through time and across regions, particularly in the Indian context. Such study also contributes to a broader understanding of climatic and environmental conditions, complementing interpretations derived from pollen records (Davis and Shafer, 2006; Tunno and Mensing, 2017; van Asperen et al., 2016, 2020; Quamar et al., 2021, 2025, 2026a, 2026b; Lyudmila et al., 2026, and references cited therein).

In India, as the SCF records during late Pleistocene are lacking, hence, comments on megaherbivore extinction would be scientifically unsubstantiated and ethically wrong as well. Extinction is a complex, multi-faceted process rarely driven by a single, distinct event. Instead, it typically results from cascading ecological disruptions triggered by a major environmental or anthropogenic event (Raup, 1991, 1994). Consequently; attributing the loss of

Pleistocene megafauna to a single cause is overly simplistic. Since *Sporormiella* and other SCF offer valuable insights into past ecosystems and megafaunal biodiversity; their analyses serve as a powerful tool for reconstructing past environments (Baker et al., 2013; Johnson et al., 2015; Raczka et al., 2016).

Further study is, therefore, required to be carried out on a long core/profile with good number of AMS ^{14}C dates for understanding the late Pleistocene megafauna extinction in Indian scenario.

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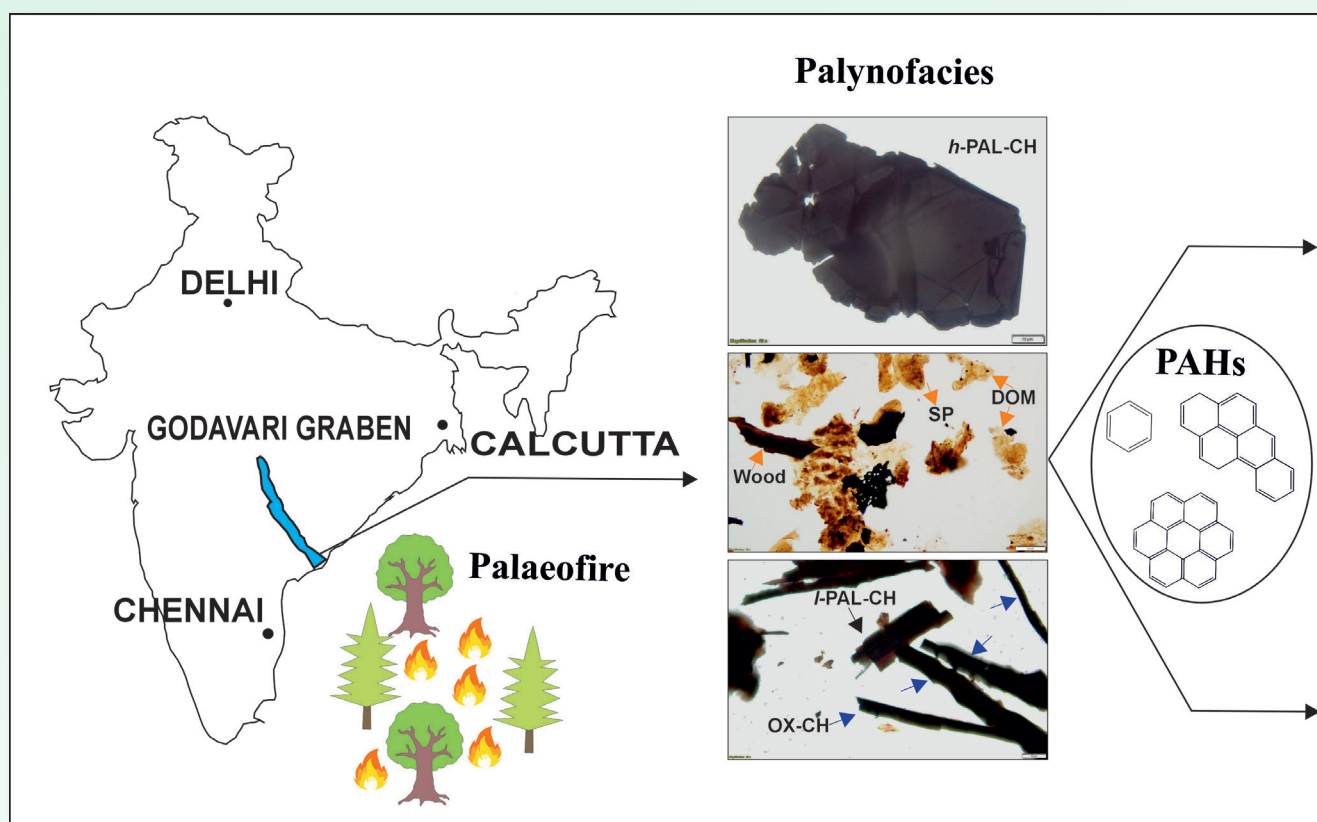
Reconstructing Permian Palaeofire Regimes Using Integrated Palynofacies and Molecular Spectroscopy (Raman and FTIR): Evidence from the Godavari Valley Coalfield, India

Neha Aggarwal, Shivalee Srivastava and Runcie P. Mathews

PALAEOFIRE activity is a critical component of deep-time terrestrial systems, which has an effect on vegetation dynamics, sedimentation patterns and global biogeochemical cycles.

The Permian period with its extensive coal-forming wetlands and high concentration of oxygen in

the atmosphere, can be considered one of the most fire-prone periods in the history of the Earth. However, it remains methodologically challenging to reconstruct the intensity, frequency and geochemical consequences of these palaeofires. The reconstruction of palaeofires is fundamentally based on palynofacies analysis,



Graphical abstract illustrating an integrated palynological and molecular approach to decipher Permian palaeofire activity in Godavari Valley Coalfield using Raman and FTIR Spectroscopy

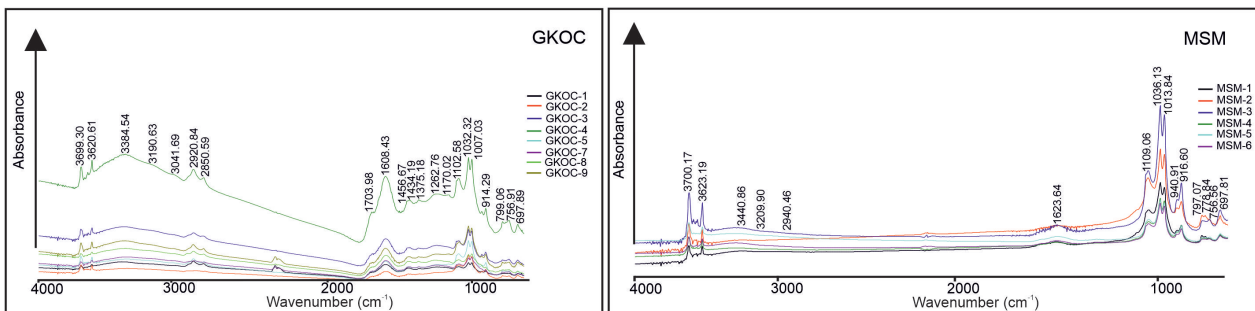
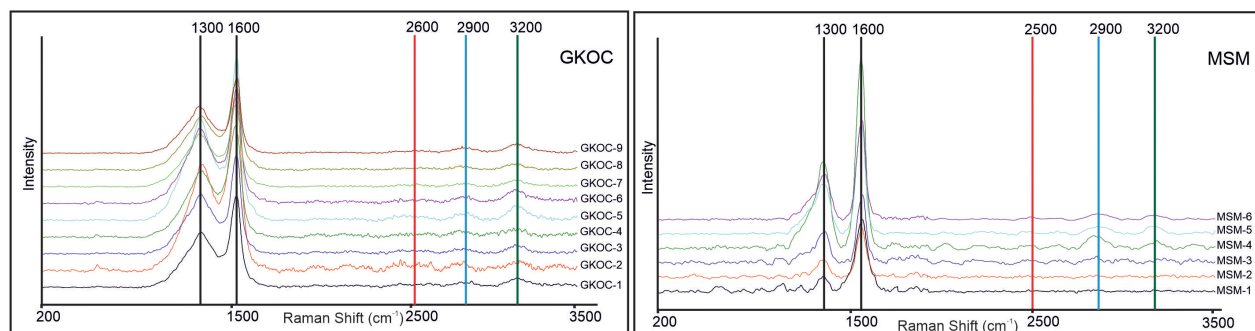
which quantitatively evaluates the composition, distribution, and preservation of sedimentary organic matter components. When vegetation burns, residues left behind last hundreds of millions of years. These remainders are termed as carbonaceous remains and they contain physical and chemical traces of the fires that created them. These signatures allow researchers to measure the intensity of fire, reconstruction of the palaeodepositional environment, and the degree of post-depositional changes of organic matter across time. Moreover, geochemical evidence of palaeofire is also provided by the identification of polycyclic aromatic hydrocarbons (PAHs) stable compounds that were formed in the course of incomplete combustion. Although these compounds were traditionally investigated using complex analytical methods, such as Gas Chromatography-Mass Spectroscopy (GC-MS), more recent non-destructive techniques like Raman and Fourier Transform Infrared (FTIR) spectroscopy, which allow rapid characterization of fire-affected organic matter, providing insights into its

molecular structure, thermal maturity, and chemical composition.

A recent multi-proxy study of the Artinskian (c. 290–283 Ma) sediments of the Godavari Valley coalfield (southern India) combines palynofacies analysis with Raman and FTIR spectroscopy to give new information about the signatures of the Permian palaeofires. The integrated application of these techniques allows the direct correlation of microscopic palaeofire remains with molecular-scale evidence of palaeofire. To perform a palaeofire reconstruction, fifteen samples of carbonaceous shales were selected according to the occurrence of fire-affected microcharcoal detected during pre-screening of the palynofacies analysis. These samples were collected from open cast mines (GKOC) and borehole (MSM), which contain a variety of lithological variations.

Opaque phytoclasts (microcharcoal; CH), which appear completely opaque under a transmitted light microscope and lack visible internal structure, were

Raman Spectroscopy



FTIR Spectroscopy

classified into oxidation-derived particles (OX-CH) and fire-derived charcoal (PAL-CH) in an earlier study by Aggarwal et al., 2025. Based on this already established distinction, this research article further subdivides the fire-derived charcoal (PAL-CH) category to two classes, based on their intensity: High-intensity palaeofire charcoal (*h*-PAL-CH) and low-intensity palaeofire charcoal (*l*-PAL-CH). This classification is determined by the existence and visibility of microtextures of the surface (e.g., grooves, linear striations, surface impressions). This refinement helps improve the palaeofire interpretation, as the microcharcoal morphology can be related to the intensity of combustion and thermal change, allowing a better separation of fire-derived particles and a more accurate reconstruction of fire regimes and geochemical influences.

In order to get beyond the visual observations (palynofacies analysis), we employed Raman spectroscopy and Fourier Transform Infrared (FTIR) spectroscopy in the study to analyse the molecular structure of the organic matter. Raman spectroscopy showed apparent molecular transformations in the organic matter. Most of the previous studies rely on first-order Raman signals, D-band (Disordered carbon $\sim 1350\text{ cm}^{-1}$) and G-band (Graphitic carbon $\sim 1600\text{ cm}^{-1}$). The increasing aromatic condensation and structural ordering is reflected in systematic changes in band widths (D-FWHM, G-FWHM) and intensity

ratios ($R1 = ID/IG$). The application of second-order Raman spectral features ($2500\text{--}3200\text{ cm}^{-1}$), such as 2D overtones, D+G combination bands and 2G bands are one of the most significant innovations of this study to understand the maturity of carbonaceous material formed during palaeofires.

According to the first-order Raman parameters of the borehole samples (MSM), thermal maturity increases, as indicated by the rise in the R1 ratio from 0.22 to 0.46 and the D-FWHM/G-FWHM ratio from 0.97 to 2.13, reflecting enhanced aromatic condensation, associated with high-temperature. Second-order Raman bands (e.g. 2D at $2560\text{--}2589\text{ cm}^{-1}$) also appear well-developed in these samples, which supports increased structural ordering and frequent fire influence. Interestingly, the 2D peak within the range of about 2560 cm^{-1} is correlated with D-band overtones, and it is inter-ring C-C stretching of large, conjugated aromatic structures (pericondensed PAHs). On the other hand, first-order Raman parameters of the GKOC samples display more moderate and consistent values ($R1 \sim 0.59\text{--}0.73$; D/G ratios $\sim 2.05\text{--}3.40$) with weaker second-order features ($\sim 2620\text{--}2680\text{ cm}^{-1}$), indicative of less intense or partially reworked fire residues. The 2D peaks are shifted to $\sim 2650\text{ cm}^{-1}$, which can be attributed to smaller aromatic ring systems and more amorphous carbon structures (catacondensed PAHs).



FTIR Spectroscopy Instrument at BSIP, Lucknow



Raman Spectroscopy Instrument at BSIP, Lucknow

FTIR spectroscopy was used in conjunction with Raman data in determining functional groups in the organic matter. There are systematic differences in the analysed samples: strong aromatic C=C stretching ($\sim 1600\text{--}1625\text{ cm}^{-1}$) represents high aromaticity. The absence of aliphatic CH bands (~ 2920 and 2850 cm^{-1}) in the samples of MSM is also evidence of highly carbonised material. GKOC samples, on the other hand, are more diversified with both consistent aromatic C=C ($\sim 1600\text{--}1625\text{ cm}^{-1}$) and certain aliphatic C-H stretching (~ 2920 and 2850 cm^{-1}) and CH_2/CH_3 bending ($\sim 1450\text{--}1375\text{ cm}^{-1}$), reflecting a mixture of aromatic and less-altered organic matter. Finally, MSM samples record intense combustion, and GKOC samples reflect less intense or partially altered fire signals.

The work is a significant outcome in the research on palaeofires, as it combines palynofacies and molecular spectroscopy within a high-resolution analysis framework. Among the most significant innovations is optimization of microcharcoal to high- (*h*-PAL-CH) and low-intensity (*l*-PAL-CH) forms that provide a direct correlation between charcoal morphology, fire intensity, and geochemical signatures and provides a possibility to cross-validate palaeofire signals. The research also has the advantage of combining microscopic data with Raman and

FTIR techniques, which enables the robust cross-validation of palaeofire signals. Surprisingly, second-order Raman bands (2D, D+G, 2G) are more sensitive to the formation of PAHs and aromatic complexity, which can no longer be restricted to the conventional method. In addition, it demonstrates that Raman spectroscopy can be employed as the rapid, non-destructive screening technique, which can improve the efficiency of the PAH-contaminated, fire-damaged, sediments detection. Together, these contributions are a methodological and conceptual contribution to the field and a strong base of future high-resolution palaeofire research.

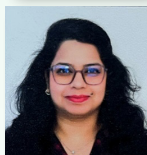
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Did ancient Indian forests give birth to Jamun's giant family?

Sadanand, Harshita Bhatia and Gaurav Srivastava

If you have ever eaten a ripe Jamun during summer, you have already encountered a member of one of the world's largest tropical tree groups: *Syzygium*. This remarkable genus includes Jamun (*Syzygium cumini*), rose apple, water apple, and hundreds of evergreen trees spread across Asia, Africa, Australia, and the Pacific islands. Yet, despite their modern distribution, scientists have long debated where this giant family of trees actually originated.



A recent fossil discovery from the Himalayan foothills may now help answer that question.

Researchers from the **Birbal Sahni Institute of Palaeosciences (BSIP)**, Lucknow, and **Academy of Scientific and Innovative Research (AcSIR)**, Ghaziabad have discovered exceptionally preserved fossil leaves of *Syzygium* from the Kasauli town of Solan district, Himachal Pradesh. These fossils are more than 22 million years old and belong to the Early Miocene Period, when the Himalaya were still rising and northern India was warmer and wetter than it is today. The fossils were found preserved within thin shale deposits formed by ancient river systems under humid tropical conditions. Although they appear like ordinary dried leaves pressed into

stone, they carry valuable information about ancient forests, climate, and the evolutionary history of tropical plants.

The fossil leaves show remarkable similarities to modern *Syzygium* species. Their elliptic shape, smooth margins, and distinctive vein patterns closely resemble leaves of present-day evergreen forest trees. To verify their identity, scientist compared the fossils with 156 modern plant species belonging to 21 different plant families and also used statistical analysis to determine which living plants most closely matched the fossils. The results strongly confirmed that the leaves belonged to *Syzygium*. Based on their unique features, the researchers identified them as a completely new fossil species and named it *Syzygium paleosalicifolium*.

However, the discovery became even more important when researchers re-examined older fossil records from different parts of India. Earlier fossil

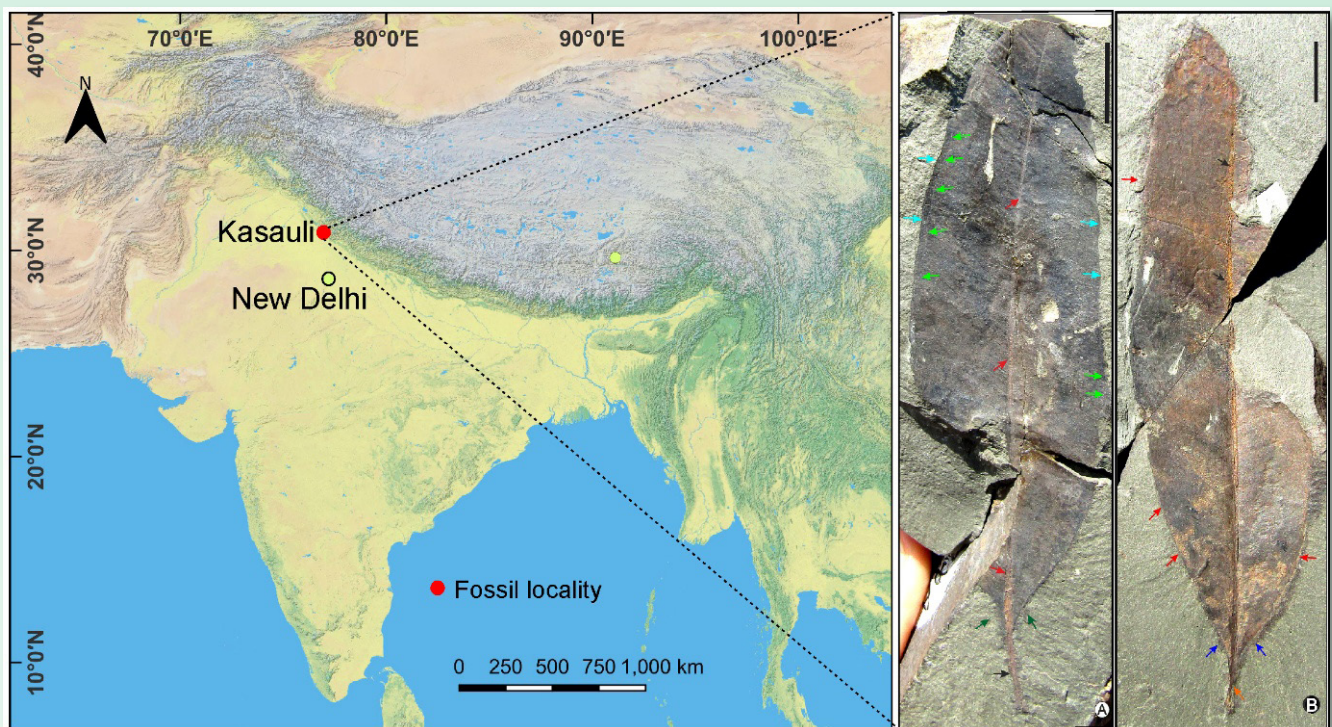


Figure: (Left) Map showing the fossil collection locality. (Right) Photograph of the fossil specimen; coloured arrows highlight distinct morphological features (adapted from Sadanand et al., 2026).

leaves from rocks nearly 50 million years old also showed strong similarities with modern *Syzygium*. This suggests that the genus may have existed in India much earlier than previously believed.

For many years, some scientists proposed that *Syzygium* originated in Australia or nearby regions before spreading into Asia. The Indian fossil evidence now presents a different possibility — that India itself may have played a major role in the origin and diversification of this tropical tree group.

This idea connects closely with the fascinating “Out of India” hypothesis. Millions of years ago, India was part of the ancient southern supercontinent Gondwanaland along with Africa, Antarctica, Madagascar, Australia, and South America. When Gondwanaland began to break apart, the Indian Plate drifted northward like a giant island carrying plants and animals with it. Eventually, India collided with Asia, leading to the formation of the Himalaya and

open migration pathways for tropical species into Southeast Asia and beyond.

Scientists now believe that the ancestors of modern *Syzygium* may have travelled during this geological journey. Instead of originating solely in Australia, the genus may have diversified on the Indian landmass before spreading into other tropical regions after India’s collision with Asia.

The study also highlights how closely Earth’s geological and biological histories are connected. As the Himalaya gradually rose, they altered rainfall patterns, river systems, and temperatures across South Asia. Forests shifted, species adapted to new environments, and some plants migrated into entirely different regions. Ancient *Syzygium* trees likely survived many of these environmental transformations over millions of years. Today, *Syzygium* species continue to play an important ecological role in tropical ecosystems. Their fruits provide food for birds, bats, and mammals,

while their flowers support pollinating insects. Several species also hold medicinal and cultural significance. Jamun, for example, is widely valued in traditional medicine and is commonly associated with blood sugar regulation.

What makes discoveries like these especially significant is that fossils are far more than simply “dead plants preserved in rocks.” They are natural archives of vanished worlds. The shapes and vein patterns preserved in fossil leaves help scientists reconstruct ancient climates, vegetation, and migration routes of plants across drifting continents.

Such studies are also increasingly relevant today. Modern tropical forests are facing rapid climate change, habitat destruction, and biodiversity loss. Understanding how plants responded to environmental changes in the geological past may help scientists predict how present-day ecosystems could react in the future.

The fossil leaves from Kasauli remind us that the forests surrounding us today are survivors of an extraordinarily long history. The Jamun tree growing beside a village pond or roadside may belong to a lineage that witnessed drifting continents, the rise of the Himalaya, and dramatic climatic shifts long before humans appeared on the Earth.

In this way, every fossil leaf becomes more than just an imprint in stone. It becomes a messenger from an ancient tropical world, preserving the story of India's forests and their remarkable journey through deep time.

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From Deep Time to Deep Learning: How Artificial Intelligence is Transforming Indian Palaeosciences

Ranveer Singh Negi, Anjali Trivedi and Mahesh G Thakkar

IMAGINE a computer identifying a 250-million-year-old fossil pollen grain within seconds, recognizing subtle differences between nearly identical fossil species, reconstructing ancient climates from thousands of geological records, or discovering hidden patterns within decades of palaeontological data that might otherwise take generations of scientists to unravel. Such possibilities, once confined to science fiction and futuristic movies, are increasingly becoming scientific reality through Artificial Intelligence (AI). The years following the COVID – 19 pandemic have witnessed an unprecedented digital transformation, often described as the beginning of a new technological or industrial revolution driven by data, connectivity, automation, and AI. From online banking and digital payments to telemedicine, education, e-commerce, and e-governance, our daily lives have rapidly shifted towards an increasingly digital ecosystem.

India has embraced this transformation with remarkable enthusiasm. The recently held *AI Impact Summit 2026* in New Delhi, was organized under the broader *India AI Mission*. The summit, inaugurated by the Hon'ble Prime Minister, brought together global technology leaders, innovators, policymakers, researchers, and AI pioneers to discuss the future of Artificial Intelligence and its societal impact. The summit attracted widespread public attention and highlighted the growing role of intelligent technologies in shaping the nation's digital future. Today, AI-powered systems are becoming increasingly common in everyday life, from virtual assistants and conversational chatbots to image-generation

platforms, autonomous machines, and advanced decision-support systems. Digital technologies have fundamentally altered public expectations, making information, services, and products available almost instantly at the touch of a screen.

These developments reflect a broader global transition toward a data-driven and AI-enabled society. Artificial intelligence is no longer a distant concept confined to research laboratories; it has become an integral component of modern economic, social, and scientific systems. In such a rapidly evolving world, an important question naturally arises: if AI is transforming nearly every field of human endeavour, can it also revolutionize our understanding of Earth's deep past?

The answer is an unequivocal yes. Across the globe, researchers are increasingly integrating AI and Machine Learning (ML) to palaeontology, palynology, palaeobotany, micropalaeontology, climate modelling, biodiversity studies, automated taxonomy, fossil imaging, and Earth-system science. During the past decade, numerous studies have demonstrated how intelligent algorithms can assist scientists in identifying fossils, analysing microscopic images, integrating complex datasets, reconstructing ancient environments, and uncovering patterns hidden within vast scientific archives. What once seemed futuristic is rapidly becoming an indispensable tool for exploring Earth's deep-time history. Palaeosciences have always been data-rich disciplines. Every fossil, pollen grains, rock sample, geochemical signature, and climate proxy serves as a natural archive of Earth's past, helping scientists reconstruct ancient

environments, trace climatic shifts, and understand how life and landscapes have evolved through deep time. For nearly eight decades, the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow, has generated and curated vast scientific archives like palaeobotany, palynology, micropalaeontology, vertebrate palaeontology, geochemistry, palaeoclimate studies, archaeology, ancient and modern DNA, and Quaternary science. Collectively, these resources constitute one of India's most valuable repositories of

information on ancient life, environmental change, climate evolution, biodiversity, and geological processes.

Yet the challenge today is not the availability of data, but our ability to utilize it effectively. A significant portion of this scientific wealth remains distributed across publications, fossil collections, microscope slides, laboratory records, field photographs, geochemical databases, and institutional archives. As a result, enormous volumes



Figure 1 Glimpses of the brainstorming programme at BSIP: (a) invited dignitaries addressing the inaugural session (from left to right): Prof Mahesh G Thakkar (Director, BSIP and Patron), Dr GK Goswami, IPS (Chief Guest), Prof Ashok Sahni (Special Guest), Shri Sanjeev Kumar Singh, IFS (Guest of Honour), and Dr Pauline Sabina Kavali, Scientist-E, BSIP (Comperer); (b) speakers during the technical session (from left to right): Dr Anjali Trivedi, Scientist-E, BSIP (Convener), Prof Arunabha Mukhopadhyay (IIM Lucknow), Prof Puneet Misra (University of Lucknow), Mr Prakash Sharma (IIT, Kanpur), and Mr Ankit Khurana (C-DAC, Mohali). (Photo courtesy: Director, BSIP)



of valuable information remain underutilized despite their scientific significance. This situation presents a paradox: while the quantity of palaeoscientific data has increased exponentially, many analytical workflows continue to rely heavily on painstaking manual observations and expert interpretation. Extracting meaningful observations and diverse datasets often require years of painstaking efforts. It is precisely here that AI-assisted approaches offer exciting possibilities. Instead of replacing scientists, AI can assist them in organising, integrating, analysing, and extracting knowledge from vast and complex datasets. By accelerating routine tasks and revealing previously hidden patterns, intelligent systems can enable researchers to focus more effectively on interpretation, hypothesis testing, and scientific discovery.

Recognizing this emerging opportunity, BSIP recently organized a brainstorming session entitled *From Deep Time to Deep Learning: Unlocking Palaeosciences through Palaeobiological Data and AI Innovation*. Conducted under the guidance of the Director (BSIP), Professor M.G. Thakkar, the programme was convened by Dr. Anjali Trivedi, and brought together experts from diverse disciplines, including palaeosciences, computer science, environmental science, law, forensic science, and data management, to explore future roadmaps for AI-enabled research. The event featured distinguished speakers including **Shri Sanjeev Kumar Singh** (Member Secretary, Uttar Pradesh Pollution Control Board), **Prof. Ashok Sahni** (Professor Emeritus, Panjab University), **Dr. G.K. Goswami** (Director, Uttar Pradesh State Institute of Forensic Science), **Prof. Arunabha Mukhopadhyay** (Indian Institute of Management, Lucknow), **Dr. Punnet Misra** (University of Lucknow), **Shri Prkalpa Sharma** (IIT Kanpur), and **Shri Ankit Khurana** (C-DAC). A central theme that emerged from the discussions was that AI is not a distant technology waiting to arrive—it is already transforming scientific research worldwide. In medicine, AI-assisted systems are helping doctors diagnose diseases from medical images, improve screening programmes, and analyse vast quantities of healthcare data. In astronomy, machine-learning

algorithms are identifying previously unknown celestial objects from enormous observational datasets. Similar developments are now beginning to reshape palaeontology, palynology and climate science.

Among the most promising applications discussed during the session was image-based fossil identification. Fossil pollen grains, spores, microfossils, leaves, wood remains, and skeletal structures often exhibit highly complex morphological features that require years of specialized training to recognize accurately. Recent advances in computer vision and deep learning have demonstrated that neural networks can be trained to identify and classify such specimens with remarkable efficiency. These systems are best viewed not as replacements for expert knowledge, but as intelligent assistants capable of rapidly sorting, comparing, and analysing large collections while leaving interpretation and scientific reasoning firmly in human hands.

The potential of AI extends far beyond fossil identification. Modern palaeosciences increasingly rely on multiple lines of evidence, including fossil assemblages, geochemical signatures, sedimentological records, geophysical observations, remote sensing data, and climate proxies. AI systems are particularly effective at integrating diverse datasets and identifying relationships that may not be immediately apparent through conventional approach. These capabilities could significantly enhance efforts to reconstruct ancient climates, understand biodiversity change through geological time, investigate environmental responses to major volcanic events, and explore the long-term evolution of Earth systems.

Several examples discussed during the session highlighted uniquely Indian opportunities for developing *India-centric AI-assisted Earth-system models*. The country's geological record preserves evidence of the Late Palaeozoic Ice Age, the extensive Glossopteris flora of Gondwana, the remarkable northward journey of the Indian plate from the Southern Hemisphere to its eventual collision with Eurasia, the Deccan volcanic eruptions, and detailed Quaternary records of monsoon variability. Together, these archives document some of the most significant events in Earth history and provide an exceptional record of climatic, environmental, tectonic, and

biological change. AI-assisted integration of these datasets could help address longstanding global questions related to climate transitions, biodiversity evolution, environmental resilience, plate tectonics, and mass extinctions.

The enthusiasm surrounding AI, however, was accompanied by an equally important message of caution. Participants repeatedly emphasized that AI

systems are only as reliable as the data used to train them. While AI possesses immense transformative potential, its critical application can create scientific, legal and societal challenges. Concerns were raised regarding deepfakes, fabricated scientific outputs, hallucinated citations, cybersecurity risks, and digital misinformation. Consequently, issues of trust, accountability, transparency, and validation



Figure 2. Glimpses of the concluding session of the brainstorming programme at the BSIP: (a) open brainstorming and panel discussion chaired by Prof Mahesh G Thakkar, Director, BSIP; and (b) panellists and participants at the conclusion of the programme. (Photo courtesy: Director, BSIP)



have become increasingly important in AI-enabled research. The discussions repeatedly returned to a fundamental principle familiar to all data scientists: *garbage in, garbage out*. Meaningful AI applications depend on high-quality, well-curated, metadata-rich, and scientifically validated datasets. Participants also highlighted the importance of emerging governance frameworks, including India's **Digital Personal Data Protection (DPDP) Act**, intellectual property and cybersecurity, regulations, and evolving international initiatives aimed at ensuring responsible AI development. Before advanced algorithms can unlock new scientific insights, substantial effort must first be invested in digitizing, standardizing, and validating the vast volumes of valuable yet underutilized information preserved within palaeoscientific collections and repositories. Robust audit trails, provenance tracking, accountability mechanisms and ethical guidelines will be essential to ensure that future AI-assisted scientific systems remain transparent, reproducible, and trustworthy.

Perhaps the most important message emerging from the programme was that AI is not here to replace scientists. Rather, it is a powerful tool that can augment human expertise, accelerate routine workflow, and reveal patterns hidden within complex datasets.

Scientific judgement, domain knowledge, creativity, and critical interpretation will remain central to the research process. The future of palaeosciences will, therefore, depend not on machines alone, but on productive collaboration between scientists, computational experts, and intelligent technologies within a strong *human-in-the-loop* framework.

The brainstorming session also underscored the immense value of BSIP's palaeobiological archives as a national scientific resource. Built through decades of dedicated fieldwork, laboratory investigations, and scholarly research, these collections represent a unique repository of India's deep-time heritage, and responsibly analysing these datasets, BSIP has the opportunity to help develop a new generation of AI-enabled scientific tools capable of addressing questions that span millions of years of the Earth history.

The journey from deep time to deep learning has only just begun. As palaeosciences enter the era of big data, artificial intelligence offers an unprecedented opportunity to bridge the gap between historical archives and future discoveries. For institutions, such as the BSIP, the question is no longer whether AI will influence palaeosciences, but how effectively the scientific community can harness its potential while preserving the rigor, reliability, and curiosity that have always defined the study of the Earth's past.

About authors



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Radiocarbon Dating: How Scientists Read the Age of the Past

Anjali Trivedi and Anupam Nag

IMAGINE finding a piece of charcoal in an ancient hearth, a fragment of bone buried deep in soil, or sediment layers carrying ancient pollen grains that hold clues to the vegetation and climate of the human past. Now imagine being able to say, with reasonable confidence, how many thousands of years old each of these is. That's the everyday magic of radiocarbon dating, a technique that has quietly reshaped archaeology, palynology, geology, and several other fields since the middle of the 20th century.

At its core, radiocarbon dating works by measuring how much carbon-14 remains in something that was once alive, and comparing it against a known international standard. The lower the carbon-14, the older the sample. This simple idea, once it was developed, gave scientists something they had never really had before: a reliable clock for the ancient world.

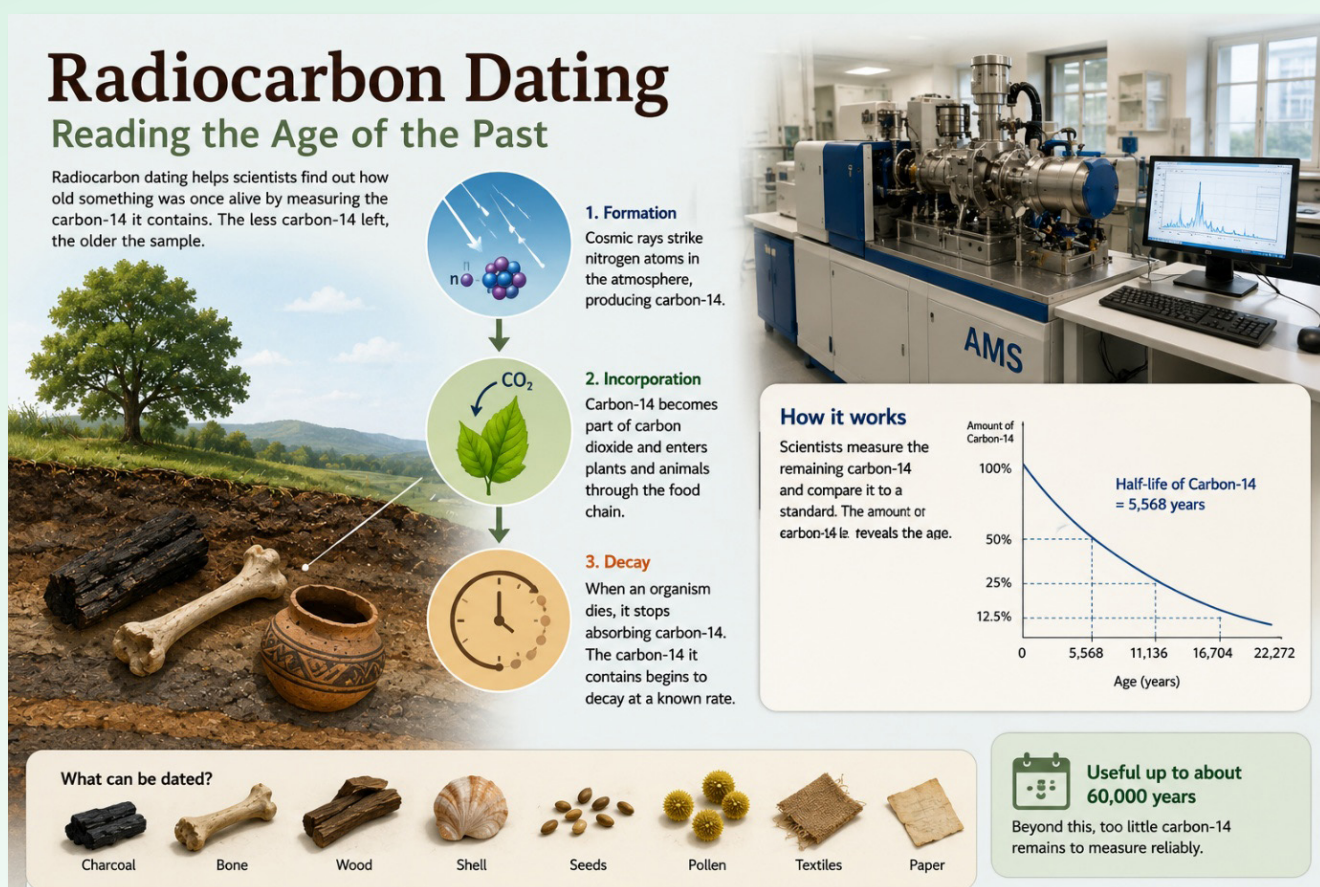


Figure 1. Schematic illustration of radiocarbon dating, showing the formation of carbon-14 in the atmosphere, its incorporation into living organisms, and its use in determining the age of ancient organic remains through AMS analysis.

A DISCOVERY THAT CHANGED HOW WE SEE THE PAST

The method was developed in the late 1940s by **Willard Libby**, an American chemist working at the University of Chicago. Libby was the first to propose that this unstable form of carbon might exist in living organisms, and he went on to lead the research that confirmed it. He also calculated carbon-14's half-life, the time it takes for half of it to decay, at roughly 5568 ± 30 years. For this work, he received the **Nobel Prize in Chemistry** in 1960.

It's hard to overstate how much this changed things. Before radiocarbon dating, dating an ancient artifact often relied on guesswork, comparisons, or written records, none of which were available for prehistoric material. Suddenly, archaeologists had an objective tool. The shift was significant enough that historians now refer to it as archaeology's "radiocarbon revolution." Today, the technique reaches well beyond archaeology too, into geology, oceanography, climate science, and even medicine.

WHERE DOES CARBON-14 COME FROM?

Carbon exists in nature in three forms. Two are stable, carbon-12 and carbon-13, and one, carbon-14, which is mildly radioactive and unstable. It forms continuously high in the atmosphere, when cosmic rays strike nitrogen atoms. This newly formed carbon-14 quickly combines with oxygen to become carbon dioxide, which then enters the air we breathe and the food chain we're part of.

Plants absorb this carbon dioxide, and animals absorb it by eating plants (or other animals). As long as plants and animals are alive, it keeps taking in carbon-14 at roughly the same rate it's losing it. But the moment an organism dies, that exchange stops. From then on, the carbon-14 already inside it simply decays, slowly and predictably, following the same fixed half-life every time. Measuring how much is left tells us how long ago that organism died.

HOW SCIENTISTS ACTUALLY MEASURE IT

Three main methods exist for measuring carbon-14 in a sample. The two older ones, gas proportional counting and liquid scintillation counting, both work by detecting the beta particles given off as carbon-14 decays. In gas counting, the sample is converted into carbon dioxide gas and placed in a detector. In liquid scintillation counting, popular mainly in the 1960s, the sample is dissolved in a liquid containing a special chemical that flashes light when struck by a beta particle; two sensors confirm each flash before it's counted.

The modern approach, Accelerator Mass Spectrometry (AMS), works differently and far more efficiently. Rather than waiting around for radioactive decay to happen and counting the particles it releases, AMS directly counts the actual carbon-14 atoms in the sample and compares them to the stable carbon-12 and carbon-13 atoms present. This means smaller samples and quicker, more precise results, which is why AMS has largely become the standard today.

WHAT CAN BE DATED?

Almost anything that was once the part of a living thing can potentially be dated this way: wood, charcoal, bone, shell, leather, seeds, hair, peat, pollen, textiles, paper, and even old wall paintings or blood traces. Some non-living materials, like the aragonite in certain shells, can also be dated, provided they formed while absorbing atmospheric carbon-14 in the usual way. Before testing, samples usually need to be cleaned, sometimes with simple washing, sometimes with more involved chemical treatment, to strip away anything that might distort the result.

WHERE THE METHOD FALLS SHORT

No dating method is perfect, and radiocarbon dating has its own clear boundaries. The most basic one is range: it only works reliably on samples up

to about 60,000 years old. Beyond that, too little carbon-14 remains to measure with any confidence.

There's also the matter of sample size. Conventional testing requires a relatively large amount of material, roughly 10 to 100 grams, depending on what's being tested. Newer AMS techniques have shrunk that requirement dramatically, down to just 20 to 50 milligrams in some cases. Either way, the material doesn't survive the process. Testing it means losing it.

Contamination is the trickiest issue of all. Because the test is essentially counting a very small number of atoms, even a tiny amount of "extra" carbon, picked up from soil, handling, or modern residue, can throw the results off significantly. A sample that's truly a million years old, if even slightly contaminated, could end up reading as just 40,000 years old. That's why careful cleaning and pretreatment matter so much before a sample ever reaches the lab.

RADIOCARBON DATING IN INDIA

In India, radiocarbon dating facilities are available at several premier research institutions, including the Birbal Sahni Institute of Palaeosciences (Lucknow), Physical Research Laboratory (Ahmedabad), Inter-University Accelerator Centre (New Delhi), and Bhabha Atomic Research Centre (Mumbai). These facilities have played a quiet, but important role in piecing together the subcontinent's environmental and archaeological past, from dating lake and peat sediments that reveal long-term shifts in monsoon patterns, to establishing timelines for archaeological sites across the country.

OTHER CLOCKS FOR OTHER TIMESCALES

Radiocarbon dating isn't the only tool available, and it isn't always the right one. Each dating method has a range and a purpose it suits best. Dendrochronology, or tree-ring dating, uses the growth patterns of long-lived trees and can stretch back roughly 12,500 years for oak and 8,500 years for bristlecone pine, though it depends entirely on finding well-preserved wood.

For far older material, scientists turn elsewhere. Potassium-argon dating can date volcanic rock anywhere from under 100,000 years old to more than 4 billion years old, making it useful for some of the oldest geological questions on the Earth. Rubidium-strontium dating works across a similarly vast range, from a few million to several billion years, and is used both to understand how the Earth and solar system formed and, in archaeology, to trace ancient patterns of human migration and trade. Together, these methods complement each other. Where radiocarbon dating leaves off, others pick up, allowing scientists to piece together a timeline that stretches from a few centuries ago to the very origins of our planet.

More than seventy years after Willard Libby first proposed it, **radiocarbon dating remains one of paleoscience's most dependable tools**. It has been refined considerably since the 1940s, sample sizes have shrunk, precision has improved, and calibration has made its results more reliable than ever, but the basic principle Libby identified still holds. Few discoveries in modern science have given us such a clear way to listen to the past on its own terms.

About authors



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Road Through Time: A Himalayan Journey Across 500 Million Years

Ranveer Singh Negi and Hukam Singh

A GEOLOGICAL TRAVELOGUE FROM THE MALLA JOHAR SUPERGROUP

THERE are roads in the Himalaya that do not merely connect villages; they connect worlds separated by hundreds of millions of years. The road through the Malla Johar Supergroup is one such extraordinary route, allowing travellers to journey across nearly half a billion years of the Earth's history in just a few days. In the far northern frontier of Uttarakhand, where the Dhauli Ganga and Girthi Ganga rivers carve through towering mountains near the Indo-Tibetan border, the rocks themselves preserve memories of vanished oceans, ancient beaches, tropical reefs, volcanic eruptions, and ultimately the rise of the mighty Himalaya. Together, these remarkable rocks form a natural archive of the Earth's history. Geologists collectively call this succession as the Malla Johar Supergroup. During the BSIP's maiden geological expedition here, our team travelled through the remote landscapes of Chamoli and Pithoragarh districts. Yet this was not simply a scientific field tour; it was indeed a time travel. The journey began near Niti and Malari, climbed through Sumna and Rawlibagar, crossed the Kioto Valley, reached the classical Jurassic localities of Laptal, and finally ascended through volcanic terrains to Balcha Dhura Pass along the India-Tibet border, one of the most spectacular geological archives preserved in the Indian Himalaya. The mountains here are not silent. They speak through fossils, sediments, colours, textures, folds, and landscapes. One only needs to learn their language.

ENTERING THE TETHYAN HIMALAYA: WHERE TWO WORLDS MEET

Our journey began along the Dhauli Ganga valley, passing through remote Himalayan localities, such as Geldung, Kharwasia Nala, Basudhara Tal, Goting, and finally Niti village. Located above 3,000–4,000 metres, these villages remain snowbound for much of the year. Historically, they formed part of ancient Indo-Tibetan trade routes where traders exchanged salt, wool, borax, and grains, using yaks and sheep caravans across some of the world's highest mountain passes. Even today, traces of this cultural connection survive in architecture, dialects, and seasonal migration patterns. Near Niti, the rocks suddenly change. The dark, ancient crystalline rocks beneath our feet give way to younger layers that were once deposited on the floor of a vast ocean. Geologists call this boundary the South Tibetan Detachment System, one of the most important geological contacts in the Himalaya. Standing at this contact feels like standing between two different Earths. Below lie rocks forged deep within Earth's crust under immense pressure and temperature. Above begin thick sedimentary sequences preserving a nearly continuous archive from the Precambrian to the Cenozoic, spanning almost the entire history of complex life on the Earth.

INTO THE PRECAMBRIAN SEAS

Above the tectonic boundary occur the oldest sedimentary rocks of the region, poorly explored Precambrian successions that remain among the least understood geological archives of the Himalaya.

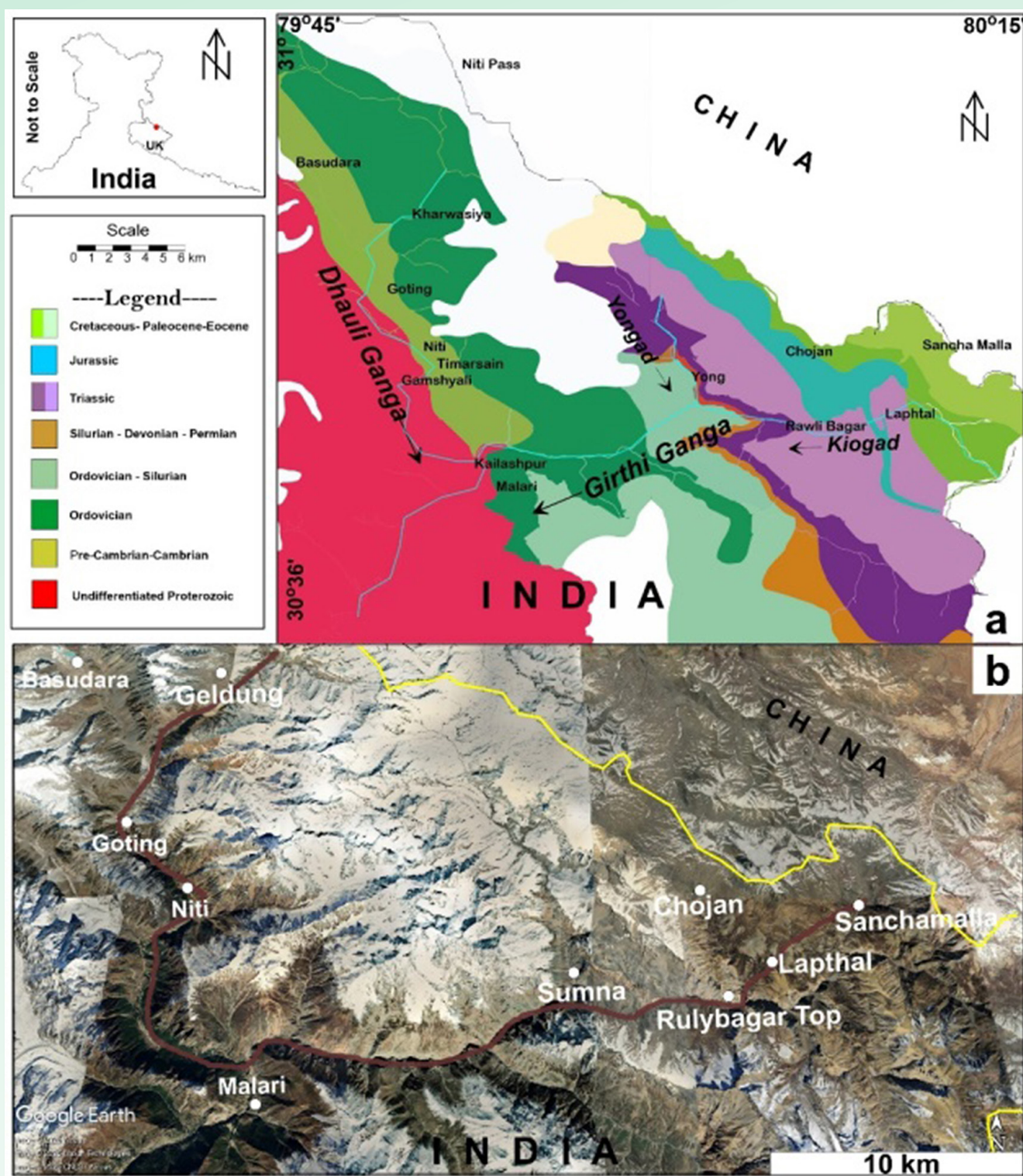


Figure 1. (a) Geological map of the Malla Johar Supergroup, Uttarakhand (modified after GSI). (b) Google Earth image showing key localities and the Dhauri Ganga – Girithi Ganga – Kiogad valley traverse, representing a journey across nearly 500 million years of Earth history from west (left) to east (right).



Rocks here reveal traces of ancient coastlines and shallow marine environments that existed long before complex life evolved. These rocks were deposited when the Indian continent was still part of the southern supercontinent Gondwana, situated far south of the equator.

At that time, the Himalaya did not exist. Instead, **where icy winds now sweep across barren mountains, warm shallow seas once stretched to the horizon** dominated by microbial life. Sedimentary structures preserved in these rocks like wave marks, sand layers stacked like dunes, and tidal signatures indicate fluctuating coastal conditions, beaches, tidal flats, and shallow marine systems.

THE CAMBRIAN EXPLOSION: WHEN LIFE LEARNT TO BURROW

As we moved farther along the Dhauli Ganga valley toward Geldung and Goting, the rocks began telling a completely different story. Nearly 538 million years ago, during the Cambrian Period, Earth witnessed one of the most extraordinary biological revolutions in history, the Cambrian Explosion. Complex animal life diversified rapidly in the oceans, and the sea floor suddenly became alive with activity. Trace fossils preserved within these rocks reveal that early organisms had already begun burrowing into sediments, crawling across the sea floor, and engineering marine ecosystems.

Trace fossils are not the remains of animals themselves. They are clues like footprints left in wet sand, showing where ancient creatures crawled, rested, or searched for food. Mud cracks, wave marks, tidal structures, and sand dunes like stacked sand layers preserved in the succession, indicate environments remarkably similar to modern tidal flats and coastal lagoons.

It is astonishing to imagine that the snow-clad Himalayan peaks of today were once sandy shorelines washed by Cambrian tides.

ORDOVICIAN RIVERS, BEACHES, AND ANCIENT STORMS

Near Kharwasia and Malari, thick beds of giant pebbles cemented together, begin to dominate the landscape. Massive pebble-rich horizons and spectacular sedimentary structures record high-energy rivers and ancient coastlines that existed about 470 million years ago, during the Ordovician time, when neither dinosaurs nor humans had yet evolved. These rocks preserve evidence of rapidly flowing streams descending from nearby uplands and carrying pebbles into shallow marine basins. Ancient beach systems, tidal channels, storm and wave influenced sand bodies remain beautifully preserved within the succession. Today, these outcrops stand beside narrow mountain roads, traversed by army convoys, shepherds, and occasional geological teams, the roads that follow coastlines older than the dinosaurs.

GIRTHI GANGA VALLEY: A CONTINUOUS ARCHIVE FROM THE ORDOVICIAN TO THE PERMIAN

From Malari to Sumna, the road follows the spectacular Girthi Ganga valley, where the mountains expose one of the finest continuous geological successions of the Himalaya. Few places in India offer such magnificent natural cross-sections through Earth history. The rocks change colour and character every few kilometres, grey limestones, dark shales, reddish horizons, sandy beds, and fossiliferous carbonates, each representing a different ancient environment. Fossils of brachiopods, corals, crinoids, and trace fossils indicate that this region remained submerged beneath warm tropical seas for a very long geological time. The succession also records repeated environmental changes. Devonian sandstone rocks indicate the return of shallow, high-energy coastal systems, while black shales of Permian age point toward quieter, oxygen-poor marine conditions. Driving through this valley, every bend in the road peels back another layer of the Earth's ancient past, with the mountains quietly unfolding a story written in stone.



Figure 2. (a) Panoramic view of Triassic successions along the zig-zag unmetalled road beside the Kio Gad valley; (b) road leading toward the classical Jurassic section at Laptal; (c–d) deeply incised canyon exposing Ordovician–Silurian strata along the Girthi Ganga valley; (e) BRO milestone and board describing Girthidobla as the place “where sun does not meet the earth”; and (f) BRO signboard referring to the valley as the “Grand Canyon of India” (images c–f courtesy: Devbhoomi Rakshak).



TROPICAL SEAS OF THE TRIASSIC

Farther along the route appear striking chocolate-coloured carbonate build-ups and limestone cliffs belonging to the Triassic succession that began around some 250 million years ago. These rocks formed after the Earth's greatest mass extinction at the end of the Permian, when nearly 90 percent of marine life disappeared. Yet the seas recovered. Reef systems flourished once again in the tropical waters of the Tethys Ocean. The famous Kalapani Limestone exposures preserve evidence of warm carbonate platforms teeming with marine life nearly 240 million years ago. The surrounding Kioto peaks present breath-taking views of folded and twisted rock layers that appear almost frozen in motion, as though the mountains themselves were dancing. Fossil-rich limestones and carbonate build-ups testify to thriving reef ecosystems that once flourished beneath warm blue seas. Standing amidst these barren Himalayan cliffs, it becomes difficult to imagine that corals and shell-bearing organisms once lived here in tropical marine waters.

LAPTAL: THE JURASSIC WORLD OF THE HIMALAYA

Descending along the Kioto River tributary toward Laptal after Rawlibagar top, we enter one of the classical Jurassic sections of the Himalaya that takes us back to the bottom of a deep ocean, some 170 million years ago. Famously known among the geologists, the Spiti Formation, appears as thick successions of dark, fossil-rich marine shale deposited in relatively deeper offshore environments. These rocks are renowned for their ammonites, a squid-like marine animals whose beautifully coiled shells now serve as nature's time stamps, helping geologists determine the age of rocks. This was the age of dinosaurs on land, but in the Tethyan Ocean, ammonites ruled the seas. The black shales, fine laminations, and marine fossils indicate calm oceanic conditions where fine sediments accumulated slowly on the sea floor over millions of years. Even today, the landscape around Laptal possesses an austere beauty having barren grey hills,

icy winds, turquoise lakes, and deep silence broken only by streams and falling stones.

THE SLOW DEATH OF THE TETHYS OCEAN

Above the Jurassic rocks appear greenish glauconitic sandstones and shales of the Cretaceous Period, a time about 145–66 million years ago, when dinosaurs still ruled the land and the Tethys Ocean had begun its slow retreat. The green mineral glauconite indicates slow sedimentation in shallow seas, while the rocks record changing sea levels as the Indian continent drifted steadily towards Eurasia. Higher up, striking red shales, cherts, and deep-sea sediments containing microscopic fossils, such as radiolarians and foraminifera. These fossils served as the tiny clues that helped geologists reconstruct the vanished oceans, revealing an increasingly unstable marine world. Near Balcha Dhura Pass, volcanic rocks preserve evidence of submarine eruptions, signalling the final stages in the closure of the Tethys Ocean. Then came the birth of the Himalaya. As India collided with Eurasia, the ocean floor was compressed, folded, uplifted, and thrust thousands of metres into the sky. Marine limestones that once formed beneath warm tropical seas now crown Himalayan peaks, while isolated exotic limestone blocks, perched atop dark volcanic rocks like crowns, stand as the last surviving fragments of the vanished Tethys Ocean and today mark the borderlands between India and Tibet.

A LANDSCAPE WHERE TIME REMAINS VISIBLE

Today the valleys of Niti, Malari, Sumna, Kioto and Sanchamalla appear remote and sparsely inhabited. Military roads, glacial rivers, high-altitude meadows, and Indo-Tibetan cultural influences define the modern landscape. Yet beneath every mountain slope lies a nearly continuous archive of the vast Earth history. The irony is profound: rocks preserving evidence of the Earth's earliest marine ecosystems now stand among the youngest mountains on the planet. Few journeys anywhere in the world allow travellers



Figure 3. (a) Malari village situated beside the Kunti Nala; (b) Sumna area showing the Garhwal–Kumaon boundary and the confluence of Yong Gad and Kio Gad tributaries of the Girthi Ganga (images a–b courtesy: Devbhoomi Rakshak); (c) Niti village along the Dhauliganga valley near the South Tibetan Detachment System (STDS); and (d) an ammonite fossil recovered from the Jurassic black shales of the Laptal area.

to move so seamlessly from Precambrian tidal flats to Cambrian ecosystems, Ordovician coastlines, Jurassic seas, Cretaceous shelves, and finally the violent birth of the Himalaya. The Malla Johar Supergroup is,

therefore, far more than a geological unit. It is one of India's greatest natural history museums, without walls. And every bend in its Himalayan roads reveals another chapter of the Earth's extraordinary story.

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Unveiling the impact of Deccan volcanism on India's flora in the age of dinosaurs

Palynologist and palaeobotanist **Dr. Shreya Mishra**
in conversation with **Dr. Nimish Kapoor**

THE late Maastrichtian period, a pivotal moment in Earth's history, witnessed significant ecological shifts, particularly in the Indian subcontinent, where volcanic eruptions from the Deccan Traps coincided with major climatic and geographical changes. How did these events shape the flora of the Indian Plate? To answer this, **Dr Nimish Kapoor** spoke with **Dr Shreya Mishra**, a leading palaeobotanist and expert on Deccan Volcanism's impact on ancient floral biota. Dr Mishra takes us through her groundbreaking research on floral turnover during the Maastrichtian, shedding light on how volcanic eruptions, climate shifts, and plate tectonics interplayed to influence the evolution of India's ancient plant life.

The Maastrichtian is the final stage of the Cretaceous period in the geologic time scale, lasting from approximately 72 to 66 million years ago. It is named after the city of Maastricht in the Netherlands, where rocks from this time period were first studied.

In this exclusive interview, Dr Mishra discusses her team's comprehensive study of the Lameta and intertrappean deposits, which provide crucial insights into the flora's response to the cataclysmic events of the late Cretaceous.

The Late Cretaceous, the final part of the Cretaceous period, spanned from about 100 million to 66 million years ago. This was the last phase of the Mesozoic Era, famously known as the "Age of Dinosaurs." The period ended with the Cretaceous-Paleogene (K-Pg) mass extinction event, which was

caused by a combination of factors, including massive volcanic eruptions (like the Deccan Volcanism) and an asteroid impact.

Through examining the balance between volcanic activity, climate shifts, and biotic migration, Dr Mishra's research uncovers patterns of floral succession that challenge previous assumptions about the impact of Deccan Volcanism. Despite widespread destruction, certain plant species thrived, while others adapted to the dramatically altered environment. Dr Mishra offers fresh perspectives on how these ancient events shaped the biodiversity we see today.

Here are the excerpts from the interview.

▪ **Can you explain what Deccan Volcanism is and how it impacted the Indian subcontinent during the late Cretaceous period?**

Imagine a time when India was not just home to dinosaurs, but also the site of one of the largest volcanic outbursts the Earth has ever seen.

About 66 million years ago, towards the very end of the dinosaur age, a series of gigantic volcanoes erupted in what is today central and western India. This event is known as Deccan Volcanism. Instead of a single explosive eruption, it involved lava pouring out again and again, spreading like thick molten rivers over vast areas. Over a relatively short geological time (a few tens of thousands of years), these eruptions covered the land with more than one

million cubic kilometres of lava—enough to bury the entire Indian subcontinent under a mountain of rock.

Geologists call such massive volcanic events Large Igneous Provinces (LIPs). Simply put, these are periods when the Earth's interior leaks enormous amounts of molten rock onto the surface, reshaping landscapes on a continental scale.

forms suddenly disappeared.

But lava was only part of the problem. Along with molten rock, the volcanoes released huge amounts of gases into the atmosphere: Sulfur dioxide (SO_2), which can block sunlight and cause short-term cooling and acid rain; Carbon dioxide (CO_2), a greenhouse gas that leads to long-term global warming and Chlorine (Cl), which can damage the ozone layer.



These eruptions happened during a critical window of time known as the Maastrichtian–Danian interval, which marks the transition from the Age of Dinosaurs (Cretaceous Period) to the early Age of Mammals (Palaeogene Period). This timing overlaps closely with the famous Cretaceous–Paleogene (K–Pg) boundary, when dinosaurs and many other life

Together, these gases disturbed Earth's climate, first causing rapid cooling and then warming, upsetting rainfall patterns, oceans, forests, and food chains. Plants struggled, ecosystems weakened, and animals that depended on them faced severe stress. Because of its sheer scale and perfect timing, Deccan Volcanism is now considered one of the major contributors to



the mass extinction at the K–Pg boundary—an event that wiped out dinosaurs and cleared the stage for the rise of mammals, eventually shaping the world we live in today.

Global and Regional Impact of Deccan Volcanism (brief, clear, and complete) are explained here:

Global impact: The Deccan volcanic eruptions released enormous quantities of gases such as carbon dioxide (CO₂), sulfur dioxide (SO₂), and methane into the atmosphere. CO₂ and methane acted as greenhouse gases, causing rapid global warming, while SO₂ formed sulfate aerosols that reflected sunlight and led to short-term global cooling. These repeated swings between warming and cooling made Earth's climate highly unstable on a planetary scale. Such severe environmental stress contributed directly or indirectly to a mass extinction that eliminated nearly 75% of Earth's species, including all non-avian dinosaurs and marine organisms like ammonoids, along with major turnovers in plant, mammal, and reptile communities—marking one of the greatest biological crises in Earth's history.

Regional impact in India: On the Indian subcontinent, Deccan Volcanism was a transformative geological and ecological event during the Late Cretaceous. Lava flows spread across central, western, and southern India, forming the Deccan Traps, which today cover about 500,000 square kilometres, with lava piles exceeding 2 kilometres in thickness in parts of western India. The intense eruptions and gas emissions likely triggered widespread wildfires, acid rain, and extreme climatic disturbances, causing large-scale destruction of regional ecosystems. However, over longer timescales, the newly formed volcanic landscapes also created fresh habitats and nutrient-rich surfaces, enabling ecological recovery and evolutionary diversification of surviving plant and animal lineages in post-volcanic India.

- **The Deccan Traps are famous for their volcanic eruptions. How do you think**

these eruptions affected the environment and plant life during the Maastrichtian? (The Maastrichtian is the final stage of the Cretaceous period in the geologic time scale, lasting from approximately 72 to 66 million years ago. It is named after the city of Maastricht in the Netherlands, where rocks from this time period were first studied).

There is unequivocal evidence supporting the existence, scale, and intensity of the Deccan Volcanism. However, its ecological impact varied regionally and across biological groups. For terrestrial plants, the effects were largely localized and short-lived rather than global or permanent. The eruptions occurred in pulses—brief, intense phases of volcanic activity followed by longer dormant periods. Active phases caused localized destruction of vegetation through wildfires, lava flows, and gas emissions. However, during quiescent phases, rapid floral recovery occurred, aided by resilient seed and spore banks and immigration from unaffected nearby refugia (legacy flora). The warm (~26 °C) and humid (~2270 mm/year) tropical climate across much of the Indian Plate provided ideal conditions for regrowth, facilitating swift recolonization and even adaptive diversification. Thus, while Deccan Volcanism did cause episodic ecological disruptions, it did not lead to long-term floral collapse during the Late Maastrichtian. However, its cumulative impact across the Cretaceous–Paleogene (K–Pg) boundary may have been more severe, potentially exacerbated by concurrent global stressors such as the Chicxulub impact.

- **How did the volcanic activity specifically influence the flora of the Indian Plate during the late Maastrichtian?**

Our study reconstructs three phases of floral response related to episodic Deccan Volcanism in the Indian subcontinent during the late Maastrichtian

Stage I: During the active volcanic phases, extensive lava outpourings and associated tectonic activity drastically altered the landscape,



leading to the destruction of existing vegetation and widespread ecological disruption. However, the formation of shallow volcano-tectonic depressions, which accumulated rainwater to form ephemeral lakes, created localized niches for early successional plant communities. The pioneer flora consisted primarily of stress-tolerant, opportunistic taxa such as creeping swamp-dwelling pteridophytes and hardy herbs, including early representatives of the Fabaceae family. These taxa were adapted to unstable substrates and fluctuating hydrological regimes.

Stage II: Following the cessation of volcanic activity, the environment stabilized under favorable climatic conditions—characterized by warm mean annual temperatures ($\sim 26^{\circ}\text{C}$) and high precipitation (~ 2270 mm/year). These tropical conditions supported extensive ecological recovery and facilitated a resurgence in floral diversity. This phase is marked by the establishment of a highly diversified megathermal angiosperm-dominated flora, comprising over 70 plant taxa representing 31 families. Dominant families included Arecaceae (palms), Sapotaceae, Fabaceae, Euphorbiaceae, and Rhizophoraceae, reflecting a shift toward mature, structurally complex tropical forest ecosystems.

Stage III: A renewed phase of volcanic activity led to another episode of widespread forest destruction, likely through lava inundation, wildfires, and climatic stress. Despite this setback, the floral communities exhibited notable resilience. Once the volcanic activity subsided and climatic conditions stabilized, plant life rapidly rebounded, drawing once again from legacy seed and spore banks and demonstrating ecological adaptability.

- **From your research, it seems that there were multiple phases of volcanic activity. Could you briefly explain how these phases affected plant life at different stages?**

Scientists believe that the Deccan volcanic eruptions did not happen all at once. Instead, they occurred in three main phases, spread over

time. These phases describe episodes of lava eruption, not direct stages of plant response.

- Phase I took place during the late part of the dinosaur age and involved only about 6% of the total lava. Compared to later eruptions, this phase was relatively less destructive.
- Phase II was the most severe and dramatic. It produced nearly 80% of all the lava and happened around the Cretaceous–Palaeogene boundary, the same time when dinosaurs went extinct. This phase likely caused the maximum environmental stress.
- Phase III occurred after the dinosaur extinction, in the early age of mammals, and contributed the remaining 14% of the lava flows.

Understanding how plant life responded to these phases is extremely challenging. This is because scientists often lack precise age dates, the sediment layers were formed at different times in different places, and plant remains are not preserved equally everywhere.

What we do know is that the recovery of plants after volcanic eruptions depended mainly on two factors. First, there needed to be a quiet gap between eruptions, giving plants time to regrow. Second, distance mattered—areas farther away from the main eruption centres suffered less damage.

Interestingly, regions at the outer edges of the Deccan volcanic area show richer and more diverse plant remains than areas closer to the likely eruption centre near the Narmada–Tapti region, which faced harsher conditions. However, scientists stress that this idea is still tentative and needs further evidence before firm conclusions can be drawn.

- **Your study suggests that the flora experienced a “resilient recovery” during volcanic dormant phases. Can you describe this recovery process and how it contrasts with the initial destruction caused by volcanic eruptions?**



All lifeforms respond uniquely to climatic perturbations, with some species perishing while others adapt and evolve. These divergent outcomes are driven by differences in morphology, physiology, and ecological interactions with their environment. The Cretaceous–Paleogene (K–Pg) mass extinction illustrates this differential survival well: while dinosaurs vanished, mammals diversified. Similarly, in the plant kingdom, contrasting responses are evident between gymnosperms and angiosperms.

Prior to the Deccan Volcanism, the Indian subcontinent supported seasonally dynamic floras dominated by a mixture of gymnosperms and angiosperms. Gymnosperms, being slow-growing with less efficient reproductive strategies, were more vulnerable to environmental stress. In contrast, angiosperms exhibited advanced physiological traits—such as rapid growth, efficient water transport, and effective seed dispersal—that conferred greater ecological plasticity. India's paleolatitudinal position during the late Maastrichtian favoured a seasonally dry tropical climate, which influenced the composition and structure of plant communities. However, the tectonic collision of the Indian Plate with the Réunion hotspot triggered the onset of Deccan Volcanism and rapid northward drift of the Indian Plate. This dual tectono-volcanic scenario brought significant environmental upheaval. The episodic lava outpourings and widespread forest fires destroyed large tracts of pre-existing vegetation. Concurrently, the plate's latitudinal shift introduced less seasonal, perennially wet tropical conditions—more conducive to angiosperm proliferation. The post-volcanic landscape, although barren, was rich in volcanic soils (e.g., basalt-derived regolith), providing fertile ground for ecological succession. Primarily, these fertile lands were colonized by the *Anemia*, a polyploid pteridophyte which can thrive well within the stressed environments. Later on, Angiosperms, with their rapid growth rates and adaptive reproductive strategies, quickly colonized various habitats within lowland shallow marine embayment settings. .

The tropical conditions—characterized by mean annual temperatures around 26 °C and annual precipitation exceeding 2270 mm—further promoted development of hyperdiverse flora within emergent tropical forest ecosystems.

Despite the large-scale ecological disruption caused by Deccan Volcanism, the resilience of flora was remarkable. Vegetation recovery was facilitated by seed and spore banks from adjacent undisturbed refugia, which, coupled with favorable climatic conditions, enabled swift recolonization. Thus, while gymnosperm-dominated communities suffered long-term decline, angiosperms emerged as the dominant floristic element in the post-volcanic ecosystems, exemplifying a profound biotic turnover driven by climate, tectonic, volcanism, and evolutionary adaptability.

- **Could you explain what you mean by the "tropical flora's resilience" in the context of the Deccan Volcanism?**

The tropical rainforests exhibit the highest net primary productivity (NPP) among all terrestrial ecosystems. This exceptional productivity is attributed to several interrelated ecological and physiological factors. Tropical rainforests harbor the greatest biodiversity on Earth, functioning as extensive gene pools for a wide range of plant and animal species. Structurally, they are vertically stratified into multiple canopy layers, which optimize light interception and photosynthetic efficiency. In addition, tropical ecosystems benefit from rapid nutrient cycling facilitated by warm temperatures and abundant microbial activity, ensuring continuous nutrient availability. Year-round access to sunlight and moisture further supports uninterrupted photosynthesis and biomass accumulation. These combined factors contribute to the high ecological stability and resilience of tropical rainforests, especially when compared to more seasonally constrained ecosystems like temperate or deciduous forests.

A notable study by Lloyd and Farquhar (2008) on the Amazon rainforest demonstrated that

DO YOU KNOW?

Deccan Volcanism refers to the large-scale volcanic activity associated with the formation of the Deccan Traps, a massive volcanic province in India. The Deccan Volcanism represents the eruption of vast quantities of lava over a period of several million years, primarily during the late Cretaceous period, around 66 million years ago. This volcanic activity is believed to have had significant effects on the environment and global climate, contributing to the ecological upheaval at the end of the Cretaceous, which coincides with the mass extinction event, including the demise of the dinosaurs.

Deccan Traps refers to the large, extensive formation of flood basalts located in western and central India, which were created by the eruption of immense volumes of lava. The term "Traps" comes from the Scandinavian word for stairs, referring to the step-like hills that are characteristic of these lava plateaus. The Deccan Traps cover an area of about 500,000 square kilometers and represent one of the largest volcanic provinces on Earth. The lava flows that formed the Deccan Traps are thought to have contributed significantly to atmospheric changes, including climate cooling and global warming due to the release of gases like CO₂ and SO₂, which likely played a role in the end-Cretaceous extinction event.

Late Cretaceous Flora refers to the plant life that existed during the Late Cretaceous period, which lasted from approximately 100 to 66 million years ago, just before the Cretaceous-Paleogene (K-Pg) extinction event. During this time, the Earth's climate was generally warmer than today, and the plant life was diverse and varied, with significant evolutionary developments in both gymnosperms (like conifers) and angiosperms (flowering plants).

The Late Cretaceous flora is notable for the rise and diversification of **angiosperms**, or flowering plants, which began to dominate many ecosystems during this period. This period also saw the continued presence of **gymnosperms**, including conifers, cycads, and ginkgos. Ferns and other pteridophytes were also widespread.

In the late Cretaceous, forests were abundant, and plant life existed in a wide variety of habitats, from dense tropical forests to more temperate regions. The floral diversity during this period laid the foundation for modern ecosystems, and the appearance of flowering plants marked a major shift in plant evolution, influencing the structure of terrestrial ecosystems and contributing to the eventual rise of mammals after the mass extinction event at the end of the Cretaceous.

The Intertropical Convergence Zone (ITCZ), also known as the **doldrums**, is a region near the equator where the trade winds from both the Northern and Southern Hemispheres meet. It is characterized by low atmospheric pressure and is a belt of converging winds that creates significant weather patterns. The ITCZ is a zone of intense sunlight and rising warm air, which often leads to heavy rainfall and thunderstorms.

The position of the ITCZ shifts seasonally, moving slightly north or south of the equator depending on the time of year. This zone plays a crucial role in global weather patterns, particularly in tropical regions, by influencing the distribution of rainfall and the formation of tropical storms.



In the context of the Deccan Volcanism, the ITCZ is significant because the shifting of the Indian Plate through this zone would have influenced the climate and ecosystems, particularly by providing a warm, humid environment that was conducive to the growth of tropical plants, especially during phases of volcanic quiescence.

The Indian Plate is a tectonic plate that covers the majority of the Indian subcontinent, including parts of the surrounding oceans. It is one of the Earth's major tectonic plates and plays a key role in the geological history and evolution of the region. The Indian Plate was originally part of the ancient supercontinent Gondwana and began to break away from it around 100 million years ago during the Late Cretaceous period.

As it moved northward, the Indian Plate collided with the Eurasian Plate around 50 million years ago, leading to the uplift of the Himalayas and the Tibetan Plateau. This collision is still ongoing today, causing frequent seismic activity in the region. The Indian Plate also includes the Indian Ocean floor, and the movement of the plate has influenced the geography, climate, and biodiversity of the Indian subcontinent.

In the context of the Deccan Volcanism, the shifting of the Indian Plate had a significant impact on the climate and ecosystems of the region. As the plate moved, it also shifted within the Intertropical Convergence Zone (ITCZ), contributing to the development of specific climatic conditions, such as warm and humid environments that facilitated the growth of tropical plants during the late Maastrichtian period.

The Cretaceous–Paleogene (K–Pg) mass extinction event was a major global extinction event that occurred about 66 million years ago, marking the boundary between the Cretaceous and Paleogene periods. This event is one of the most significant mass extinctions in Earth's history, wiping out approximately 75% of all species, including many terrestrial plants and animals.

The most famous casualties of this extinction event were the non-avian dinosaurs, which became extinct. However, it also affected marine life, including ammonites, marine reptiles, and many species of plants, insects, and other animals. The K–Pg event is notable not only for the extinction of so many species but also for its lasting effects on the Earth's ecosystems, setting the stage for the rise of mammals and eventually the evolution of humans.

The primary cause of the K–Pg mass extinction is widely believed to be a massive asteroid impact near the present-day Yucatán Peninsula in Mexico, creating the Chicxulub crater. This impact would have released enormous amounts of energy, triggering massive wildfires, tsunamis, and climate changes, including a "nuclear winter" effect where dust and debris blocked out sunlight, leading to a dramatic drop in global temperatures. This would have disrupted ecosystems and food chains on a massive scale.

In addition to the asteroid impact, other factors such as volcanic activity (like the Deccan Traps in India) and climatic shifts may have also contributed to the environmental changes that caused the mass extinction. These volcanic eruptions released large quantities of greenhouse gases like carbon dioxide, further affecting the climate and contributing to the upheaval.

The K–Pg mass extinction marks the end of the Mesozoic Era (the **Age of Dinosaurs**) and the beginning of the Cenozoic Era, which saw the rise of mammals and the eventual dominance of humans.



elevated atmospheric CO₂ levels and warmer temperatures—conditions analogous to those during the Deccan Volcanism—can enhance tropical plant growth. During the Deccan volcanic episodes, significant quantities of greenhouse gases, including CO₂, were released into the atmosphere, leading to a transient warm and humid climate. Rather than uniformly suppressing vegetation, these altered environmental conditions may have actually promoted floral proliferation in certain regions. Specifically, tropical plant communities likely responded positively to the elevated CO₂ and temperature regime, facilitating increased photosynthetic activity, rapid growth, and diversification. Therefore, rather than resulting solely in ecological collapse, the aftermath of Deccan Volcanism also created favourable conditions for the expansion and evolutionary advancement of tropical angiosperm-dominated floras.

- **How did the shifting of the Indian Plate within the Intertropical Convergence Zone (ITCZ) influence the plant life during the late Maastrichtian?**

The northward drift of the Indian Plate into the Intertropical Convergence Zone (ITCZ) during the Late Cretaceous induced two key changes in its flora. Firstly, the plate's new paleolatitudinal position brought seasonally wet tropical conditions that favored the dominance and diversification of angiosperms, well-adapted to warm, humid climates. Secondly, the formation of the Kohistan–Ladakh arc acted as a biogeographic corridor, enabling floristic exchange between India and the equatorial tropical regions of Africa and South America, which shared similar climates and flora during the Maastrichtian. Together, these factors promoted increased tropical angiosperm diversity on the Indian Plate, reflecting the combined influence of tectonics, climate, and biotic dispersal.

- **How did the warm, humid climate that followed the volcanic eruptions help certain plant species, particularly angiosperms,**

thrive and diversify?

Warm and humid conditions on the Indian Plate during the Late Maastrichtian resulted from its northward drift into lower latitudes and greenhouse gas emissions from Deccan Volcanism, which raised global temperatures. This shift transformed a seasonally dry pre-Deccan climate, favoring gymnosperms, into a seasonally wet tropical regime during the syn-Deccan phase, promoting a mixed gymnosperm–angiosperm flora. Intense volcanism destroyed much of the existing vegetation, but the new warm, humid conditions favored angiosperms, whose rapid growth and advanced ecology allowed them to outcompete gymnosperms across most terrestrial ecosystems.

- **What differences did you observe between the plant life in the pre-Deccan (Lameta deposits) and syn-Deccan (intertrappean deposits) phases? (The pre-Deccan and syn-Deccan phases refer to distinct periods in the late Cretaceous, particularly around the time of the Deccan Volcanism in India, which occurred during the Maastrichtian stage. These phases are distinguished based on their relationship to the volcanic activity associated with the Deccan Traps, one of the largest volcanic provinces on Earth.)**

The pre-Deccan flora (Lameta Formation) was intermixed Gymnosperm-angiosperm dominated, ecologically less diverse floral community encompassing tropical (often palms), subtropical, moist deciduous and arid forms which existed within seasonally dry climates. While, the syn-Deccan flora was angiosperm dominated with very high diversity that prevailed within seasonally wet tropical climates.

- **How significant was the transition from gymnosperm-dominated flora in the pre-Deccan phase to the angiosperm-dominated flora in the syn-Deccan phase?**

The Deccan Volcanism actually set the stage for today's world. The gymnosperms are



non-flowering plants while angiosperms are flowering plants. So, the dominance of angiosperms brought all the scenic beauty in our surrounding by adding colourful flowers along with unprecedented physiological and ecological diversity. Angiosperms are responsible for the vibrant array of flowers, fruits, and varied leaf morphologies that characterize today's landscapes. Not only this, angiosperms are the foundation of global food security, providing the majority of our staple crops, including cereals, grains, vegetables, and fruits, many of which are prized for their flavors and nutritional value. The diversification of angiosperm flora also fostered the co-evolution of a vast array of animal life, particularly insects, which depend on flowering plants for food, habitat, and pollination. Ecosystems like the angiosperm-rich Amazon rainforest, known as the "lungs of the Earth," highlight the lasting ecological impact of this floral transition driven by Deccan Volcanism.

- **Your research discusses the biogeographic connections between the Indian Plate and other continents. How did the flora of India interact with flora from South America and Africa during the Maastrichtian?**

During the Maastrichtian, the Indian and African plates were linked by the Kohistan–Ladakh island arc, while South America and Africa remained connected via the Rio Grande Rise–Walvis Ridge (RGR–WR) seamount chain. Beyond these paleogeographic connections, all three continents shared similar warm and humid climatic conditions, situated within an equatorial humid belt extending beyond 30°S latitude. This climatic and geographic continuity facilitated the establishment of biotic corridors during the Late Maastrichtian, enabling extensive floristic migration onto the Indian Plate from Africa and South America. Consistent with this, the Maastrichtian flora from the Yeotmal region in India exhibits significant floristic nestedness, with approximately 61.2% similarity to contemporaneous South American and African taxa, reflecting strong Gondwanan biogeographic affinities.

- **In your study, you utilized palynology and palynofacies analysis to understand the impact of volcanism on the flora. Could you explain what these terms mean and how they helped you uncover details about the ancient plant life in India?**

Palynology, derived from the Greek word meaning "study of dust," refers to the analysis of microscopic, acid-resistant organic particles such as pollen, spores, and certain planktonic organisms (e.g., dinoflagellates and acritarchs) in both modern and fossil forms. Paleopalynology, specifically, focuses on fossil palynomorphs. These microfossils are often well-preserved in the geological record due to the presence of sporopollenin, an exceptionally resilient biopolymer in their walls.

Palynomorphs, typically ranging in size from 1 to 500 micrometers, exhibit distinct stratigraphic distributions, making them powerful tools for biostratigraphy. When their Nearest Living Relatives (NLRs) can be identified, they also serve as proxies for reconstructing paleovegetation, paleoclimate, and paleoecology, through the principle of physiological uniformitarianism—the assumption that fossil taxa had similar ecological requirements as their modern counterparts. Moreover, the spatial and temporal patterns of palynomorphs enable reconstructions of paleobiogeographic distributions across geological time. In the present study, palynomorph recovery from the studied core sequence was excellent. The occurrence of the stratigraphically diagnostic taxon *Aquilapollenites* confirms a late Maastrichtian age. The exceptional preservation of morphological features further enabled robust identification of NLRs, facilitating detailed paleoenvironmental reconstructions.

Complementing the palynological data, palynofacies analysis—the study of sedimentary organic matter residues—provided key insights into depositional settings. By evaluating the composition and preservation of amorphous organic matter, phytoclasts, and palynomorphs, we inferred conditions such as marine versus



terrestrial influence, oxic-anoxic states, proximity to sediment source, and hydrodynamic energy of the depositional environment. This multiproxy approach significantly strengthens interpretations of the Late Maastrichtian ecosystem dynamics on the Indian Plate.

- **How do the findings of your study connect to the broader context of the Cretaceous-Paleogene (K-Pg) mass extinction event, particularly regarding the impact on faunal species such as dinosaurs?**

Deccan Volcanism occurred on the Indian Plate, so India serves as the ideal archetype to test hypothesis relating to the Cretaceous-Paleogene (K-Pg) mass extinction event. Late Maastrichtian Deccan associated deposits can be divided into two: pre-Deccan Deposits and syn Deccan deposits. The dinosaur's fossil records including bones, eggs, nesting sites etc. have been abundantly reported from the pre-Deccan Deposits (Lameta Formation), while there only few fragmentary records of dinosaur fossils with total absence of nesting sites in the syn-Deccan Deposits (intertrappean deposits), may be transported. While, there are no dinosaur fossil record reported from the Danian aged Deccan deposits.

- **Was the Deccan Volcanism the primary cause of the mass extinction, or did it interact with other factors like climate change?**

Deccan Volcanism and Chicxulub Impact are individually or cumulatively regarded as the triggering agent for Cretaceous-Paleogene (K-Pg) mass extinction event. Chicxulub Impact was the sudden mega-catastrophic event while Deccan Volcanism imposed gradual climatic disturbance for ~1 Ma in an episodic manner. However, the maximum magmatic outpouring and release of harmful gases associated with the Deccan Volcanism occurred across the Cretaceous-Paleogene (K-Pg) boundary. With the discovery of large asteroid crater in the Gulf of Mexico and thick and expansive basalt deposits across central, western and southern India, both events potential stand a chance

to be regarded as triggering agent for the Cretaceous-Paleogene (K-Pg) mass extinction event. However, the debate still continues even after decades of research. Besides, identifying the main triggering agent, the impact of these two events in different regions and life forms is also disputed.

- **Your research suggests that the tropical flora of the Indian Plate was resilient to volcanic disruption. What lessons can we draw from this when considering the impacts of current and future climate change on global ecosystems?**

The rapid tropical floral recovery during the late Maastrichtian reveals the innate stability within these ecosystems from the external climatic changes. The flora inspite of declining diversified and dominated the terrestrial landscape. This raises hope that in the times of increasing greenhouse gases, tropical rainforests may respond positively and recover rapidly against any climatic calamity. However, we should also consider that every biotic life form bears a threshold for the changing climatic conditions and any change beyond their threshold can bring irreversible change.

- **Looking ahead, what other research questions would you like to explore related to Deccan Volcanism and its impact on ancient ecosystems?**

The Deccan Volcanism represents one of the most significant environmental upheavals of the Phanerozoic, primarily characterized by extensive basaltic lava flows emplaced during magnetochron C29R. While the sheer scale of magmatism is well documented, several critical aspects of this geological event remain poorly understood. These include the precise timing and duration of eruptive phases, the magnitude and mechanisms of biotic stress, and whether Deccan volcanism served as the sole, primary, or synergistic trigger—in conjunction with the Chicxulub impact—for the end-Cretaceous mass extinction. As the geographical center of this massive igneous province, the Indian Plate

serves as a natural laboratory for investigating these unresolved questions. However, progress is hindered by several limitations: the disruption of sedimentation due to episodic volcanism, the scarcity of continuous and radiometrically dated stratigraphic sequences, and the absence of datable minerals in many terrestrial deposits of the Deccan Volcanic Province (DVP).

To date, research—including our current analysis—has largely focused on the late Maastrichtian phase of Deccan volcanism. Moving forward, I intend to extend this investigation to the Cretaceous–Paleogene (K–Pg) boundary, aiming to evaluate the volcanic impact on biotic turnover during this critical interval of Earth history. This future work may help disentangle the relative contributions of Deccan volcanism and the Chicxulub impact in driving one of the most profound mass extinctions in the fossil record.

- **What is the most important takeaway from your study for students and the general public interested in understanding the intersection of geology, climate, and biology during critical periods in Earth's history?**

Palynology serves as the foundational tool underpinning the hypotheses and interpretations in this study. Originally developed to meet the biostratigraphic needs of the fossil fuel industry, its prominence has waned as fossil fuel resources decline and funding agencies increasingly favor high-cost, multiproxy approaches. While palynology may seem like a basic science without immediate societal applications, it has evolved into a versatile proxy integral to diverse scientific inquiries. For instance, when

combined with phylogenetics, palynology elucidates the evolutionary history of plant families; integrated with entomology, it reveals ancient plant-insect interactions; and coupled with coexistence analysis, it enables quantitative reconstructions of paleoclimate.

Despite its scientific significance, palynology faces a funding crisis and diminishing practitioner base, making it challenging to secure support or even qualified reviewers for palynological research. This critical discipline risks obsolescence unless urgent efforts are made to recognize its value and ensure its continuation. Supporting palynology is essential for advancing our understanding of Earth's past and preserving a vital tool in paleoscience.

Thank you, Dr. Shreya Mishra for sharing the insights into this remarkable aspect of Earth's history. Your work has truly enhanced our understanding of how volcanic activity shaped the world's biodiversity.

For more details on the impact of the Deccan Volcanism and the Maastrichtian period on India's ancient flora, please refer to Dr Shreya Mishra's article, where she discusses the palynological and palaeoclimatic findings in depth. Her research offers a detailed analysis of the floral changes during the late Cretaceous, shedding light on how volcanic eruptions and climate shifts affected plant life on the Indian Plate.

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About Interviewer



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Resonance and Healing: When Music Dialogues with Science, Communication, and Health

Nimish Kapoor, Adrita Choudhuri and Mayank Shekhar

MUSIC is a universal language that reaches beyond words, touching memory, emotion, and the body parts in ways that science has only begun to map and harness. Over recent decades, an interdisciplinary field spanning neuroscience, psychology, medicine, physics and the humanities has converged on a simple but powerful insight: music is not merely aesthetic ornamentation. It is a medium of communication, a regulator of physiological states, and a therapeutic tool with measurable effects on brain and behaviour. Exploring music's capacities, thus, addresses multiple pressing needs: better mental-health care, non-pharmacological interventions for neurological and chronic conditions, and more

inclusive, emotionally resonant ways to communicate science to the public.

At the neural level, music engages widespread brain networks. Listening and performing music recruit auditory cortices, motor systems, limbic regions tied to emotion, and prefrontal areas involved in attention and expectation. Rhythmic structure aligns with motor circuits and can entrain heart rate and breathing; melodic contours interact with memory circuits, sometimes unlocking autobiographical recollections. Neuroimaging and electrophysiology show that music can modulate neurotransmitter systems involved in reward and stress regulation, such as dopamine and cortisol pathways. These biological

अनुनाद और उपचार
कार्यशाला:
संचार एवं चिकित्सा के रूप में संगीत के
वैज्ञानिक दृष्टिकोण

**Workshop on
Resonance and Healing:**
Scientific Perspectives on
Music as Communication and Therapy

27 मई 2026

बीरबल साहनी पुराविज्ञान संस्थान, लखनऊ



effects underlie observable outcomes: improved mood, reduced anxiety, enhanced cognitive performance on tasks requiring attention and working memory, and even reduced perception of pain.

Beyond individual physiology, music is fundamentally social. Group singing and rhythmic movement synchronize participants' bodies and brains, increasing feelings of social connectedness and trust. This social bonding function has implications for public health, loneliness and social isolation are major risk factors for mental and physical illness, and community music programs can be preventive, restoring social networks and offering collective meaning. Because music is culturally embedded, interventions that use music can be tailored to cultural preferences, increasing acceptability and adherence in diverse populations.

Clinical applications of music are broad and increasingly evidence-based. Music therapy, delivered by trained practitioners, uses music within

a therapeutic relationship to achieve individualized goals, emotional expression, rehabilitation of motor skills, communication for non-verbal patients, and more. In neurology, rhythmic auditory stimulation has been shown to improve gait and timing in Parkinson's disease and post-stroke motor rehabilitation. In psychiatry, structured music interventions reduce symptoms of depression and anxiety and improve quality of life. In palliative care, music supports symptom relief and emotional processing for patients and families. Importantly, music-based approaches can complement pharmacological and psychotherapeutic treatments, offering low-risk, low-cost adjuncts that improve holistic outcomes.

Two success stories illustrate music's transformative potential. The first is the use of group singing programs for people with dementia. In multiple clinical and community studies, singing preserved emotional memory, improved mood, and reduced agitation among participants. One longitudinal



program in the UK organized weekly community choirs specifically for people with early-to-moderate dementia and their caregivers. Over months, participants showed stable or improved mood scores and reported increased social engagement; caregivers noted reductions in caregiving stress and better shared moments of recognition and emotional connection. The program's success rested on accessible repertoire, an emphasis on participation (not performance), and integration with local health services.

A second example comes from rhythm-based gait training for Parkinson's disease. Clinicians have used rhythmic auditory stimulation, metronome beats or music with a strong, regular pulse—to improve stride length and walking speed. A multicentre trial demonstrated that patients who trained with personalized rhythmic cues showed clinically meaningful improvements in gait and balance compared with conventional physiotherapy alone. Many participants also reported secondary benefits: greater confidence in mobility and reduced fear of falling, which translated into higher levels

of daily activity and improved quality of life. This intervention's power lies in entrainment: the motor system couples to external rhythm, bypassing some impaired internal timing mechanisms.

While these successes are promising, effective translation from lab to clinic and community requires careful design. One must consider dose (frequency and duration), individual differences (musical preferences, cultural background, and baseline cognitive function), and the therapeutic context (one-to-one vs group, active music-making vs passive listening). Standardization and rigorous evaluation—randomized controlled trials where feasible, alongside qualitative studies that capture lived experience—are both needed. Ethical attention to consent, cultural sensitivity, and equitable access is essential, especially when working with vulnerable populations.

These themes were central to the workshop “Resonance and Healing: Scientific Perspectives on Music as Communication and Therapy,” held at the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow, on 27 May 2026. The workshop convened



researchers, clinicians, and communicators to examine how sound, rhythm, and musical structure influence cognition, emotion, and physiology; and how those effects can be meaningfully communicated and applied. Presenters highlighted interdisciplinary research linking neural mechanisms to clinical outcomes, showcased case studies like the dementia singing program and rhythmic gait training, and discussed strategies for culturally informed public engagement. Participants emphasized that music's therapeutic promise is maximized when science, clinical care, and community practice collaborate: when evidence guides practice, and when lived experience shapes research.

In sum, music offers a bridge between data and human experience. As a subject of scientific inquiry and a vehicle for therapeutic intervention, it invites researchers to listen, not only to neural oscillations and behavioural metrics, but to the narratives,

cultures, and communal rhythms that make music deeply human. When science and music dialogue, they open pathways for healing that respect both measurable outcomes and the lived, resonant quality of human life.

SCIENCE COMMUNICATION REIMAGINED: FROM INFORMATION TO EXPERIENCE

A recurring theme throughout the workshop was the need to rethink science communication itself. Traditionally, science communication has focused on accuracy, clarity, and dissemination. However, contemporary challenges, ranging from mental health crises to misinformation, demand approaches that go beyond transmission of facts.

The workshop highlighted that effective science communication must also engage emotion, memory,



and personal experience. Scientific ideas resonate most deeply when people can feel them, not just understand them intellectually. Music, with its universal and non-verbal nature, emerges as a powerful ally in this process.

Participants discussed how music can serve as a bridge between scientific concepts and human experience, making abstract ideas tangible. Unlike text or numbers, music bypasses linguistic and educational barriers, directly engaging the brain's emotional and sensory systems. This makes it especially relevant in popular science outreach, public health communication, and community engagement.

MUSIC AND RESONANCE: THE SCIENTIFIC FOUNDATION

At its core, music is an organized system of sound waves, frequencies, and rhythms. The workshop emphasized that resonance, the synchronization between external sound vibrations and internal biological rhythms, is central to understanding music's impact on the human body.

Scientific studies in neuroscience demonstrate that listening to music activates multiple regions of the brain simultaneously, including areas responsible for emotion (limbic system), memory (hippocampus), attention (prefrontal cortex), and movement (motor cortex). This multisensory engagement explains why music can calm anxiety, elevate mood, stimulate memory, or energize the body.

The discussions underscored that music is not merely “heard”, but processed biologically, influencing heart rate, breathing patterns, hormonal secretion, and neural connectivity. Such effects provide a measurable scientific basis for music therapy as a legitimate health intervention.

INDIAN MUSICAL KNOWLEDGE AND CONTEMPORARY SCIENCE

A significant dimension of the workshop was the exploration of Indian classical music as a structured and systematic sound tradition with deep therapeutic

potential. The raga system, which organizes melodies according to specific tonal frameworks, time cycles, and emotional expressions, was discussed as an early form of experiential knowledge linking sound and human psychology.

From a scientific perspective, the association of particular ragas with specific moods and times of day aligns closely with modern understandings of circadian rhythms and neurochemical balance. While traditional knowledge articulated these effects in philosophical or aesthetic terms, contemporary research is now attempting to measure and validate them through brain imaging, physiological monitoring, and clinical studies.

The workshop emphasized that integrating such indigenous knowledge systems with modern scientific methodologies can enrich global research on music therapy and mental health, especially in culturally diverse societies like India.

TECHNICAL SESSION I: THERAPEUTIC DIMENSIONS OF MUSICAL STRUCTURE

The first technical session focused on the therapeutic potential embedded within musical structure and was delivered by Shri Kanhaiya Lal Pandey, noted musicologist, poet, and researcher, and former Additional Member, Railway Board. Widely known for his scholarly work on raga analysis and Hindi film music, Shri Pandey has devoted decades to understanding how musical grammar interacts with human emotion and cognition.

Drawing upon detailed audio-visual presentations, the session examined how melody, rhythm, tempo, scale patterns, and tonal progression interact with human emotions and bodily responses.

It was explained that slow-tempo, low-frequency, and melodically stable musical forms tend to activate the parasympathetic nervous system, promoting relaxation and stress reduction. In contrast, faster rhythmic cycles and dynamic tonal variations stimulate alertness, motivation, and emotional release.

Illustrative examples from Indian classical music and familiar Hindi film songs were used to



demonstrate how raga-based compositions subtly shape emotional states, often without the listener's conscious awareness. The session clearly established that music therapy is not about passive listening, but about purposeful engagement with carefully chosen musical forms, tailored to specific mental and emotional needs.

An important highlight of this session was the interactive exchange with participants. Through discussion and live engagement, participants were encouraged to reflect on their own emotional responses to different musical patterns. The session culminated in a participatory segment where attendees sang simple, familiar compositions collectively. This shared musical experience vividly demonstrated how group singing can foster calmness, emotional bonding, and a sense of mental peace, reinforcing the scientific principles discussed earlier.

TECHNICAL SESSION II: MUSIC AS A MEDIUM OF COMMUNICATION AND HEALING

The second technical session approached music from the perspective of communication studies and health sciences and was conducted by Dr Umesh C. Pathak, media scholar, communication educator, and researcher. Dr Pathak has worked extensively on the role of media, culture, and alternative communication forms in social well-being and education.

Through structured presentations, the session explained how music functions as a powerful non-verbal language, capable of transmitting meaning, emotion, and intent without reliance on spoken or written words.

Music was discussed as a simultaneous carrier of message, emotion, and experience. In therapeutic contexts, this enables individuals to express feelings, such as anxiety, grief, or emotional fatigue, that may be difficult to articulate verbally. From a science communication standpoint, music was positioned as a medium capable of carrying complex ideas in an intuitive and emotionally resonant form.

Scientific studies cited during the session showed how music-based interventions influence stress hormones like cortisol, enhance endorphin release, and support emotional regulation. Applications in stress management programs, mental health care, and emotional rehabilitation were discussed in detail, reinforcing music's role as a science-backed tool for healing.

This session was also highly interactive. Participants engaged in dialogue on how music could be integrated into educational spaces, workplaces, and everyday routines to support mental well-being. The experiential component, where participants joined in singing for relaxation and mindfulness, emerged as a powerful moment of collective learning, translating theory into lived experience.



MUSIC AS A THERAPY: EVIDENCE-BASED INSIGHTS

A major strength of the workshop lay in its strong grounding in **scientific evidence**. Drawing upon a wide range of national and international studies, the discussions demonstrated that music therapy has moved well beyond anecdotal claims and is now increasingly supported by rigorous empirical research. The evidence presented during the sessions clearly established music therapy as a **complementary health practice** with measurable benefits across multiple domains of physical and mental health.

Stress and Anxiety Reduction: Research evidence strongly supports the role of music in reducing stress and anxiety. A 2022 meta-analysis covering 47 studies with 2,747 participants reported a medium-to-large overall effect of music therapy on stress-related outcomes (effect size $d = 0.723$). Interestingly, the impact was found to be stronger in non-Western countries, highlighting the cultural relevance of music-based interventions. Indian studies have similarly shown that music therapy

significantly reduces depression, anxiety, and stress levels, particularly among patients diagnosed with depressive disorders. Further reinforcing these findings, a 2024 randomized controlled trial involving women undergoing brachytherapy revealed that music intervention led to a significant reduction in pain ($P < 0.001$) and also had a positive effect on depressive symptoms.

Mental Health Support: The workshop highlighted substantial evidence supporting music therapy in mental health care. A 2025 systematic review and meta-analysis of randomized controlled trials, published in *BJPsych Open*, demonstrated that music therapy was significantly more effective than control interventions in reducing depressive symptoms (SMD -0.97), improving quality of life (SMD 0.51), and enhancing sleep quality (SMD -0.61). Indian research, including studies conducted at NIMHANS and other institutions, has shown that music therapy benefits individuals with anxiety disorders, depression, and schizophrenia by improving mood regulation and social interaction. Additionally, a 2024 study published in *Nature* focusing on breast cancer patients found that music therapy significantly reduced anxiety (SMD $= -0.82$) and depression (SMD $= -0.76$), providing moderate, but compelling evidence of its mental health benefits.

Neurological Rehabilitation: Music therapy has also emerged as a promising intervention in neurological rehabilitation. A comprehensive 2017 review of controlled studies published on PubMed concluded that music-based interventions, such as music listening, singing, and instrument playing—positively influence motor performance, speech, and cognitive functions in patients with stroke, dementia, Parkinson's disease, epilepsy, and multiple sclerosis. Building on this, a 2025 systematic review in *BIO Integration* confirmed that techniques, such as Melodic Intonation Therapy (MIT) and Rhythmic Auditory Stimulation (RAS) promote neuroplasticity. These approaches were shown to significantly improve emotional regulation, cognitive function, language expression, and motor abilities in stroke patients, while also reducing depression and anxiety. In the



Indian context, an indigenous adaptation of Melodic Intonation Therapy for post-stroke non-fluent aphasia has been developed and is currently under interventional study, highlighting local innovation in this field.

Cardiovascular Health: The therapeutic impact of music on cardiovascular health was another key focus area. A landmark seven-year study published by the American College of Cardiology in 2020 reported that music therapy, when combined with standard medical treatment, reduced anxiety levels by nearly one-third and angina symptoms by one-quarter. The study also noted long-term benefits, including an 18% reduction in heart failure rates, a 23% lower incidence of subsequent heart attacks, and a 16% reduction in cardiac mortality. Supporting these findings, a 2025 meta-analysis showed that music therapy administered before and during percutaneous coronary intervention (PCI) significantly reduced post-procedural systolic blood pressure. Indian studies have also demonstrated similar benefits, with research indicating positive effects of music therapy on hypertensive elderly individuals and patients with heart-related conditions. More recently, a 2026 report by CommonSpirit Health found that just 14 minutes of supervised singing improved vascular health and lowered cardiovascular disease risk.

Pain Management: Evidence presented at the workshop further established music therapy as an effective tool in pain management. A 2025 randomized controlled trial conducted at Ramathibodi Hospital in Bangkok showed that patients receiving music therapy alongside standard analgesia experienced a significantly greater reduction in pain scores compared to the control group. Anxiety levels were also substantially reduced, particularly in cases of non-trauma-related pain. A 2023 multi-site randomized controlled trial published in the *Journal of Clinical Oncology* demonstrated that interactive music therapy in advanced cancer patients reduced chronic pain, with the effect mediated through enhanced

self-efficacy. Indian studies have similarly reported that music therapy reduces pain perception and anxiety among cancer patients, further validating its applicability in clinical settings.

Taken together, these findings underscore a crucial point repeatedly emphasized during the workshop: **music therapy is not a replacement for medical treatment.** Instead, it represents a **scientifically supported, complementary approach** that enhances conventional care by addressing emotional, cognitive, and physiological dimensions of health. In doing so, music therapy offers a holistic pathway toward improved well-being, one that resonates deeply with both scientific understanding and human experience.

THE INDIAN CONTEXT: CULTURAL ROOTS AND WIDESPREAD ACCESSIBILITY

In the Indian context, where access to formal mental health services remains uneven and often limited, music-based interventions offer a particularly promising pathway for emotional and psychological well-being. Music therapy is inherently **low-cost, non-invasive, and widely accessible**, making it suitable for diverse social and economic settings. Deeply embedded in everyday life through devotional practices, folk traditions, and classical forms, music already functions as an informal source of comfort and emotional regulation for many communities.

The workshop emphasized that when music therapy is thoughtfully adapted to local cultural traditions, languages, and listening practices, it can evolve into a powerful tool for community health, preventive care, and public engagement. Such culturally grounded approaches not only enhance acceptance and participation, but also strengthen the effectiveness of music-based interventions in addressing stress, anxiety, and emotional distress at the grassroots level.

BSIP: EXPLORING A NEW HORIZON OF POPULAR SCIENCE COMMUNICATION

The workshop also reflected BSIP's sustained and growing commitment to **popular science communication**, an approach that seeks to connect scientific knowledge with society through culture, creativity, and everyday experience. By foregrounding music as a scientific and therapeutic subject, BSIP demonstrated how science communication can move beyond conventional formats and engage audiences in more intuitive and human-centred ways.

By facilitating a dialogue between music, health, and scientific inquiry, the institute underscored the importance of **interdisciplinary engagement** in addressing complex societal challenges, such as mental health and well-being. The workshop, thus, stood as an example of how scientific institutions can foster meaningful public engagement by integrating science with culturally resonant forms of expression, making science not only understandable, but also relatable and emotionally relevant.

WHEN SCIENCE IS HEARD, NOT JUST READ

The workshop on “Resonance and Healing” reaffirmed a simple yet profound idea: science becomes most powerful when it connects with human emotion. Music, as both a scientific phenomenon and a cultural practice, offers a unique pathway to such connection.

By combining rigorous scientific perspectives with lived musical experience, including collective singing for health and mental peace, the workshop transformed abstract concepts into tangible understanding. It demonstrated that healing is not only about medicine, but also about meaning, rhythm, and shared resonance.

In a world increasingly marked by stress and fragmentation, the dialogue between science and music offers not just knowledge, but hope, reminding us that sometimes, to understand science better, we must first learn to listen.

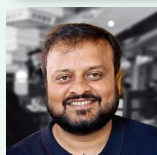
About authors



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 Adrita Choudhuri is Scientist at 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.



Dr Mayank Shekhar is Scientist at BSIP, Lucknow. He 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.

30th Indian Colloquium on Micropalaeontology and Stratigraphy

10–12 June 2026, IIT Bhubaneswar

THE remarkable participation of BSIP scientists in the 30th Indian Colloquium on Micropalaeontology and Stratigraphy, held at IIT Bhubaneswar during 10–12 June 2026, reflects the institute's scientific excellence and leadership in the field of micropalaeontology. Through numerous oral and poster presentations, technical discussions, and active scientific engagement, BSIP researchers showcased their significant contributions to micropalaeontology, palynology, biostratigraphy, and palaeoenvironmental research. The strong presence of BSIP at the colloquium underscores its pivotal role in advancing palaeoscience research and promoting scientific collaboration in India.



Prof. Mahesh G. Thakkar, Director, BSIP, attended the inaugural ceremony as the Chief Guest on 10 June 2026. In his inaugural address, he highlighted the significance of microfossils in understanding Earth's history, their applications in hydrocarbon exploration, palaeoenvironmental reconstruction, and climate change studies, and the notable contributions of BSIP in the fields of palaeontology and stratigraphy.

Prof. Thakkar also attended the technical sessions, interacted with participants, and motivated researchers and students to pursue innovative and interdisciplinary research in micropalaeontology and stratigraphy.









Congratulations to **Dr. Srikanta Murthy**, Scientist-F, on receiving the prestigious **Sharda Chandra Gold Medal 2025** from the **Palaeontological Society of India** during the 30th Indian Colloquium on Micropalaeontology and Stratigraphy, held from 10–12 June 2026 at IIT Bhubaneswar, Odisha. The award recognizes his outstanding contributions to the field of palaeosciences and is a matter of pride for the scientific community.

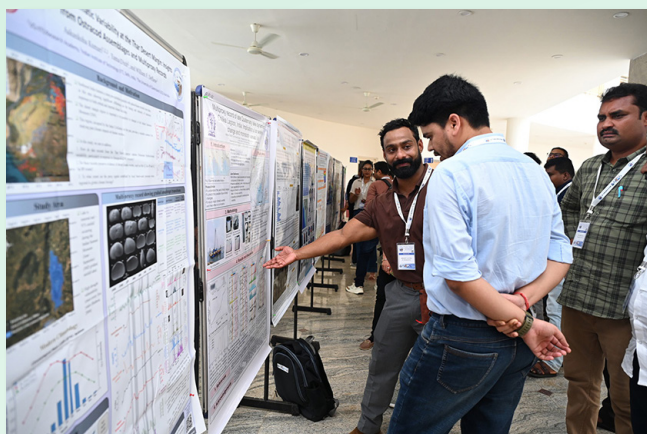


Congratulations to **Dr. Shreya Mishra**, Scientist-C, on receiving the prestigious **Mani Shanker Shukla Gold Medal 2026** from the **Palaeontological Society of India** during the 30th Indian Colloquium on Micropalaeontology and Stratigraphy, held from 10–12 June 2026 at IIT Bhubaneswar, Odisha. This distinguished honour acknowledges her promising contributions to palaeontological research and serves as an inspiration to the young scientific community.



AWARRD

Mr. Anand Rajoriya (Research scholar) is working in the Radiocarbon dating and Isotopic characterisation laboratory of BSIP. Anand has presented his PhD work and secured the **Best Poster Award** with a paper titled **A spatial record of diatom responses with altered Nitrogen and carbon cycling in wetland sediment of Tamil Nadu, India** at the 30th Indian Colloquium on Micropaleontology and Stratigraphy (ICMS-2026) at IIT Bhubaneswar during 10-12th June 2026.



EVENT

International Day of Yoga, 2026

Birbal Sahni Institute of Palaeosciences celebrates 12th International Day of Yoga on Sunday 21 June, 2026 with the theme "Yoga for Healthy Ageing".



National conference on Environmental Crisis and Public Health

3-4 June 2026, CSIR-IITR Lucknow



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.

The image displays a large vertical banner on the left and a collection of circular graphics on the right. The banner features the INQUA logo at the top, followed by the text "XXII INQUA 2027" and the theme "Quaternary Science as Societal Services". Below this is a stylized illustration of a building with a rainbow arching over it, and the text "Welcome to India". At the bottom of the banner are the logos of the Ministry of Earth Sciences and the Ministry of Science & Technology, Government of India. The circular graphics on the right include a QR code, the website "www.inquaindia2027.in", and several circular images with "Welcome to India" text, featuring various Indian landmarks and cultural elements. The overall design is vibrant and celebratory, with a mix of traditional Indian motifs and modern graphic elements.

XXII INQUA 2027
Theme
Quaternary Science as Societal Services

Welcome to India

Ministry of Earth Sciences
Government of India

Ministry of Science & Technology
Government of India

Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow
National Centre for Polar and Ocean Research (NCPOR), Goa
Association of Quaternary Researchers (AOQR)

ICMS 2028



BSIP to Host the 31st Indian Colloquium on Micropalaeontology and Stratigraphy in 2028

following Successful Participation in the 30th ICMS at IIT, Bhubaneswar

THE active participation of scientists from the **Birbal Sahni Institute of Palaeosciences (BSIP)** in the **30th Indian Colloquium on Micropalaeontology and Stratigraphy (ICMS)**, held at IIT Bhubaneswar during 10–12 June 2026, highlighted the Institute's scientific excellence and leading role in the field of micropalaeontology. Through oral and poster presentations, technical discussions, and scientific interactions, BSIP researchers showcased their significant contributions to micropalaeontology, palynology, biostratigraphy, and palaeoenvironmental studies.

ON this occasion, BSIP achieved a major milestone by **successfully securing the bid to host the 31st Indian Colloquium on Micropalaeontology and Stratigraphy (ICMS)** in Lucknow in 2028. This prestigious achievement reflects BSIP's leadership in advancing palaeoscience research in the country and strengthening scientific collaboration among researchers. It is a matter of immense pride for the Institute and reaffirms its commitment to promoting excellence in Earth and palaeoscience research at the national level.



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

