PALAEOSCIENCE TODAY

Tracing Time, Telling Stories

Volume 1 Issue 2 2025

1946

Birbal Sahni Institute of Palaeosciences

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

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Cover Page: A reconstruction of fossil *Williamsonia sewardiana* from Rajmahal Hills, Bihar (India) by late Professor Birbal Sahni

From the Chief Editor's Desk

WHEN DISTANT DESERTS FEED OUR GRASSLANDS: DUST, CYCLONES AND THE HIDDEN STORY OF PHOSPHORUS

AT first glance, a desert dust storm over North Africa or the Middle East seems far removed from the fate of a grassland in western India. Likewise, a powerful cyclone churning over the Arabian Sea is often viewed only through the lens of destruction - strong winds, heavy rainfall, and damage to life and property. Yet nature rarely works in isolation. Hidden within these dramatic atmospheric events is a quieter, less visible process that can profoundly influence the health of our landscapes: the movement of life-supporting nutrients.

Grasslands cover nearly half of the Earth's land surface and support millions of people through agriculture, livestock rearing, and ecosystem services. In India, grasslands are especially vital for pastoral communities and regional food security. However, these ecosystems are also fragile and highly sensitive to nutrient availability. Among all nutrients, phosphorus plays a decisive role. Without sufficient phosphorus, plants struggle to grow, roots weaken, and productivity declines -no matter how much water or sunlight is available.

Traditionally, we have understood phosphorus to come mainly from the soil itself, released slowly through the weathering of rocks and recycled by plants and microbes. What is becoming increasingly clear, however, is that the atmosphere also acts as a long-distance delivery system for phosphorus. Fine dust particles lifted from deserts can travel thousands of kilometers before settling on distant lands, quietly fertilizing ecosystems far from their source.

The recent study that inspires this editorial explores exactly this phenomenon, using Cyclone *Biparjoy* as a natural experiment. As the cyclone developed over the Arabian Sea and made landfall along the western coast of India in June 2023, it followed atmospheric pathways already rich in desert dust from the Middle East, North Africa (MENA), and the Thar Desert. The cyclone did not just bring rain and wind—it also helped carry and deposit phosphorus-bearing dust into the Banni grassland of Kachchh, one of Asia's largest and most distinctive grassland systems.

Why does this matter? Because the Banni grassland, once renowned for its productivity, has been steadily degrading over the past several decades. Erratic rainfall, rising salinity, invasive species, and human pressures have all taken their toll. In such stressed environments, even small changes in nutrient supply can make a significant difference. Understanding how nature itself delivers nutrients

- sometimes in unexpected ways - offers valuable insights for sustainable management and restoration.

One of the most important messages from this research is that it is not just the amount of phosphorus that matters, but its form. Much of the phosphorus present in soils is "locked" and unavailable to plants. The study shows that after the cyclone, not only did total phosphorus in the soil increase, but a larger fraction of it became available for plant uptake. This shift was linked to favorable moisture conditions and a rise in beneficial soil microorganisms that help convert locked phosphorus into usable forms.

In simple terms, the cyclone created the right conditions for nature's own recycling system to work more efficiently. Rainfall moistened the soil, dust delivered fresh mineral nutrients, and microbes did the biochemical work of making phosphorus accessible to grasses. The result was a measurable improvement in what scientists call phosphorus activation, a key indicator of soil fertility in grassland ecosystems.

This finding invites us to rethink how we view extreme weather events. Cyclones are rightly associated with risk and loss, but they are also part of the Earth's natural circulation system. Over long periods, such events can redistribute water, sediments, and nutrients across regions. From a paleo-scientific perspective, this is not new. Geological records show that dust transport, storm tracks, and climate extremes have shaped soils and ecosystems for thousands of years. What is new is our ability to observe these processes in real time, combining satellite data with ground-based measurements.

The story of phosphorus travelling from distant deserts to Indian grasslands also highlights how interconnected our planet truly is. Actions and changes in one region - such as desertification or land-use change can influence ecosystems far away through atmospheric pathways. In a warming world, where dust storms and intense cyclones may become more frequent or more powerful, these connections are likely to strengthen.

For policymakers, land managers, and local communities, such insights are highly relevant. They remind us that ecosystem management cannot rely solely on local interventions. Broader climatic and atmospheric processes must also be taken into account. Protecting grasslands like Banni requires an integrated understanding of climate, geology, biology, and human activity - precisely the kind of holistic approach that palaeoscience encourages.

At the Birbal Sahni Institute of Palaeosciences, we view studies like this as bridges between past, present, and future. By learning how nutrients moved across landscapes under past climatic conditions, and by observing how they move today during extreme events, we can better anticipate how ecosystems may respond tomorrow. Such knowledge is essential not only for scientific advancement, but also for building resilience in vulnerable regions.

Ultimately, the journey of phosphorus - from desert dust to grassland soil, from locked mineral to living plant, tells us a powerful story. It reminds us that Earth's systems are dynamic, interconnected, and often surprising. Invisible processes in the sky can shape life on the ground. Recognizing and respecting these hidden pathways is a crucial step towards living more sustainably within the limits of our changing planet.

As readers of *Palaeoscience Today*, we invite you to look beyond the immediate impacts of storms and dust clouds, and to appreciate their deeper role in Earth's life-support systems. In doing so, we gain not only scientific insights, but also a renewed sense of humility and responsibility toward the landscapes that sustain us.

Dr. Seema Sharma and Dr. Rupak Dey of KSKV Kachchh University are gratefully acknowledged for their research conducted in the Banni region, which has been published in Nature Scientific Reports.

Warm regards,

Prof. Mahesh G. Thakkar
Chief Editor

Editorial

DEVELOPMENT IN PALAEOSCIENCE: FROM MICROSCOPES TO MODELS

PALAEOSCIENCE means 'knowing the past' and deals with disconnected past. It differs slightly from geoscience (Earth Science) and is nearly a subset of it. Because geoscience deals with terrestrial processes that are temporally in a continuum with the past. Palaeoscience seeks to answer a simple, but thoughtful question: how has Earth's climate and environment changed through time?

The answers lie hidden in natural archives, such as lake sediments, peat bogs, ocean floors, cave deposits, and tree rings. Palaeoscience, in fact, offers a long-term perspective that extends far beyond the limits of modern observations (as climate change accelerates and environmental uncertainties grow). Traditional tools allow scientists to read these archives. Pollen grains reveal past vegetation, microfossils record ocean conditions, and charcoal fragments tell stories of ancient fires.

These observations provide the raw evidence of Earth's environmental history. The foundation of palaeoscience rested on careful fieldwork, meticulous laboratory analyses, and the trained eye of the researcher peering through a microscope, counting pollen grains and other microfossils and identifying them, or deciphering sedimentary textures. These traditional tools remain indispensable. However, palaeoscience is undergoing a remarkable transformation today. While microscopes remain essential, they are now joined by powerful computers, sophisticated models, and vast digital datasets. As a matter of fact, in recent years, the scale and precision has changed with which these stories can be told.

Advances in dating techniques now allow researchers to place past events on more accurate timelines. High-resolution chemical analyses reveal subtle shifts in temperature, rainfall, and ecosystem health. At the same time, computers have become indispensable partners in palaeoscientific research.

Statistical methods help separate meaningful climate signals from background noise, while machine-learning tools are beginning to assist in identifying microscopic fossils that once required years of taxonomic training. One of the most exciting developments is the growing connection between palaeoscience and climate modelling. Climate models are commonly used to simulate future warming scenarios (but they also need to be tested against real-world evidence).

This is where palaeodata play a vital role. By comparing model outputs with reconstructions of past climates, such as ice ages, monsoon shifts, or sudden droughts, scientists can assess how well models capture Earth's natural variability. In some cases, palaeodata are now directly incorporated into models, creating a bridge between observations of the past and predictions of the future.

There is; however, a danger that palaeoscience becomes overly model-driven, losing sight of proxy limitations, taphonomic biases, and regional specificities. The future of the discipline, therefore, depends on maintaining a balance: where technological innovation enhances, rather than replaces, fundamental observational skills. Equally important is the need to train the next generation of palaeoscientists.

Tomorrow's researchers must be fluent in both classical proxy analysis and modern computational methods. Interdisciplinary literacy, spanning geology, ecology, statistics, and climate science, will be essential. Open data initiatives and collaborative platforms further emphasize transparency, reproducibility, and global inclusivity in palaeoscience research.

As palaeoscience evolves from microscopes to models, its core mission remains unchanged: to decode Earth's long-term memory. In an era of rapid environmental change, the strength of palaeoscience lies precisely in its ability to unite deep-time evidence with cutting-edge tools. By embracing innovation while preserving its empirical foundations, palaeoscience is uniquely positioned to provide the long-term context needed to understand, and prepare for, the planet's uncertain future.

In continuation with the 1st Issue of ***Palaeoscience Today***, the present Issue covers the articles on various aspects, such as Origin of Life, Mountains, climate shifts, and forgotten forests of Kashmir Valley (India), Rising carbon, dying forests: A warning from past climates, Beyond 1.5°C: Evidence of warming as a warning, Plant contributions to hydrocarbon generation, Medicinal and aromatic plants for natural healing, Tracing footprints of Monsoon, Tree-ring science for climate, ecology, and earth surface processes, Palynomorphs as aeroallergens, Palaeoclimate, News related to Founder's Day Celebration, INQUA 2027, IISF 2025, INSA Science Week Celebration, INSA Anniversary General Meeting, and Induction Ceremony 2025, etc.

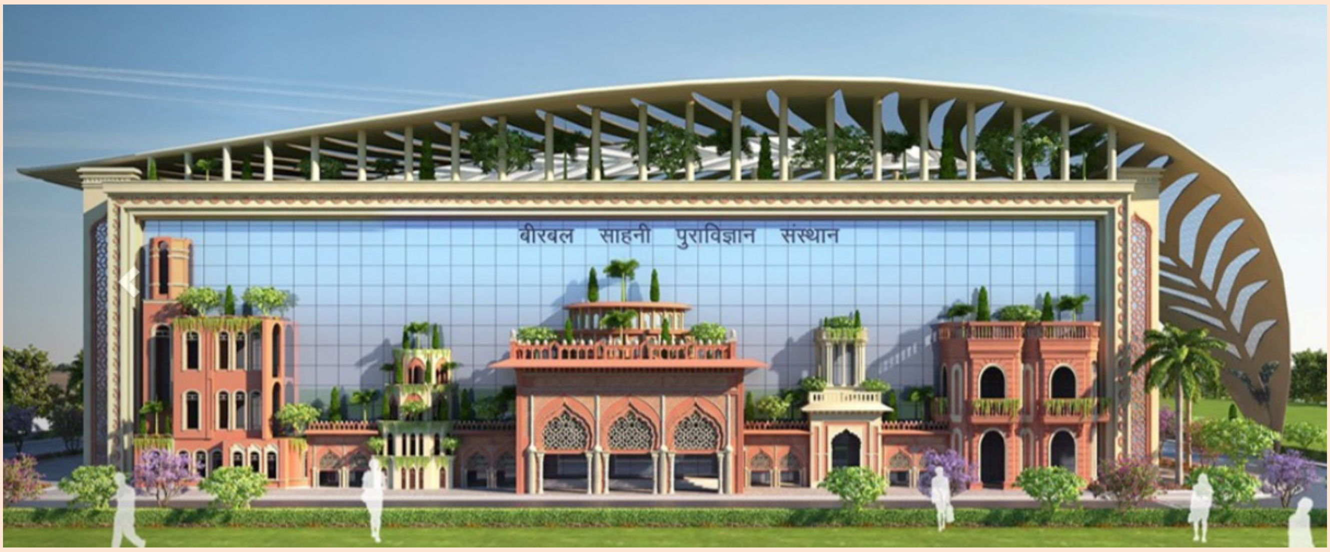
I believe that the readers will definitely enjoy going through the articles of the present issue.

I extend my hearty greetings to all the readers at the dawn of the New Year. May the New Year (2026) bring lots of happiness, good health and success to you all.

Happy New Year!

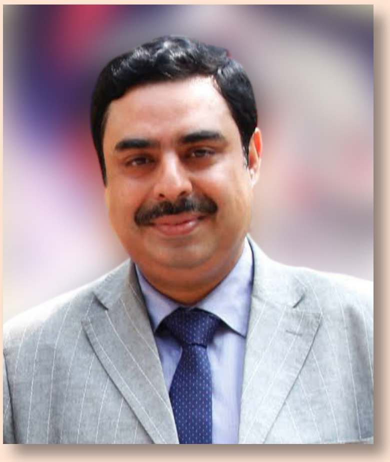
Best wishes.....

Dr. Md. Firoze Quamar
Editor



From the Coordinating Editor's Desk

READING THE DEEP PAST, SHAPING THE FUTURE: WHY INDIA'S GEOLOGICAL SITES MATTER



IN an age when tourism is often measured by footfall and selfies, India's geological sites invite us to slow down and listen. They speak through rocks, fossils, sediments, and landscapes that have been quietly recording Earth's history for millions of years. These places are not merely scenic backdrops or extractive resources; they are open-air laboratories and classrooms. Over the last five years, the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow, has shown how research rooted in such sites can transform our understanding of past life, climate, and environments. In doing so, it has opened new dimensions for geo-tourism and science education.

Geo-tourism, at its best, is not about spectacle alone. It is about meaning: connecting visitors to the deep time of the planet and helping them appreciate why landscapes look the way they do today. The work carried out by the BSIP across India, from river deltas and coalfields to Himalayan forests and desert basins, demonstrates that geological sites can be powerful bridges between rigorous science, student learning, and responsible tourism.

GEOLOGICAL SITES AS NARRATIVES OF DEEP TIME

Unlike monuments built in decades or centuries, geological sites unfold stories across millions of years. Sedimentary layers, fossil assemblages, and chemical signatures together form narratives of shifting climates, evolving ecosystems, and even catastrophic events, such as mass extinctions. BSIP's research emphasizes that these stories are not abstract: they are anchored to real places that can be visited, interpreted, and conserved.

Take the Mahanadi River delta, a vast, fertile, and biodiverse composite delta on India's east coast (Odisha). Here, BSIP scientists have analysed a chronologically constrained sedimentary sequence that stretches back about 2.6 million years, into the late Neogene and early Quaternary (the time from about 7 to 1.8 million years ago when the Earth cooled, ice ages began, and early humans - genus Homo started to appear). By integrating stratigraphy, palynology (the study of fossil pollen and spores), and climate interpretation, researchers reconstructed palaeoclimate and palaeovegetation histories of the region.

For a student or visitor, this delta is no longer just a flat expanse of mud and mangroves, it becomes a living archive of monsoon variability, sea-level changes, and ecosystem resilience. Interpreted thoughtfully, such a site could anchor geo-tourism circuits focused on climate change education, linking past climate shifts to present-day concerns.

Similarly, in the Kumaon–Garhwal Himalaya, BSIP's tree-ring isotope studies have produced one of the longest summer drought records for the region, based on $\delta^{18}O$ values preserved in annual growth rings. $\delta^{18}O$ values are a scientific way of describing the ratio of oxygen isotopes in a natural material, and they are widely used in climate and palaeoclimate studies.

This research extends our understanding of historical moisture regimes and drought dynamics across the Himalayan arc. For geo-tourism, Himalayan sites are often marketed for adventure or heritage exploration. Adding a palaeoclimate lens, explaining how ancient trees record monsoon strength and drought, can enrich visitor experience while underscoring the Himalaya's sensitivity to climate change.

FOSSIL SITES: WINDOWS INTO VANISHED WORLDS

Fossils remain the most immediate and evocative entry point into palaeoscience. BSIP's discoveries from coalfields, river valleys, and sedimentary basins across India highlight the country's extraordinary fossil wealth and its relevance to global evolutionary questions.

The discovery of a 37,000-year-old fossilized bamboo stem from the Chirang River in the Imphal Valley, Manipur, complete with preserved thorn scars and buds, is a striking example. As the earliest evidence of thorny bamboo in Asia from the Late Pleistocene (about 126,000–11,700 years ago), it highlights the plant's ancient presence. This finding shows that Northeast India acted as a refugium during Ice Age cooling. Such a site, interpreted through guided trails or small local museums, could help visitors visualize Ice Age ecosystems in the tropics, an idea that often surprises non-specialists.

In Makum Coalfield, Assam, 24-million-year-old fossil leaves from Oligocene coal beds have recorded vegetation responses to ancient climate shifts preceding the Miocene. The Miocene was 23–5.3 million years ago, when modern plants and animals started appearing and the climate cooled.

In the Talcher Coalfield of the Son–Mahanadi Basin, fossils spanning the Permian–Triassic transition reveal ecological stress and recovery during one of Earth's greatest mass extinctions. This transition, around 252 million years ago, marks the largest mass extinction in history and the beginning of the Triassic Period.

These coalfields, frequently viewed only through the lens of mining, are also invaluable geo-heritage sites. With appropriate conservation and interpretation, they can tell stories of ancient forests, greenhouse climates, and extinction events that resonate strongly with today's environmental anxieties.

Other BSIP-studied sites, from the Raniganj Coalfield and Deccan Intertrappean beds near Sagar, to the Western Garo Hills with their marine microfossils, collectively map India's palaeogeographic evolution. They show when seas advanced inland, when volcanoes reshaped landscapes, and how plants and microorganisms responded. For students, these sites turn textbook diagrams into tangible reality.

DESERT BASINS AND JURASSIC SEAS

The Lathi Formation in the Jaisalmer Basin, Rajasthan, studied through palynology and sedimentary analysis, offers a window into Early to Middle Jurassic environments. Early to Middle Jurassic environments (about 201–163 million years ago) were times when the Earth had a warm climate, rising seas, and lots of lush vegetation. Studying tiny fossils called palynofacies helps scientists understand how deserts, rivers, and shallow seas existed in western India long ago. Today, Jaisalmer attracts tourists with its famous forts and desert sand dunes. Integrating palaeoscience narratives, Jurassic climates, ancient vegetation, and sedimentary processes, could diversify tourism beyond heritage architecture, drawing attention to the region's deep geological past.

GEO-HERITAGE AS EDUCATION INFRASTRUCTURE

BSIP's research on geological and fossil sites, as well as desert basins and Jurassic seas, shows that many fossil localities and geological features are both accessible and scientifically valuable, deserving protection. Geo-heritage isn't about fencing off sites; it's about presenting them as shared educational resources. With signage, digital guides, small site museums, and collaboration with local communities, tourism can support conservation rather than harm these fragile records.

For students, especially at school and undergraduate levels, geo-heritage sites function as field classrooms. Seeing fossiliferous layers in situ or handling replica specimens fosters a kind of understanding, no lecture can match. BSIP's research studies highlights, show how site-based research feeds directly into broader scientific questions. Translating these findings into public-facing narratives can help nurture the next generation of geoscientists.

ADDING NEW DIMENSIONS TO TOURISM

Geo-tourism does not compete with conventional tourism; rather complements it. Cultural, religious, and ecological tourism can all be enriched by geological context. A pilgrimage route gains depth when visitors learn about the tectonic forces that raised the mountains they traverse. A wildlife sanctuary becomes more meaningful when its soils and vegetation are linked to ancient sedimentary histories.

Palaeoscience research underscores that India's geological sites are not isolated curiosities. They are interconnected nodes in a national and global story of Earth history. Promoting geo-tourism around these sites can stimulate local economies, encourage conservation, and foster scientific literacy. Importantly, it can also decentralize tourism, drawing visitors beyond overcrowded hotspots to lesser-known regions, such as the Northeast, central Indian coalfields, or Himalayan foothills.

RESPONSIBILITY AND OPPORTUNITY

Of course, increased visibility brings responsibility. Fossil sites are vulnerable to vandalism, illegal collection, and unregulated development. Geo-tourism must, therefore, be grounded in strong scientific stewardship, clear guidelines, and community participation. Institutions like BSIP play a crucial role here, not only by producing research, but by advising on site management, interpretation standards, and outreach.

The opportunity is immense. As climate change and biodiversity loss dominate public discourse, palaeoscience offers long-term perspectives that are both sobering and empowering. Geological sites show us that Earth has changed dramatically before and that life has both suffered and adapted. They remind us that human society is now a geological force, shaping the planet's future strata.

LOOKING AHEAD

BSIP research reveal a simple truth: India's geological sites are among its most underappreciated assets. They are archives of deep time, laboratories for cutting-edge science, and potential hubs for meaningful tourism. By integrating research findings into geo-heritage initiatives and educational tourism, we can ensure that these sites inspire curiosity, rather than indifference.

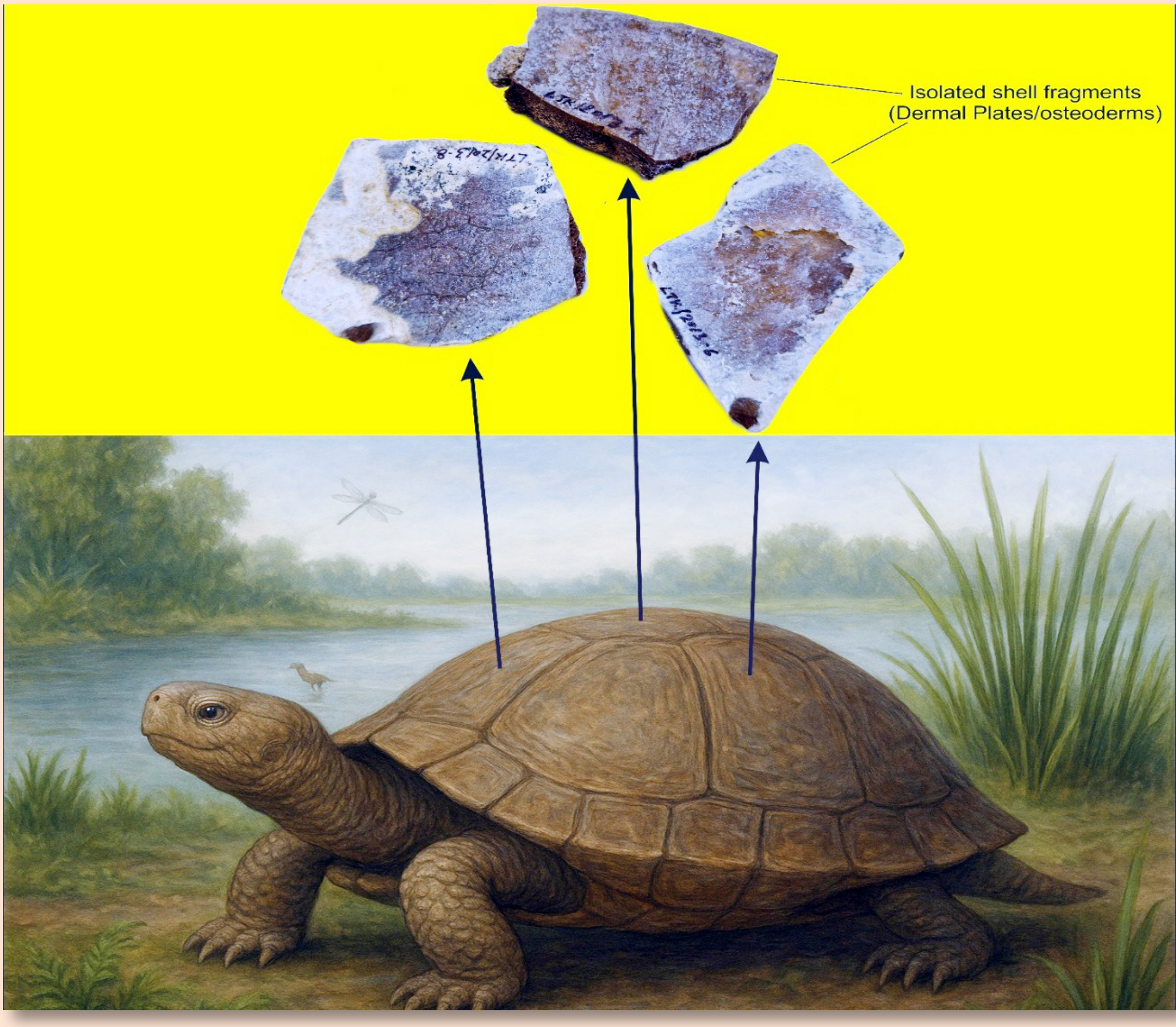
For students, encountering palaeoscience in the field can be transformative, turning abstract concepts into lived experience. For tourists, geo-heritage offers stories deeper than any guidebook anecdote. And for society at large, it fosters a sense of stewardship rooted in understanding.

Reading the rocks, after all, is not just about the past. It is about learning how to inhabit the future wisely.

Dr Nimish Kapoor
Coordinating Editor

FOSSIL FROM THE DECCAN, TELLS A SURVIVAL STORY

CHELONIAN OSTEODERMS – SURVIVORS OF EARTH'S LAST DINOSAUR AGE



These fragmentary bony plates belonged to turtles that lived just before the end-Cretaceous mass extinction. Preserved in the fossil-rich intertrappean clays/shales sandwiched between Deccan Traps basalts, they record a freshwater–brackish ecosystem where turtles were dominant scavengers. These chelonian remains add to the growing record of **survivor lineages** during the catastrophic K–Pg boundary. Turtles, unlike dinosaurs, endured the asteroid impact, highlighting their ecological resilience in freshwater systems. Alongside fishes, crocodiles, and associated reptilian coprolites, these remains capture a vibrant community that thrived in a lake linked to a freshwater stream/river in central India close to 66 million years ago.

Taxon: Chelonia gen. et sp. indet. (An indeterminate genus and species of turtle)
Element: Bony osteoderms (dermal plates).
Age: Late Cretaceous (Latest Maastrichtian; ~66 Ma).
Formation: Deccan Intertrappean Beds.
Locality: Lotkheri Village, Bhanpura Tehsil, District Mandsaur, Madhya Pradesh.
Collected by: Dr. Vivesh Vir Kapur, BSIP, Lucknow.
BSIP Museum Locality Number: 10145.
Compiled by: Dr Ranveer Singh Negi, BSIP, Lucknow.

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ARTICLE

The oxygenation of Earth: Billion-year struggle that made life possible

Kumail Ahmad and Faizan Ahmad Khan

OXYGEN, the invisible gas that sustains life makes Earth truly unique. It forms about one-fifth of the air we inhale and powers every living being, from the tiniest microbe to the largest whale. Nowhere else in our solar system we find such a perfect balance of air, water, and stability; a harmony that allows complex life to exist. However, several billions of years ago, our planet looked nothing like it does today. Around 4.6 billion years ago, Earth was a molten sphere wrapped in toxic gases. The skies were dim, the land was covered with hot lava flows, and the young Sun blazed over a barren, lifeless planet. As volcanoes calmed, rains poured for millions of years, filling the first basins and forming early oceans. In these primeval waters, microscopic life appeared in the form of tiny organisms (Cyanobacteria) that learned to use sunlight to make food, releasing oxygen as a byproduct. Initially, that oxygen vanished as quickly as it formed, reacting with metals and gases. But gradually, it began to accumulate, changing the chemistry of the air and oceans, and ultimately the course of Earth's history (Figure 1). The evidence of this transformation lies in rocks like banded iron formations and ancient sediments that record when oxygen first appeared and how it transformed the planet.

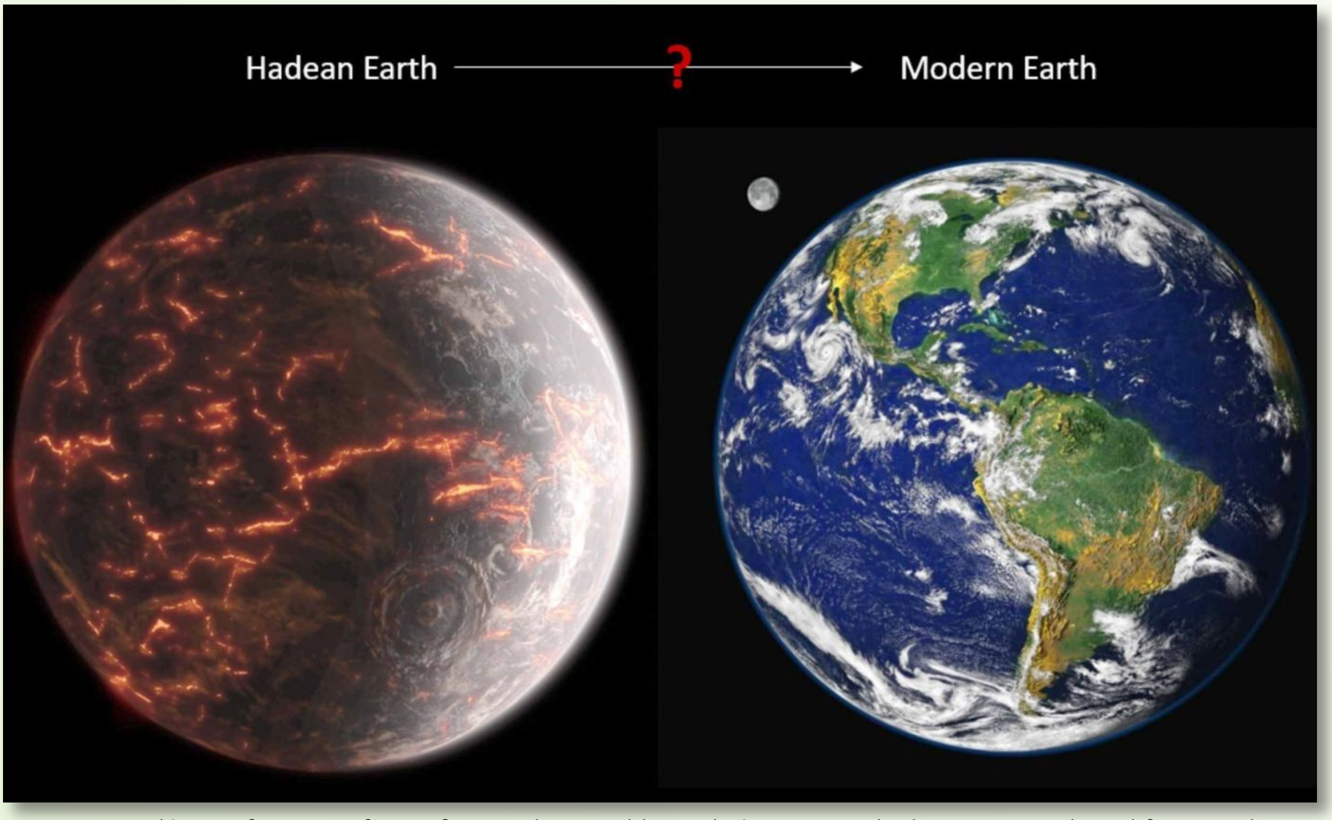

Figure 1. Earth's transformation from a fiery Hadean world to today's oxygen-rich planet. Image adapted from Earth.com.

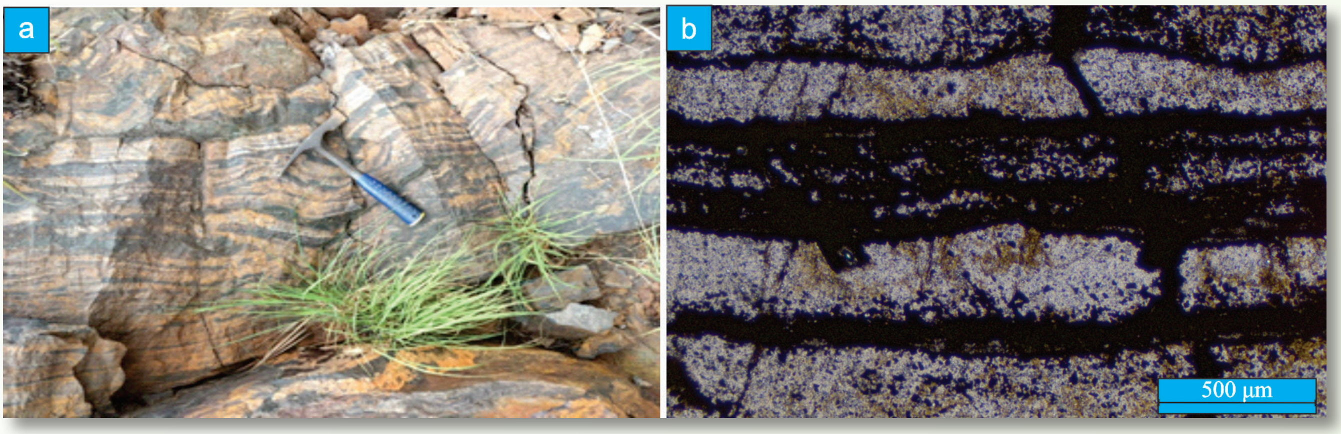

Figure 2 a. Banded Iron Formation from Chitradurga (Karnataka), recording the first traces of oxygen in Earth's oceans (~2.7 billion years ago) (Photograph by Faizan Ahmad Khan) b. microscopic image shows thin, alternating dark and light layers. The dark layers are rich in iron minerals, while the lighter layers are mostly quartz. These bands formed long ago as iron and silica settled out of ancient seawater.

THE FIERY BEGINNING
~4.6–4.4 BILLION YEARS AGO
HADEAN EON

Imagine a world made of fire. Around 4.6 billion years ago, clouds of dust and gas swirling around the young Sun began to merge, giving birth to Earth. Its surface was an ocean of molten rock, glowing red beneath a choking sky of methane, carbon dioxide, and sulfur gases. For millions of years, the planet endured a violent bombardment of asteroids and comets. Each impact melted vast regions of crust and added new material to the growing Earth. Volcanoes erupted endlessly, filling the air with steam and ash, while lightning flashed across smoky skies. There were no continents or oceans only a glowing, unstable world still in the process of formation. Gradually, the bombardment dissipated and thin crust formed over the molten surface, volcanic steams released due to volcanism and bombardment, eventually formed the first atmosphere and clouds resulting into endless rain fall, which filled out the basins to create the first oceans. The atmosphere remained toxic with carbon dioxide and methane, and any oxygen that appeared was quickly consumed by reduced compounds produced via volcanic eruptions and bombardment, forming iron-rich rocks. Eventually, this fiery beginning laid the groundwork for striking a balance between Lithosphere, Hydrosphere, Biosphere and atmosphere that we see today. The same volcanoes that once darkened the skies had also released the water vapor that built the oceans, Earth's first great chemical laboratory.

A BREATHLESS EARTH
~4.4–3.5 BILLION YEARS AGO
HADEAN – EARLY ARCHEAN

As the planet cooled, vast greenish oceans spread across its surface, rich in dissolved iron and sulfur. The atmosphere above was thick and orange, dimly lit by a weaker Sun. There was still no oxygen. Yet even in this suffocating world, something remarkable began. Deep on the ocean floor, cracks formed where hot, mineral-rich water gushed out and life made its first appearance. These early microbes needed neither sunlight nor oxygen they survived by drawing energy from reactions between water and minerals like sulfur and iron. Some may have lived in shallow volcanic pools, where heat and minerals mixed with water. It was a toxic, breathless world but no longer lifeless.

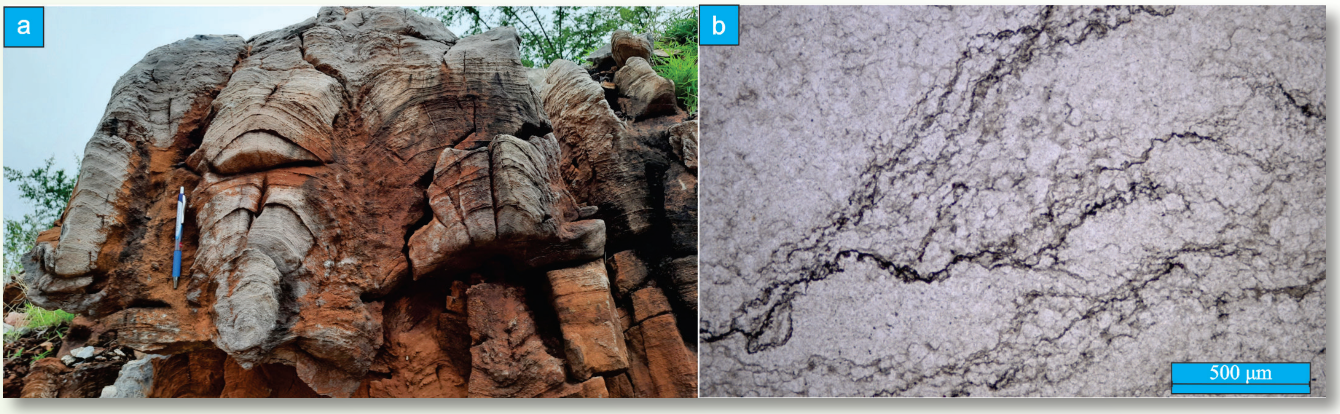

Figure 3 a. Stromatolites (~1.8 billion years old) layered structures built by microbial mats after the rise of atmospheric oxygen. (Photograph by Dr. Arvind K. Singh) b. microscopic view of stromatolite layers showing fine, wavy bands formed by ancient microbial activity. The black portions represent preserved microbial mats, which trapped and bound sediments over time, helping build the layered structure seen in the rock.

WHEN LIGHT AWAKENED LIFE ~3.5–2.7 BILLION YEARS AGO MESOARCHEAN – NEOARCHEAN

Roughly 3.5 billion years ago, life learned a new method of how to use sunlight. Some microbes developed the ability to capture solar energy and turn it into food, a process similar to what we now call photosynthesis. Initially, they used sulfur and iron compounds, which produced no oxygen. Then came a turning point where new kind of microbe cyanobacteria discovered how to use water in photosynthesis. When they split water molecules using sunlight, it released oxygen as by-product. These tiny organisms were the planet's first oxygen manufacturers, simple but powerful enough to alter the Earth forever. Cyanobacteria thrived in warm, shallow seas, forming sticky mats that proliferated enough to trapped sediments and build layered mounds called stromatolites. These structures are still found today in places like India's Chitradurga region (Karnataka). The oxygen they produced reacted with dissolved iron in seawater, forming reddish rust that sank to the ocean floor. Over millions of years, these layers hardened into banded iron formations Earth's earliest evidence of oxygen's rise and most fascinating iron deposits which we see in everyday life (Figure 2).

THE GREAT TURNING POINT ~2.4 BILLION YEARS AGO PALEOPROTEROZOIC ERA

For hundreds of millions of years, oxygen disappeared as fast as it formed, consumed by volcanic gases and iron-rich seas. But around 2.4 billion years ago, the balance shifted towards oxygen and it began to accumulate in the atmosphere. This process took approximately 300 million years which eventually came to be known as the Great Oxidation Event, the first remarkable step towards oxygenation of Earth. As the crust thickened and stabilized, volcanic eruptions became less frequent, reducing the release of gases that destroyed oxygen. Slowly, oxygen produced by cyanobacteria began to accumulate in the oceans and atmosphere. These layered structures built by cyanobacteria are called stromatolites (Figure 3). The planet's chemistry shifted from oxygen-poor to oxygen-rich. Many early microbes that could not tolerate oxygen vanished, while others evolved to use it paving the way for more complex life. It was a planetary revolution.

THE LONG QUIET - THE "BORING BILLION"
~1.8–0.8 BILLION YEARS AGO
MESOPROTEROZOIC ERA

After the Great Oxidation, Earth entered a long, steady phase. For nearly a billion years, oxygen levels remained low but stable enough that nothing major events recorded by scientists, which they called it to be the "Boring Billion period." Yet it was far from uneventful. The continents expanded and stabilized, mountains rose and eroded, and rivers carried nutrients like phosphorus and iron to the seas, feeding photosynthetic life. The surface waters held enough oxygen for microbes to survive, while deep oceans stayed largely oxygen-poor. With volcanic activity slowing, the release of oxygen-consuming gases such as hydrogen (H_2), hydrogen sulfide (H_2S), carbon monoxide (CO), and methane (CH_4) declined, reducing the chemical sinks that previously destroyed free oxygen. This long equilibrium allowed the planet's chemical cycles to stabilize quietly and prepare for life's next great leap.

FROZEN EARTH, BLUE SKIES
~720–635 MILLION YEARS AGO
CRYOGENIAN PERIOD, NEOPROTEROZOIC ERA

About 700 million years ago, Earth was locked in a deep freeze known as Snowball Earth. Ice spread from pole to equator, trapping the oceans under thick sheets. Sunlight faded, and life barely endured near volcanic vents and cracks in the ice. When the planet finally thawed, torrents of melt water carried nutrients from land into the oceans, fueling blooms of photosynthetic organisms such as cyanobacteria and early algae. Oxygen levels rose sharply during the Neoproterozoic Oxygenation Event (800–540 Ma), enriching both air and sea. For the first time, even the deep oceans held enough oxygen for complex life. Meanwhile, high in the atmosphere, sunlight turned oxygen into ozone, forming a shield that protected life from harmful radiation. The skies turned blue, the oceans clear, and from the frozen silence, a living planet was reborn.

WHEN THE SEAS CAME ALIVE
~635–540 MILLION YEARS AGO
EDIACARAN PERIOD

With steady oxygen levels and a protective ozone layer, life took its greatest leap forward. Around 635 million years ago, simple microbes began forming multicellular bodies the earliest true animals. By 600–541 million years ago, soft-bodied organisms known as the Ediacaran biota flourished worldwide. Their fossils are preserved across several iconic global sites, including the Ediacara Hills of Australia, Mistaken Point in Canada, the Nama Group of Namibia, and Charnwood Forest in the United Kingdom. India also preserves an important record of this ancient life: the Marwar Supergroup of Rajasthan, particularly the Jodhpur and Nagaur regions, hosts well-documented Ediacaran impressions and disc-shaped fossils. Although these organisms lacked shells or bones, they represent the first large, organized forms of life on Earth. Then, around 540 million years ago, the Cambrian Explosion triggered an extraordinary burst of evolution, filling the oceans with animals that could swim, crawl, burrow, and hunt.

Earth's journey from fire to life is truly remarkable and fascinating. What began as a blazing, lifeless ball of molten rock slowly turned into a world filled with oceans, air, and thriving ecosystems. Tiny microbes were the quiet architects of this change. By learning to use sunlight for energy, they released oxygen that slowly transformed the atmosphere, the oceans, and the planet's chemistry. This rise of oxygen did not happen all at once rather, it unfolded through several key stages during Earth's early history, beginning soon after the planet's formation and continuing through a series of major oxygenation steps. These successive phases of oxygen buildup are illustrated in Figure 4, which places the evolution of Earth's atmosphere and early life in a broader geological timeline.

The traces of this long and complex story are preserved in ancient rocks like red coloured iron formations, fossil stromatolites, and other signatures left behind by early life. Some of the clearest windows into this past lie in India's own geological record. The banded iron formations of the Dharwar Craton,

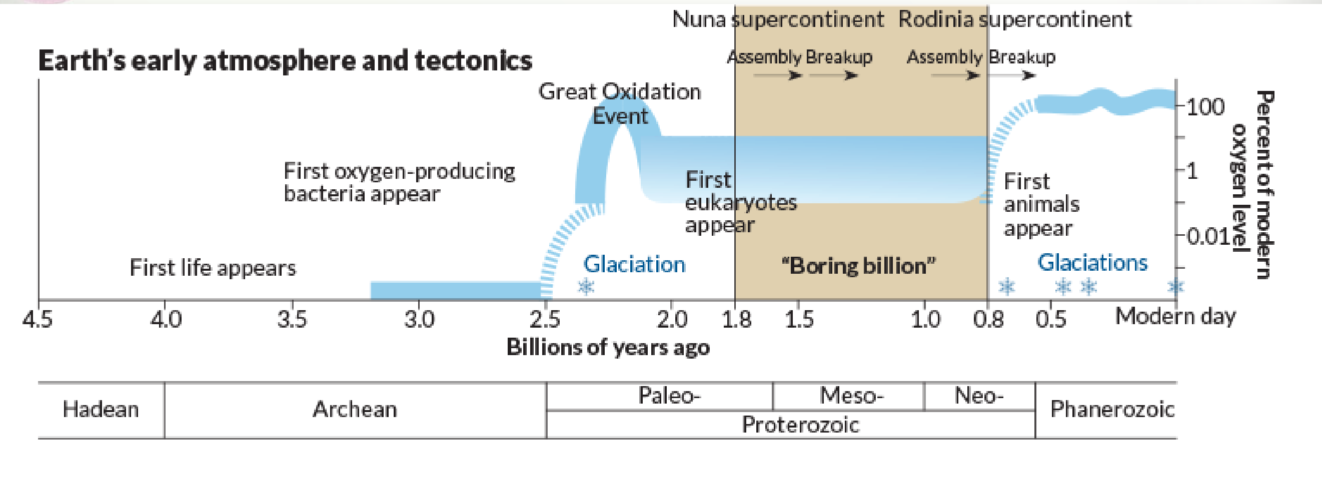

Figure 4. Overview of Earth's early atmospheric evolution, showing when oxygen first appeared and how it rose in stages over billions of years. Adapted from Lyons et al. (2014).

the stromatolites-rich carbonates of Cuddapah and the Vindhyan Basin, and the Ediacaran fossils of Rajasthan's Marwar Supergroup all offer invaluable clues about how oxygen first appeared and how life responded. Palaeomagnetic studies on these ancient Indian rocks help scientists reconstruct the drift of early continents, changes in ocean pathways, and the environments in which early life evolved. Earth's history was also shaped by many catastrophic events like asteroid impacts, massive volcanic eruptions, and global ice ages that challenged life but also opened new evolutionary doors. Together, these steady processes and sudden shocks, recorded beautifully in India's ancient terrains which shaped Earth into the oxygen-rich, living planet we know today.

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Rising Carbon, Dying Forests: A Warning from Past Climates

Harshita Bhatia and Gaurav Srivastava

EQUATORIAL rainforests, also known as tropical evergreen forests, and often celebrated as the "Lungs of the Earth," are vital for sustaining the planet's ecological balance. They house the richest biodiversity on the Earth, regulate temperature, store vast amounts of carbon, and serve as natural buffers against floods, droughts, and erosion. Additionally, they influence local and global climate systems, support migratory species, and harbor more than half of the planet's known species. Yet, the escalating anthropogenic carbon emissions and perturbations in the global hydrological cycle are placing these crucial ecosystems at grave risk.

The disruption of the hydrological cycle is increasingly evident due to the warming of our planet, mainly driven by rising atmospheric carbon dioxide (CO_2) levels. Historically stable at around 280 ppm before industrialization, CO_2 levels surged

Representative image of dying Tropical Rainforest

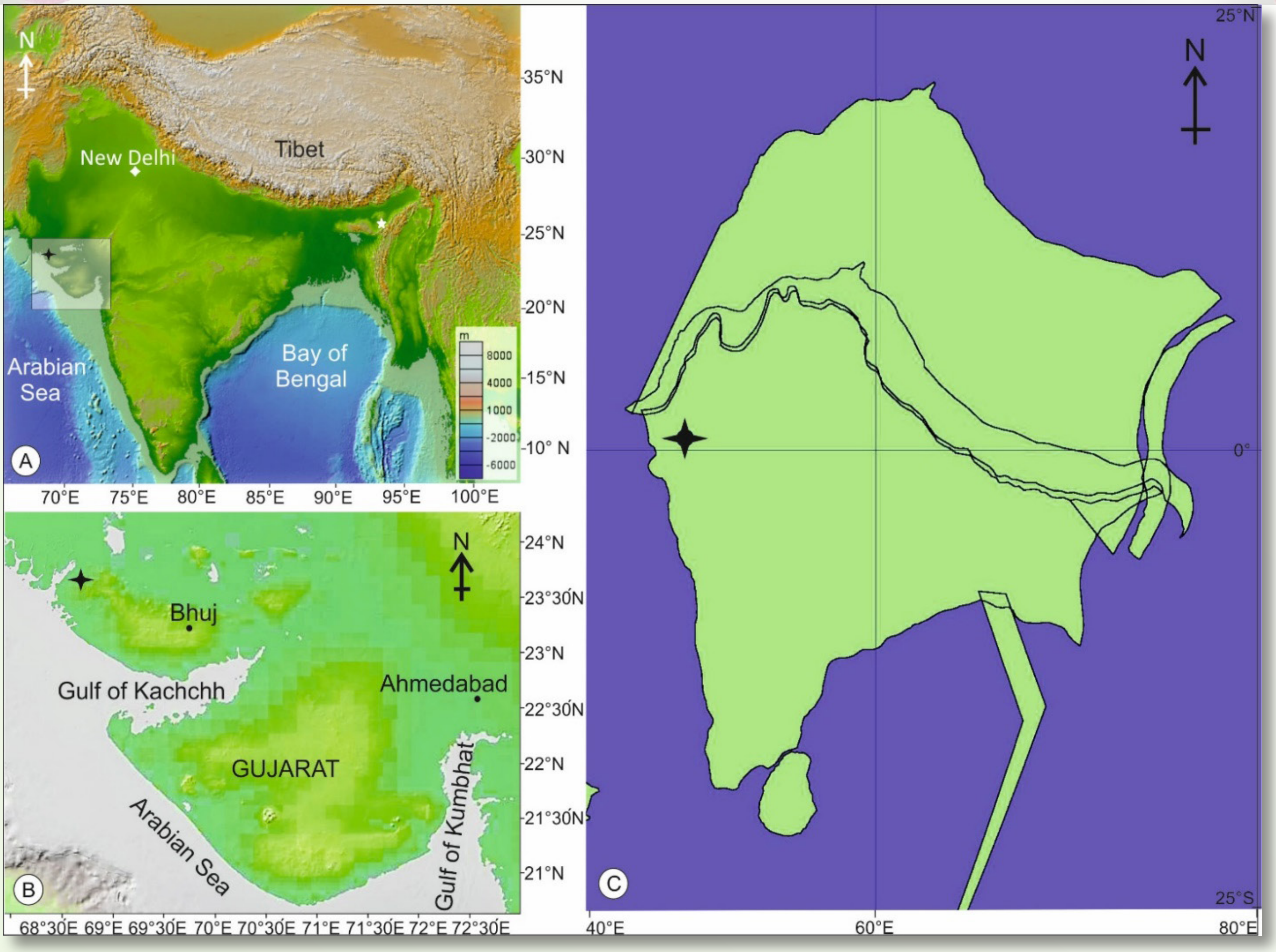

Figure 1. Map showing the fossil locality and its paleo position. A) Modern map of India and enlarged portion of the Gujarat showing the fossil locality (black solid star). B) Map showing the paleo-position of the fossil locality (black solid star) (after Srivastava et al. 2024).

to an average of 419 ppm by 2022, correlating with a 1.1 °C rise in global mean surface temperatures. If this trend persists, CO_2 concentrations could exceed 800 ppm by 2100, presenting major uncertainties for weather patterns and long-term climate stability. Understanding how atmospheric CO_2 affects rainfall dynamics is essential for building a sustainable future. Although climate models have made strides in projecting rainfall trends, they still require validation through deeper, long-term data.

Looking into Earth's past offers a valuable lens. About 50 million years ago, the planet's surface was approximately 12 °C warmer than today, and CO_2 levels exceeded 1000 ppm. These ancient conditions, determined using *paleoproxies*, geological markers preserved in rocks or sediments, help scientists reconstruct past climates and understand how such elevated CO_2 levels impacted global weather, particularly rainfall.

Importantly, a warming Earth strengthens the hydrological cycle but doesn't necessarily translate to more rainfall. Climate projections often struggle with this nuance due to a lack of long-term empirical data. Fossil records, however, can help clarify these relationships. Around 53.7 million years ago, during an extreme warming event known as the Eocene Thermal Maximum 2 (ETM-2), CO_2 levels exceeded 1000 ppm and temperatures soared by over 10 °C. This event is widely considered a useful analog for

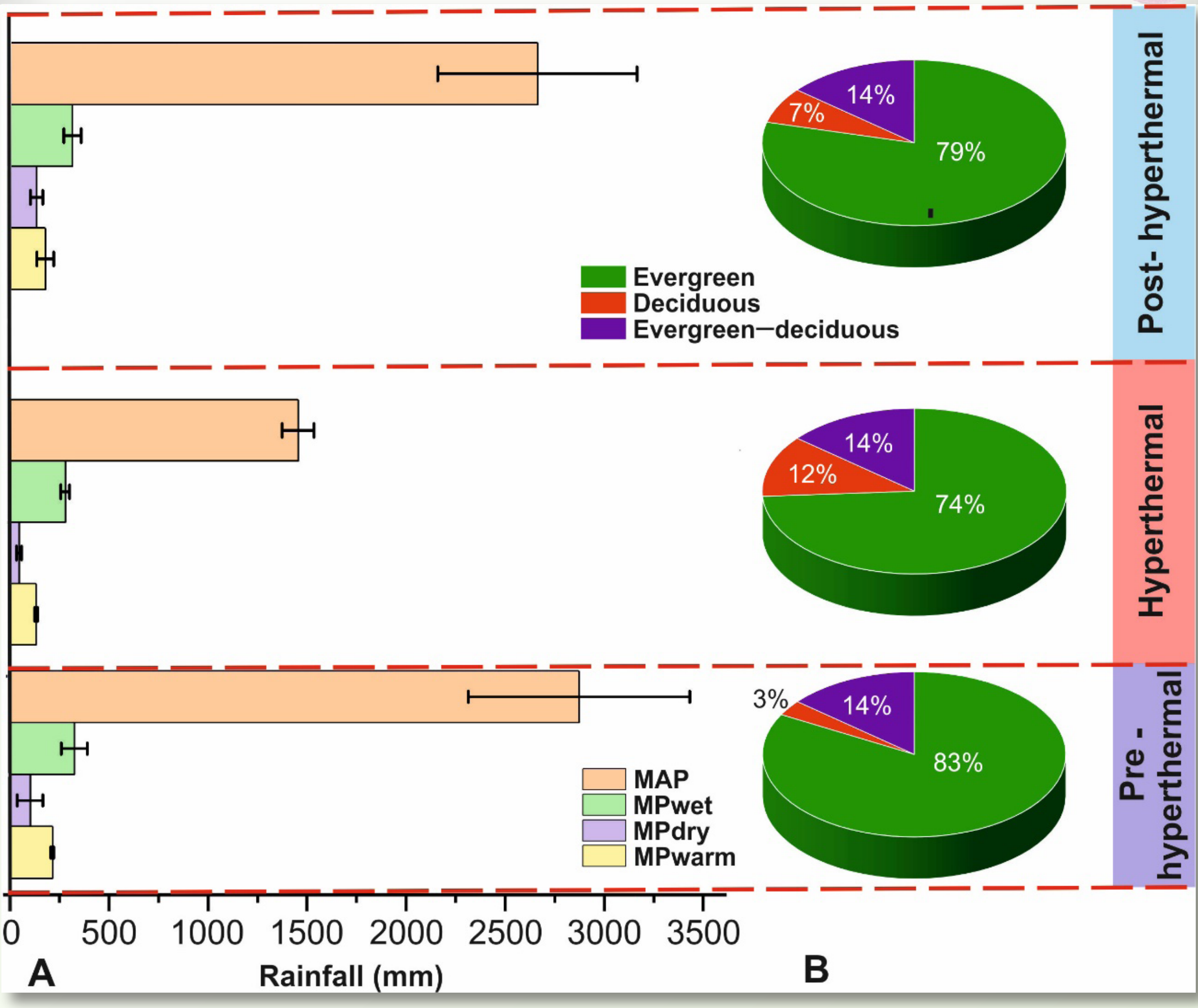

Figure 2. Diagram showing the reconstructed rainfall and the forest types. A) Bar diagram showing seasonal rainfall reconstruction of mean annual precipitation (MAP), precipitation during the wettest months (MPwet), precipitation during the driest months (MPdry), precipitation during the warmest months (MPwarm) in pre-hyperthermal, hyperthermal, and post-hyperthermal phases of the ETM-2. B) Pie diagrams showing changing patterns of forest types during pre-hyperthermal, hyperthermal, and post-hyperthermal phases of the ETM-2 (after Srivastava et al., 2024).

future climate scenarios shaped by unchecked carbon emissions.

The equatorial zone, home to more than two-thirds of the world's biodiversity, is especially critical. Paleoclimate records from this region, such as those preserved in the Kutch Basin of western India, offer valuable insight. During the early Eocene (~53.7 Ma), this region lay near the equator due to the Indian plate's northward drift. Recent palynological (fossil pollen) data from lignite-rich layers in the Panandhro mine (Fig. 1) have helped reconstruct vegetation-climate interactions using *Coexistence Analysis* (CA), a methodology that assumes fossil plants shared similar climate preferences with their modern counterparts.

Findings from Srivastava et al. (2024) reveal a sharp decline in rainfall during the ETM-2 hyperthermal period, accompanied by a longer dry season (Fig. 2). The likely explanation: moist equatorial air was drawn poleward, increasing rainfall in higher latitudes, evident from the growth of palm species even in the Arctic. Consequently, while mid-to-high latitudes saw wetter climates, equatorial regions became drier.

This increased seasonality led to the expansion of deciduous forests at the cost of evergreen ones. Before ETM-2, evergreen taxa accounted for 83% of the flora, with deciduous types making up just 3%. During the warming peak, deciduous taxa quadrupled to 12%, while evergreen species declined to 74%. Notably, moisture-loving plants like palms and pteridophytes diminished, whereas more drought-tolerant legumes proliferated. Post-ETM-2, evergreen species rebounded, suggesting that the forest ecosystem oscillated in response to climate stress.

The transient shift from evergreen to deciduous dominance during peak warming illustrates how sensitive equatorial rainforests are to prolonged dry spells. The evidence strongly suggests that under future warming, driven by rising CO_2, similar patterns may emerge, jeopardizing the biodiversity and ecosystem services these forests provide.

This narrative is more than just a scientific concern, it is a warning. As atmospheric CO_2 levels continue their unprecedented rise due to human activities, the stability and survival of equatorial rainforests hang in the balance. The ETM-2 data show that even short-lived warming episodes can significantly reshape forest compositions. This highlights the urgent need to curb carbon emissions and reinforce conservation strategies. It also challenges a simplistic view of the water cycle, stronger doesn't always mean wetter.

As policymakers and climate leaders deliberate on mitigation strategies, studies like this underscore the delicate interplay between anthropogenic actions and natural systems. The fate of the "Lungs of the Earth" depends not just on what we understand, but on what we do next.

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Mawmluh Cave in Northeast India: Cradle of the Meghalayan Age

Swati Tripathi and Nivedita Mehrotra

TO understand the significance of Mawmluh Cave, we must travel back in time, approximately 4,200 years ago, to a period known as the Holocene Epoch. This is the current geological epoch, which began roughly 11,700 years ago, following the last major Ice Age. However, geologists do not treat the Holocene as one continuous period. Instead, it is divided into three stages: the Greenlandian, the Northgrippian, and finally, the Meghalayan, the youngest stage and the one we inhabit now. The Meghalayan Age officially began 4,200 years ago, triggered by a dramatic climate event, a global drought known as the 4.2 ka event. This was not a localized dry spell, but a worldwide disruption that reshaped human history. Mawmluh Cave is located near Cherrapunji (Sohra) in the East Khasi Hills of Meghalaya, India, a region renowned as one of the wettest places on Earth. Located at an elevation of around 1,290 meters (4,230 feet) above sea level, the cave forms part of Meghalaya's vast limestone cave system. Stretching nearly 7 km (4.3 miles) in length, Mawmluh is among the longest caves in India. Surrounded by lush subtropical forests and fed by exceptionally high rainfall, its unique hydrology has driven the growth of spectacular stalactites, stalagmites, and columns over thousands of years. Nevertheless, Mawmluh Cave is more than a geological wonder; it is also a vital palaeoclimate archive. The stalagmites here preserve ancient rainfall records, which led to the cave's designation as the Global Boundary Stratotype Section and Point (GSSP) for the start of the Meghalayan Age.

Variations in monsoon patterns were recorded in speleothems from the Mawmluh Cave site in Meghalaya, northeastern India. This site forms the basis of the newly defined stratigraphic unit, the Meghalayan Stage/Age, with a modelled basal age of approximately 4,250 years b2k within the Holocene Epoch. The type specimen retrieved as stalagmite from the caves in Meghalaya records the abrupt 4.2 ka event and forms the basis of the youngest Stage, the Meghalayan Stage/Age and the coincident subseries/subepoch of the Late/Upper Holocene (Walker et

Figure 1. Speleothem KM-A from Mawmluh Cave, Meghalaya, the Global Stratotype Section and Point (GSSP) type specimen for the Meghalyan Stage of the Upper Holocene subseries. Image credit: Museum, BSIP, Lucknow.

al. 2018). The International Union of Geological Sciences (IUGS) formally ratified the three-fold subdivision of the Holocene Epoch, suggested by the Working Group of the Subcommission on Quaternary Stratigraphy of the International Commission on Stratigraphy (ICS), on June 14, 2018. They recognized Meghalayan as the youngest stage (Head, 2019).

Birbal Sahni Institute of Palaeosciences, (BSIP) Lucknow, India, safeguards the GSSP type specimen of the Meghalayan Stage/Age and Upper/Late Holocene Subseries/Subepoch which is the speleothem named KM-A from Mawmluh Cave in Meghalaya, northeastern India. BSIP museum is where this type specimen has been placed since November 14, 2018 (Fig. 1). The Society of Earth Scientist in 2022 handed over the IUGS certificate for instating the GSSP of the Meghalayan stage in the Mawmluh Cave, India, included in the first 100 IUGS Geological heritage sites, to BSIP since it is the custodian institute for the type specimen. This important type specimen of GSSP retrieved from northeastern India clearly further drawing the scientific community to this monsoon dominated region due to the recurring evidence of the impact of the '4.2 ka event' recorded there (Mehrotra and Shah, 2023). Interlinked responses of both humans and Earth are repeatedly observed and recorded in various studies globally.

THE 4.2 KA DROUGHT EVENT

Around 4,200 years ago, a severe and abrupt climate disturbance unfolded. This episode, known as the 4.2 ka event, was marked by widespread aridity and cooling lasting nearly 200 years. Its effects were devastating: agriculture-dependent civilizations faltered, ecosystems collapsed, and entire societies faced dramatic change like the crumbling of Mesopotamia's Akkadian Empire, famine and social upheaval of Egypt's Old Kingdom, rapid decline of the Indus Valley Civilization, one of the world's most advanced urban cultures. This global event has been detected in numerous paleoclimate archives, including stalagmites, lake sediments, tree rings, and marine sediment cores. In Mawmluh Cave, a sharp increase in oxygen isotope values ($\delta^{18}O$) in stalagmites marks a significant weakening of monsoon rainfall. This record was so clear and continuous that the International Commission on Stratigraphy selected it as the boundary marker for the start of the Meghalayan Age.

A NATURAL TIME MACHINE

Caves like Mawmluh function as natural time machines. Stalactites hang from the ceiling like stone icicles, while stalagmites rise from the floor like pillars. These speleothems form when water dripping through the cave deposits dissolved calcium carbonate (Figure 2). Over centuries, layer upon layer builds up, locking in chemical clues about rainfall and temperature. What makes Mawmluh Cave unique is the thickness and continuity of its speleothem deposits. Some stalagmites have been growing steadily for tens of thousands of years without major interruptions, providing researchers with an uninterrupted timeline of the past climate. The intense monsoon rainfall in Meghalaya leaves distinct isotopic signatures in Mawmluh Cave stalagmites, making them highly sensitive indicators of even minor changes in precipitation. For scientists, this makes the cave an exceptional archive of past climate variability, while for the Khasi communities who have lived alongside it for generations, Mawmluh remains a place of cultural significance and pride.

A LIVING LEG ACY: HERITAGE AND CONSERVATION

The northeastern India region was always subjected to human migration towards eastern Asia and is a known biodiversity hotspot and a floral and faunal migration corridor in the subcontinent. There is a distinct lack of archeological evidence in northeastern India due to which there is no direct human evidence similar to that of the global civilization collapse event. However, the preservation of the signals of an abrupt climatic change event is evident in palaeo-proxy records, such as isotope, pollen, mineral magnetic, etc. Its designation as both a GSSP and a Geoheritage site underscores the

Figure 2. Mawmluh cave, showing stalactites and stalagmites.

importance of northeastern India as a key archive of the '4.2 ka event'. Multi-proxy analyses from the region clearly reveal abrupt environmental changes associated with this event. Ongoing research aims to explore supporting evidence for human-induced impacts and potential societal responses linked to the '4.2 ka event'.

Mawmluh Cave is more than a scientific site; it is a bridge between culture, science, and conservation. Recognized as a national geological heritage site, its surroundings host rare flora and fauna adapted to Meghalaya's intense rainfall. However, it also faces threats: unregulated tourism, limestone quarrying, and pollution endanger this fragile ecosystem. For the local Khasi community, caves are steeped in tradition and often seen as sacred spaces. Protecting Mawmluh is not only about preserving a climate archive, but also about safeguarding cultural heritage and biodiversity. Mawmluh Cave stands at the intersection of Earth's climate history and human resilience. It tells the story of how global climate shifts shaped civilizations thousands of years ago and offers lessons for our future. By conserving it, we ensure that this natural archive continues to guide us, reminding us of the delicate balance of our planet's past, present, and future.

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Dr Nivedita Mehrotra, a researcher at BSIP, Lucknow, has carried out research in northeastern India, based on multi proxy data of the Late Quaternary sediments. These studies were based on understanding the palaeoclimatic changes in the remote locations of this monsoon dominated region of India.

ARTICLE

Beyond 1.5°C: Evidence of Warming as a Warning

Sneha Mary Mathew, Manoj M.C. and Shailesh Agrawal

THE current decade has brought us face-to-face with a climate emergency. According to recent World Meteorological Organization (WMO) reports, the 11 years from 2015 to 2025 will individually rank as the warmest in the 176-year observational record. The mean near-surface temperature in early 2025 already hit 1.42 °C above the pre-industrial average. Scientists warn that even a fraction of a degree more, exceeding the critical 1.5°C threshold, could trigger devastating planetary tipping points, leading to abrupt, irreversible changes, such as the collapse of ocean circulation systems and the sudden thawing of permafrost.

This reality prompts a critical question: **What happens when the planet warms not by one degree, but by five to eight degrees Celsius? Is such a massive, rapid shift even possible?**

A striking parallel lies 56 million years back, in an ancient hyperthermal event known as the Paleocene–Eocene Thermal Maximum (PETM). During this episode, global temperatures spiked by 5–8°C over a surprisingly short geologic timescale, fueled by a massive release of carbon into the atmosphere.

In summary, the PETM is a clear example of massive carbon release followed by extreme warming, offering valuable insight into how Earth may respond to modern, human-driven carbon emissions.

But the PETM's impact was not felt equally. While scientists have detailed records from the poles and deep oceans, a crucial piece of the planetary stress test has remained obscured: how did the low-latitude tropical world, the engine of Earth's weather systems, respond?

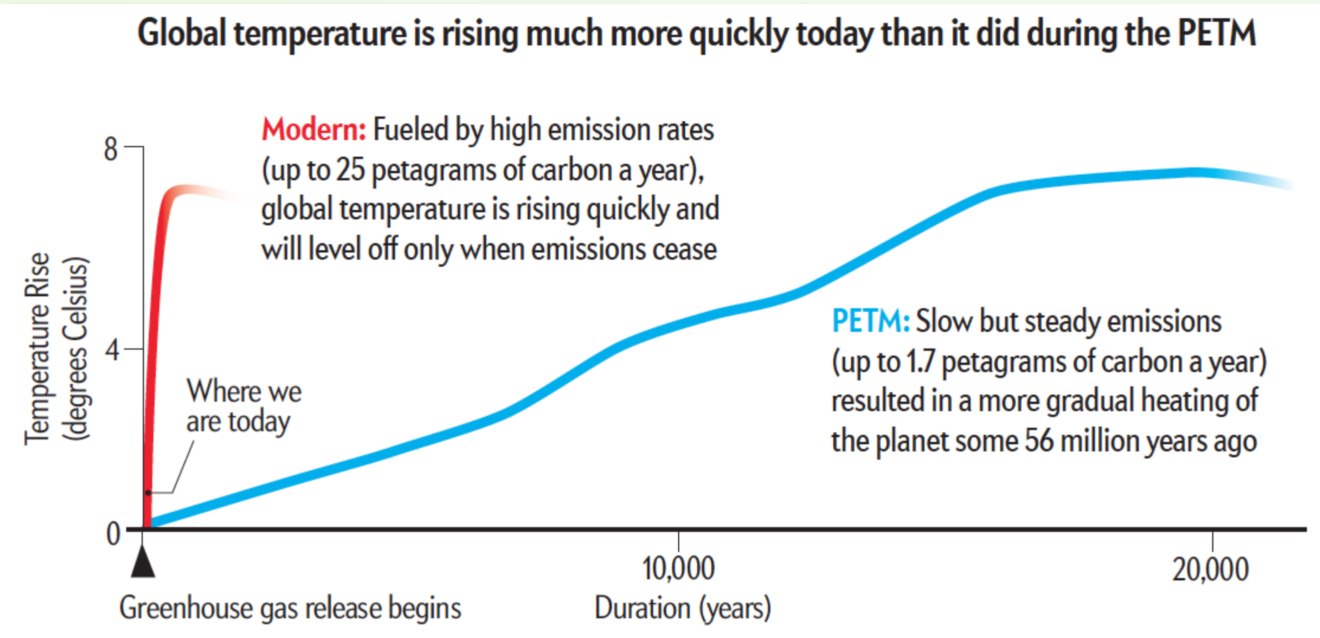

Figure 1. PETM vs. modern warming; Image source: Kump, L. (2011). *Scientific American*.

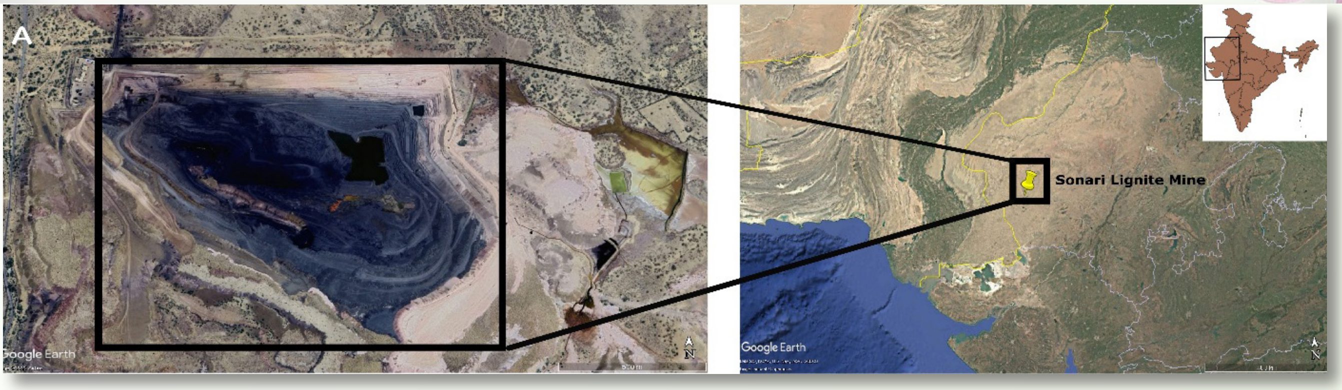

Figure 2. Sonari Lignite Mine, Barmer Basin, Rajasthan (Study Site)

At the time of the PETM, India was located near the equator, far from its present position. Understanding how this tropical landscape responded to ancient warming is important, especially today, as we ask how low-latitude ecosystems will react to continued global warming. Yet, India's geological record of the PETM has historically been sparse. To fill this critical gap, our research focused on the layered Paleogene sediments of the Barmer Basin in Rajasthan.

When we attempt to reconstruct ancient environments, we often think of fossils: bones, shells, or leaf impressions. But organisms leave behind another kind of evidence, their chemical traces. These long-lasting molecules, known as **biomarkers** or **molecular fossils**, can survive long after the physical remains have vanished. Some molecules degrade quickly, much like soft tissues in the fossil record, but others are remarkably resilient.

Among the most durable of these molecular traces are ***n*-alkanes**, long-chain molecules found mainly in the waxy coating of plant leaves. Because they are tough and resistant to decay, they often survive even when no physical fossils remain.

The history contained in these waxes is rich. By studying their composition, we can identify the types of plants that dominate the landscape and track shifts in regional climate, like sudden spikes in humidity. Most importantly, the carbon atoms locked inside these waxes act as a direct recorder of the atmosphere, telling us about the causes and ecological responses to the massive global carbon burst of the PETM.

What were we found in these molecular fossils?

When we analysed the *n*-alkanes extracted from the samples collected, several clear patterns emerged.

Primarily, the molecular fossils confirmed the main event: the carbon isotopes showed a dramatic drop, the negative Carbon Isotope Excursion (CIE), which is the globally recognizable signature of the PETM. This proved that the massive pulse of "light" carbon that defined the crisis was certainly recorded in the tropical Indian sediments.

The magnitude of the shift was staggering: the plant waxes from the Barmer Basin registered an 8.6‰ negative CIE**,** which is among the largest terrestrial signals ever reported for the PETM. This extreme carbon signal, coupled with the *n*-alkane patterns, revealed immediate and pronounced changes in vegetation and regional hydrology. As the climate warmed, humidity levels intensified, and the hydrological cycle.

With regard to the cause of PETM, we found a distinct Pre-Onset Excursion (POE), i.e., a small pre-release of carbon prior to PETM, and it suggests that the global carbon release was not a single, instantaneous event, but a pulsed crisis driven by the destabilization of Earth's major carbon reservoirs before the main thermal maximum.

Taken together, these patterns indicate that India experienced the PETM as a significant climatic event, one that altered vegetation patterns, impacted rainfall, and left a distinct chemical imprint in the sediments.

But should we view this record merely as a geological curiosity from deep time, or a hypothetical 'what if' scenario for a massive temperature rise?

Not really. As the planet warms again, this time because of human activity, the lessons from past events matter more than ever. The PETM record from western India reveals that tropical landscapes can undergo dramatic changes during rapid warming, underscoring the sensitivity of these regions and their pivotal role in the global climate system. It also reinforces the urgent need for global action on the climate crisis.

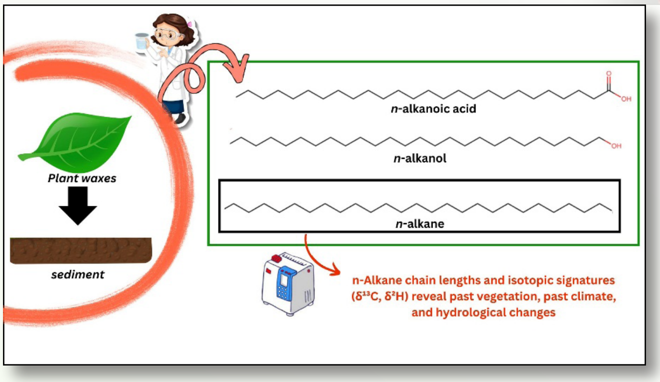

Figure 3: Leaf-wax *n*-alkanes preserved in sediments act as clues to past vegetation and climate.

Read the full study:

Mathew, S.M., Agrawal, S., Manoj, M.C., Sanyal, P., Rahi, I.C., Parmar, S., Prasad, V., Sharma, A. and Naik, A.S., 2025. Unearthing the PETM in the Indian tropics: n-alkane and bulk carbon isotope records from the Barmer Basin. *Palaeogeography, Palaeoclimatology, Palaeoecology*, p.113336. https://doi.org/10.1016/j.palaeo.2025.113336

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Plant Contributions to Hydrocarbon Generation: An Underdiscussed Perspective

Runcie Paul Mathews, Monalisa Mallick and Rimpy Chetia

PETROLEUM consisting of naturally derived or refined hydrocarbon compounds (compounds containing H and C) are formed through the thermal and biochemical alteration of organic matter buried in sedimentary rocks over geological timescales. For years, the conventional theory of petroleum formation has highlighted the contributions of marine phytoplankton and algae. The role of land plants is often "underdiscussed" because their biomass, rich in cellulose and lignin, typically forms coal rather than oil.

HOW DOES LAND PLANTS TYPICALLY FORM COAL?

Under increasing heat and pressure, this organic matter slowly transformed into peat, and eventually, into coal, which is rich in carbon.

Furthermore, it is well established that plant-derived organic matter is capable of producing natural gas. However, it has been long postulated that terrestrial plants may also contribute to oil generation and progressing studies are providing

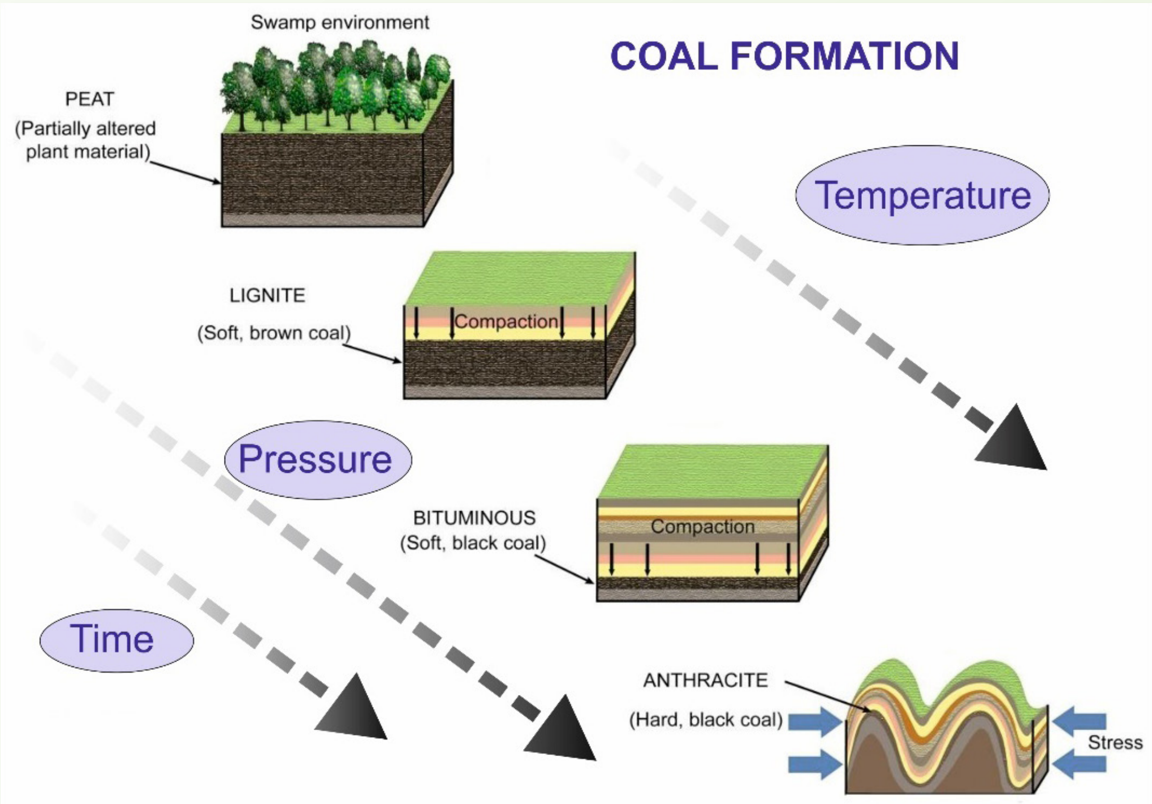


Figure: The formation of coal from plant materials (modified from Ratnayake, 2020) evidences that terrestrial plants do contribute to hydrocarbon generation in specific, often overlooked, ways. This happens when certain unique conditions prevent plant matter from becoming coal and instead funnel it toward petroleum genesis i.e., while the main pathways lead to coal, certain environmental conditions and unique plant biochemistries can create "hydrogen-rich" plant-based 'kerogen', the precursor to petroleum.

WHAT IS KEROGEN?

Before going to the answer this question we should understand about sediments and sedimentary

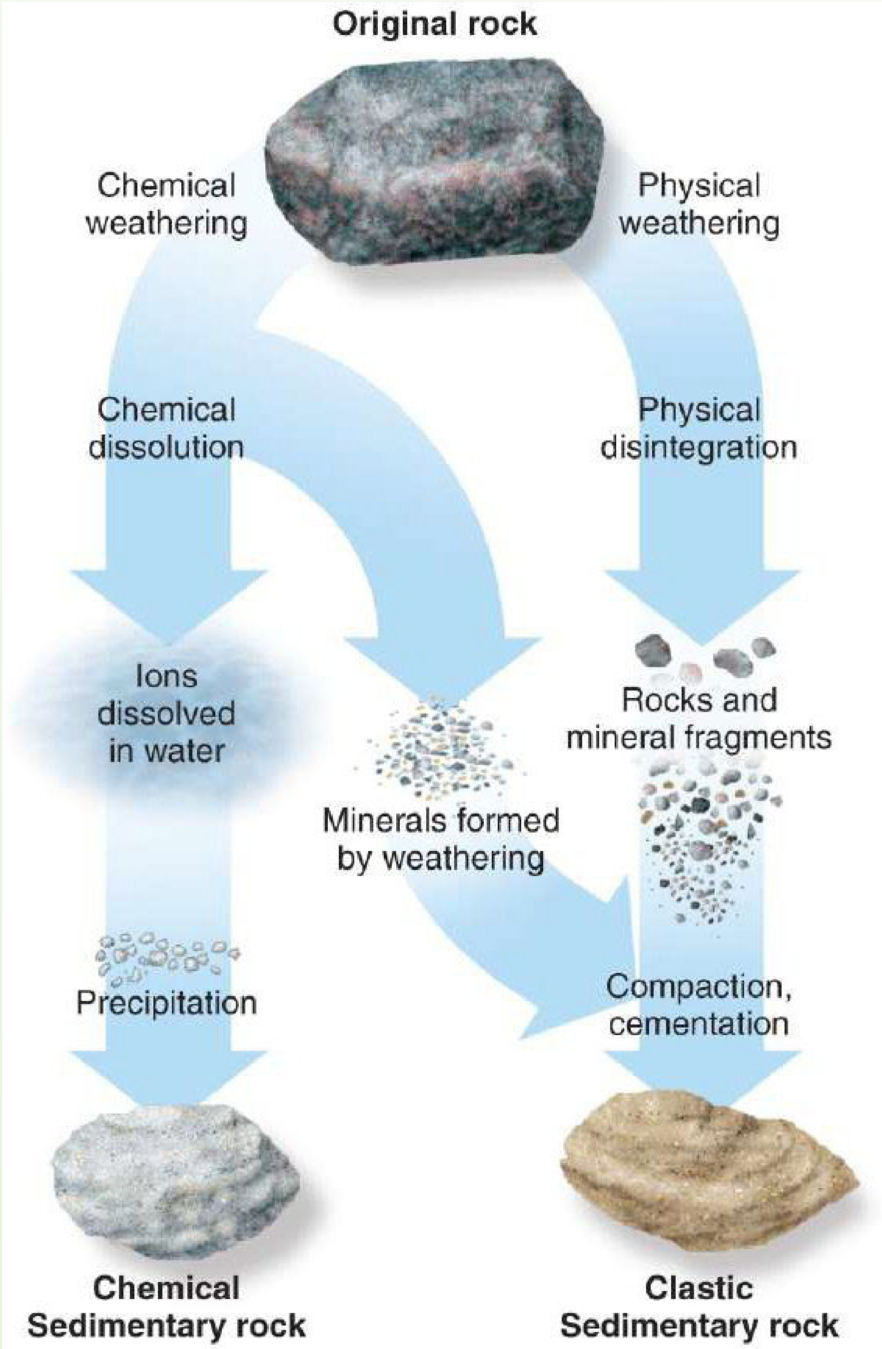


Figure: Formation of chemical and clastic sedimentary rock (from https://saalck.pressbooks.pub).

rocks. Sediments are naturally occurring particles or fragments that result from the weathering (the process of breaking down), erosion (the process of removal), and decomposition of pre-existing rocks, minerals, or organic materials. These materials are transported by agents like water, wind, ice, or gravity and eventually deposited in various environments, such as rivers, lakes, oceans, or deserts.

Sedimentary rocks are of different types viz. 1) Clastic (Detrital): Formed from fragments of pre-existing rocks (e.g., sand, silt, clay, gravel), 2) Chemical: Formed by precipitation of minerals from solution (e.g., rock salt, gypsum) and 3) Biogenic (Organic): Composed of plant or animal remains along with clastic fragments (e.g., coal, chalk, some limestones).

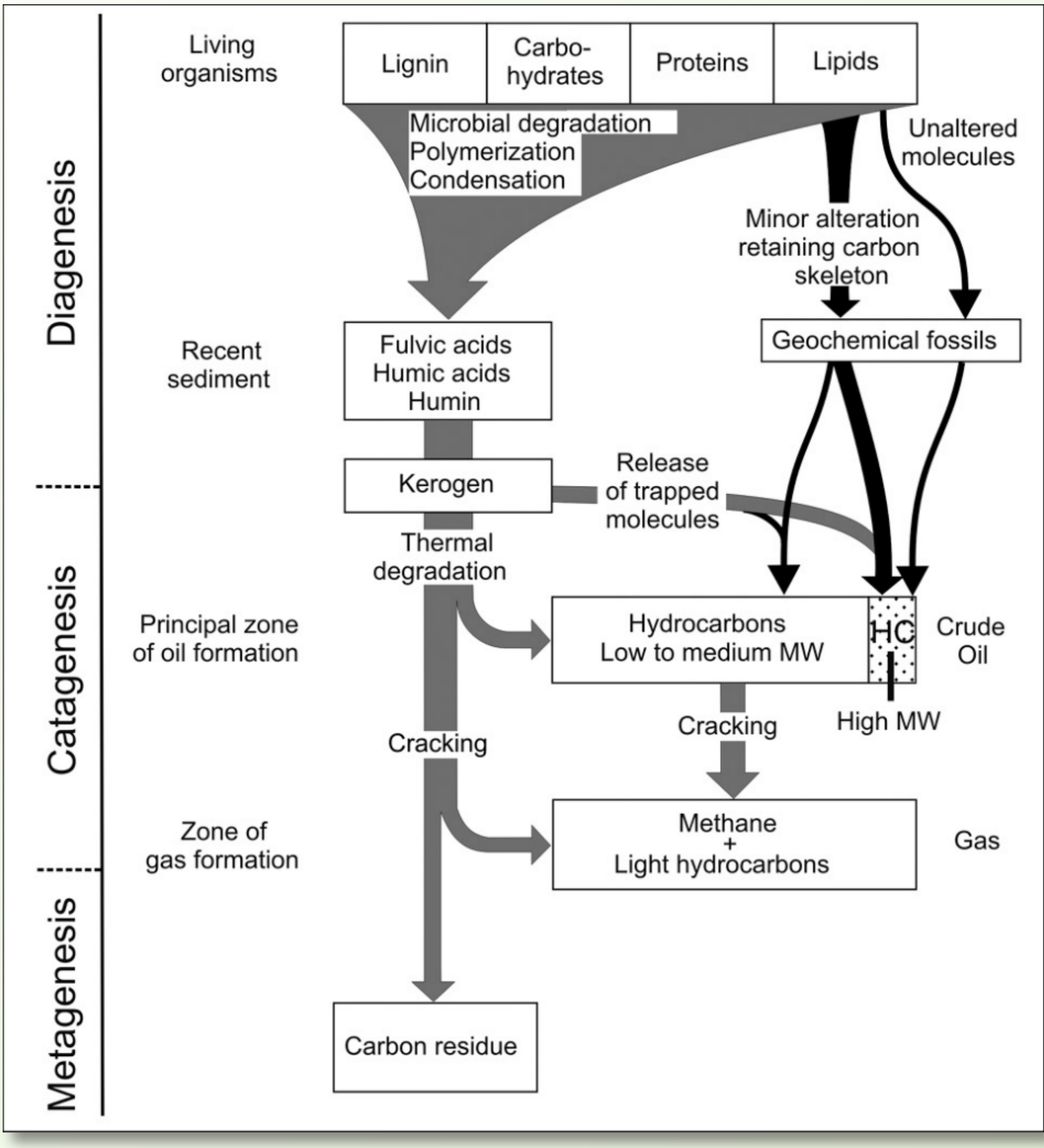


Figure: Diagram showing the formation of kerogen and further to hydrocarbons by the thermal degradation and cracking (Source: Rifts and Passive Margins).

The third type, biogenic sedimentary rock is important in the generation of hydrocarbons. Here, the rock is not only composed of inorganic mineral matter, but also organic remains derived from the dead organisms. Here, we are discussing about the plant derived organic matter.

This plant derived organic matter present in sediments can be seen as highly organic-rich rocks, such as coal or organic-lean rock, such as shale. Although less fraction in shales, these minor content of organic matter can also generate hydrocarbons under favourable conditions. Here, the important factor we had to see is the 'kerogen type'. So, as mentioned before the kerogen and its characteristic determine whether the rocks can generate hydrocarbons or not. Thus, Kerogen is the solid insoluble (to organic solvents) part of complex organic matter present in sedimentary rocks, particularly in shales, oil shales, and coals, and serves as the precursor to hydrocarbons. It is formed by the diagenetic (physical, chemical, and biological changes that sediments undergo after deposition) and catagenetic transformation (transformation where buried organic matter (kerogen) breaks down under increasing temperature and pressure) of biological materials, such as algae, plants, and microorganisms under increasing temperature and pressure during burial. It is a complex mixture of macromolecules rich in carbon, hydrogen, oxygen, nitrogen, and sulfur. When subjected to further heat during thermal maturation, the kerogen 'cracks' or breaks down to generate oil and natural gas. That other part of organic matter which is soluble in organic solvents is called as the 'bitumen'.

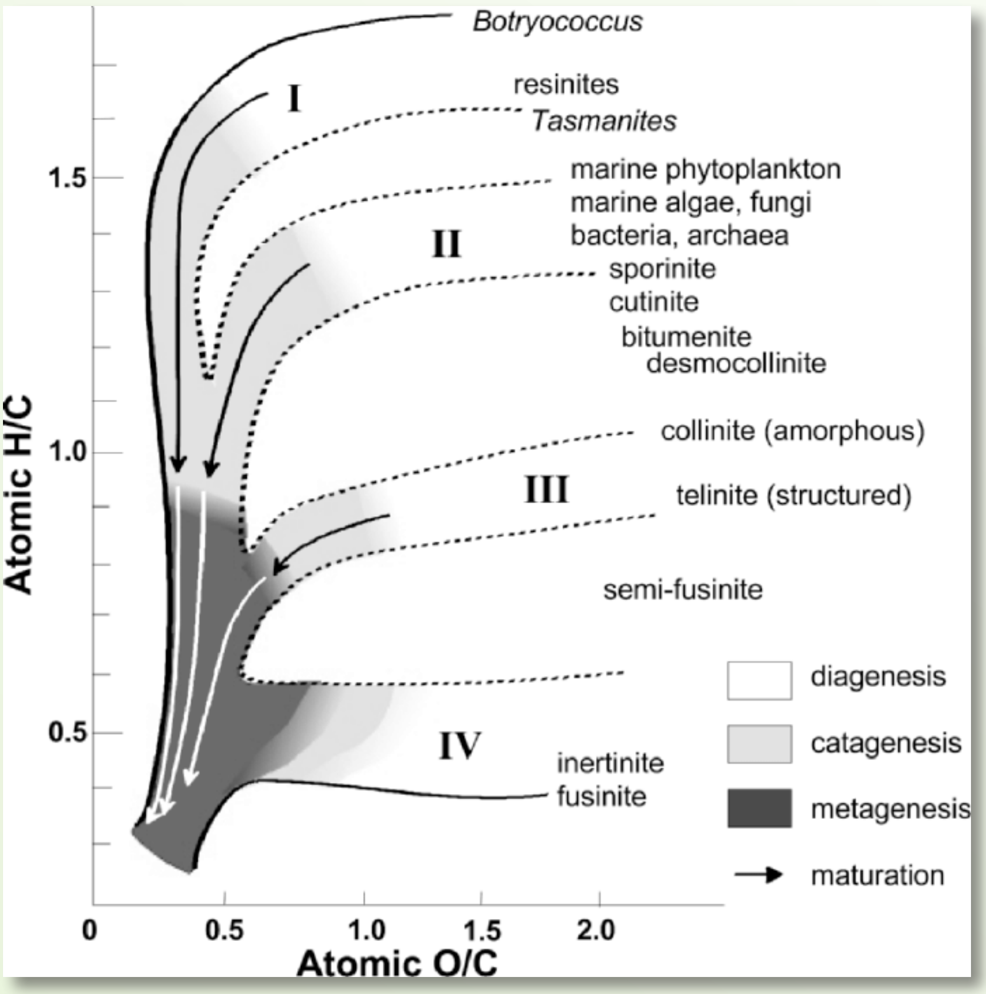


Figure: A van-Krevelen diagram showing different kerogen types, based on the atomic H/C and O/C ratios.

TYPES OF KEROGEN

Kerogen present in sediments are of four different types and the type of kerogen present in the rock determine the type of hydrocarbon generated e.g. oil or gas or mix of oil and gas. Generally, the kerogen is considered as of four types and are as follows:

Type I: Algal origin; hydrogen-rich; oil-prone.

Type II: Planktonic/marine origin; mixed hydrogen and oxygen content; oil and gas-prone. The lighter plant parts, such as resin, spores, pollen grains, cuticle etc. are also constituted in this type.

Type III: Terrestrial plant origin; oxygen-rich; gas-prone.

Type IV: Highly oxidized kerogen, not potential for hydrocarbon generation.

The classical method to determine the kerogen type is the atomic H/C vs. O/C ratio determined from the elemental (CHNSO) analysis of the rock. However, subsequent analytical developments, such as Fourier Transform Infrared (FTIR) spectrometry and Rock-Eval pyrolysis transformed the kerogen type determination rapid and more accurate estimation, which became helpful for the petroleum industry. While the FTIR mainly reveals the functional groups, such as aliphatic, aromatic groups present in the organic matter, Rock-Eval pyrolysis provides estimations of such rocks' total organic carbon content, free hydrocarbon content, amount of hydrocarbons formed during thermal breakdown of kerogen, as well as the temperature for maximum hydrocarbon production.

Along with these geochemical methods, another classical method to determine the potential of rocks to generate hydrocarbon is the petrographical analysis of organic-rich rocks often called as 'organic petrography' or simply 'coal petrography'. This method includes the study of these rocks under specialized microscope to determine the various components present in these rocks. Further, this method can also determine the 'thermal maturity'

Figure: FTIR spectrometer at the Advance Organic Petro-geochemical Laboratory, BSIP Lucknow.

CHNSO analyser at the BSIP, Lucknow

Rock-Eval 6 Pyrolyzer at the Geochronology & Isotope Studies group, NGRI, Hyderabad

attained by these rocks to understand the ability of rocks to generate hydrocarbons. This thermal maturity analysis is called the 'vitrinite reflectance' analysis among organic petrologists.

However, there are some prerequisites needed for the generation of hydrocarbons as given below:

1. UNIQUE ANOXIC ENVIRONMENTS:

- Petroleum generation requires an oxygen-depleted environment to prevent the organic matter from fully decaying. In areas where large quantities of land plants accumulated in low-oxygen marine deltas, estuaries, or lakes, they could have become part of a petroleum source rock rather than a coal deposit.
- This can occur in terrigenous environments with a high input of land-plant material, such as in swamps and coastal plains.

2. LIPIDS AND WAXES FROM PLANTS:

- Land plants produce a variety of lipid-rich materials, including resins, spores, and waxes, which have a high hydrogen content.
- When these specific parts of a plant are preserved and concentrated, they can follow the same thermal maturation path as algae and plankton, ultimately producing oil.

3. BACTERIAL ACTION ON PLANT BIOMASS:

- In oxygen-poor conditions, certain bacteria can break down plant material in a process called methanogenesis, creating biogenic methane (natural gas).
- Bacteria can also degrade and alter plant material in a way that increases its hydrogen content, making it more oil-prone during subsequent thermal maturation.

Therefore, as mentioned, hydrogen is one limiting factor for the formation of hydrocarbons, especially hydrogen to carbon ratio, and softer plant parts, such as resin, spores, pollen, cuticle, etc. are the hydrogen rich components of a plant.

HOW TO UNDERSTAND THE HYDROGEN-RICH PARTS?

As mentioned before, the organic petrographical study is one of the most suitable studies to understand the hydrogen-rich plant components in sediments. When the samples (particulate pellets prepared specifically for this purpose) are studied under microscope (under normal white light and florescence mode), these components can be determined, based on their characteristics, such as colour, shape, size, fluorescence, etc.

These various components are called as 'macerals' by organic petrologists. Hence, it can be also called as main building block of the organic-rich rock, such as coal or kerogen. These macerals belong to three main groups as follows:

Huminite/Vitrinite constituted of a group of oxygen-rich macerals. These are derived mainly from the woody tissues of terrestrial plants; vitrinite is the most abundant maceral group in many shales. This maceral group serves as a key indicator of thermal maturity, measured through vitrinite reflectance. Moderate maturity (0.6–1.2 %Ro) typically corresponds to peak oil generation, while higher maturity (>1.3 %Ro) favours gas generation.

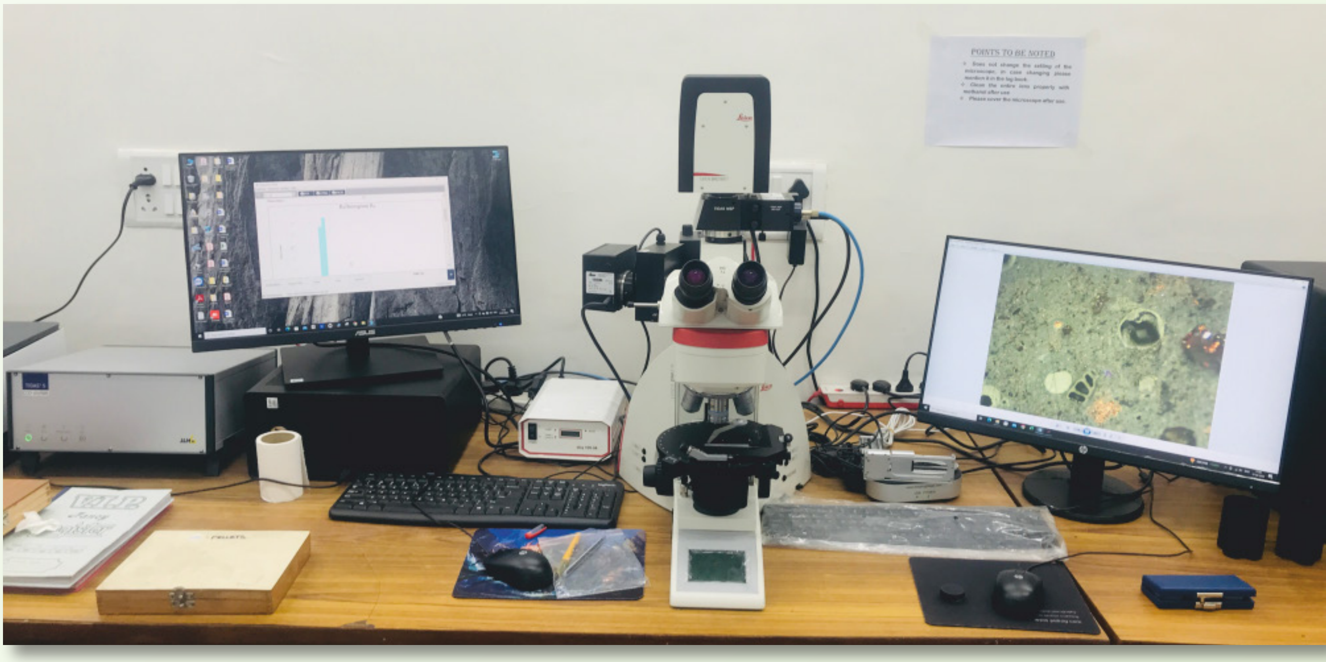
Liptinite group constituted of hydrogen-rich macerals. Composed of hydrogen-rich organic materials, such as spores, algae, and resins, liptinite macerals are excellent precursors for liquid hydrocarbons. Shales dominated by liptinite macerals are usually oil-prone and classified as Type I or II kerogen.

Inertinite *group* constituted of carbon-rich macerals. Derived from oxidized or charred plant material, inertinite has high carbon content, but low hydrogen and oxygen, making it gas-prone and/or relatively inert during thermal maturation.

Here, the huminite/vitrinite group of macerals can generate gaseous hydrocarbons, whereas the liptinite group of macerals can generate liquid hydrocarbons. Hence, a sedimentary rock, such as shale with large amount of 'liptinite macerals' has the potential to generate liquid hydrocarbons or oil under suitable conditions. Similarly, a rock consisting large amount of huminite/vitrinite macerals can generate gaseous hydrocarbons. If the rock contains both these groups, then it can generate mixture of oil and gaseous hydrocarbons. Finally, if the rock is constituted mostly of inertinite macerals, it does not have any ability for hydrocarbon generation. That said, both kerogen type and the maceral composition are important in considering the source-rock potential for hydrocarbon generation.

CONTRIBUTION OF PLANT RESINS

As said before, plant resins are one of the hydrogen-rich components of organic-rich rocks and it is also called as 'resinite' in organic petrography.



Coal Petrographic Microscope with vitrinite reflectance measurement unit at the Advance Organic Petro-geochemical Laboratory of the BSIP, Lucknow.

These are essentially plant exudates, a viscous excretions released by plants while got injured, or under certain other circumstances that hardens on atmospheric exposure. Essentially, the resin is secreted by certain plants as a measure to protect injured parts and to prevent against insects and pathogen. These plant resins are also called as 'amber' and are used widely as fragrance, incense, traditional medicines, paint varnishes or insect repellent. The fossil resins present in the rocks are even used as gemstone in jewellery.

Along with the plant resins, other parts, such as spores, pollen, cuticle, root cells can also contribute towards oil hydrocarbons. 'Alginite' or algae is another major contributor which is considered as a type I kerogen.

The importance of plant contribution to hydrocarbon generation has been mainly consequent from the organic geochemical studies of oils of South East Asia. South East Asian counties, such as Malaysia, Indonesia, Thailand, etc. contain huge reserves of oil in the Cenozoic sedimentary rocks. The source rock-oil correlation studies carried out by pioneer organic geochemists, based on the biomarker compositions revealed the presence of bicadinane and polycadinane structures in these oils. These compounds are signature biomarkers for dammar resin derived from the angiosperm family 'Dipterocarpacea' which proliferated in this region since Miocene as the source of these oils. They became one of the significant plant groups in this region since then. The plants of this family are considered as one of the prolific resin producers and directly sourced the oil in this region. This (plant) family has a pantropical distribution, but is most common in the rainforests of Southeast Asia.

Most significantly, the pioneering biomarker studies in the last few decades by Prof. Suryendu Dutta (IIT, Bombay) and later studies by scientists including Dr. Monalisa Mallick (NGRI, Hyderabad), Dr. Runcie Paul Mathews (BSIP, Lucknow), Dr. Swagata Paul (Jadavpur University) have revealed that this (plant) family existed in the Indian subcontinent during Cretaceous-Paleogene times and then migrated to south east Asia after the collision of India with Laurasia, well supporting the 'Out-of-India

Resin-rich layer in a brown coal deposit

hypothesis'. This (plant) family, which thrives in a tropical warm-humid climate, flourished across the Indian subcontinent, particularly in the south-west Indian rainforests during the Palaeocene-Eocene, when India occupied an equatorial position. This was well supported by the organic petrographical studies by Dr. B.D. Singh (BSIP, Lucknow), palynological studies by late Dr. S.K.M. Tripathi (BSIP, Lucknow) and Dr. Vandana Prasad (BSIP, Lucknow). Therefore, the hydrocarbons produced by the Cenozoic sedimentary rocks of India also have a significant input from this (plant) family. Recent biomarker studies by Kumar et al. (2021) and Mallick et al. (2023) have confirmed the contribution of dammar resin to Cambay Basin crude oils. The study of Mallick et al. (2023) shows that terrestrial organic matter, specifically plant resins can generate significant crude oil, challenging the usual assumption that it mainly produces gas.

Focusing on Eocene lignite-bearing rocks from the Cambay Basin (India), the study finds:

Resin-rich lignites: The lignites contain abundant resinite (fossil plant resin).

Oil-prone kerogen: Geochemical analyses show that these resins are rich in hydrogen and aliphatic compounds, forming Type I/II kerogen that is highly capable of generating oil during maturation.

Plant source identified: Biomarkers (e.g., cadalene derivatives, bicadinane) link the resins to dammar resin from Dipterocarpaceae plants.

Direct link to local oils: The same biomarkers appear in Eocene oils from the Cambay Basin, confirming that these resins contributed to the region's petroleum.

Overall, the chapter demonstrates that resin-rich lignites can act as effective oil source rocks with resinite, playing a key role in boosting their hydrocarbon potential.

This information not only improves the knowledge about the plant sourced hydrocarbons, but also an important contribution by the scientists using multidisciplinary studies, such as organic geochemistry, organic petrography, FTIR, Rock-Eval pyrolysis, Elemental Analysis and palynology in the Cenozoic floral diversity and its relationship with the hydrocarbon source rocks. Further, recognizing the contribution of land plants to hydrocarbon generation offers several insights, such as:

Revealing broader geologic history: It provides a more complete picture of the complex interplay of biology, chemistry, and geology that led to Earth's fossil fuel deposits.

Refines exploration strategies: A more nuanced understanding of plant contributions could help geologists identify new hydrocarbon reserves in locations not typically associated with marine organisms.

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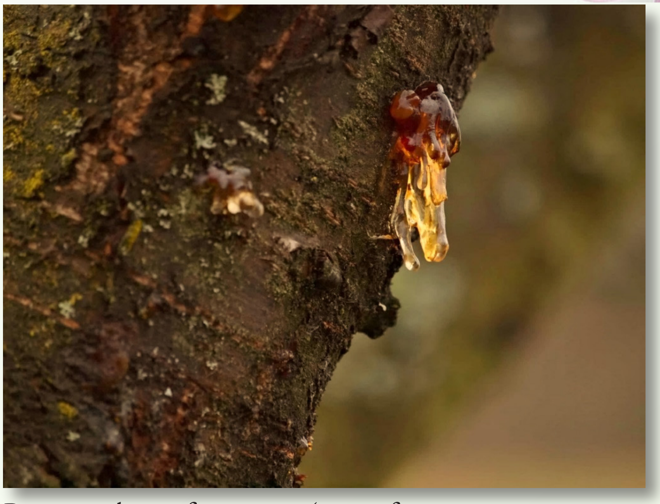
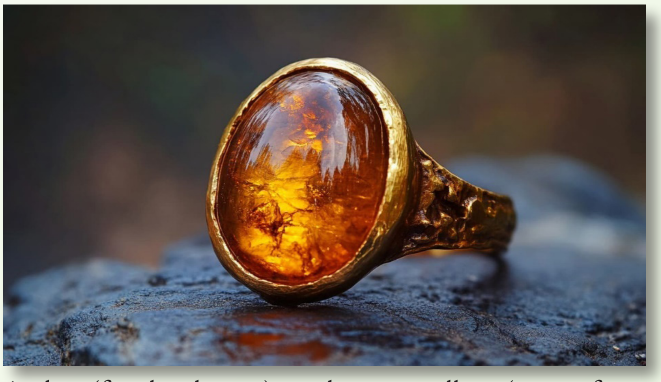
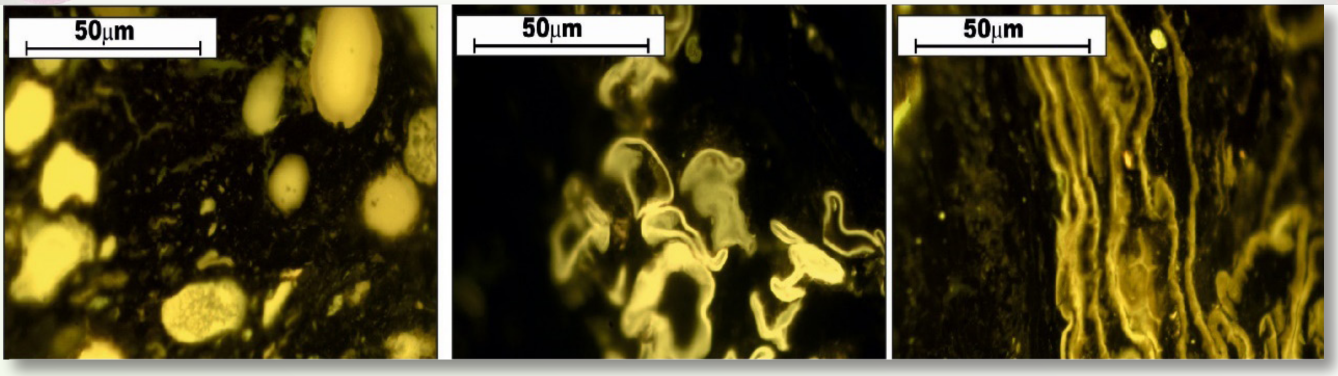


Resin exudation from a tree (image from www. zmescience.com).



Amber (fossilized resin) used as a jewellery (image from www.nobbier.com).

Amber with a fossilized insect (image from Sadowski et al., 2021).



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Living archives: tree-ring science for climate, ecology, and earth surface processes

Devi Lal, Balraju Wagmare, Arushi Kumar, Puspendra Pandey, Benjamin C Sam and Mayank Shekhar

PROLOGUE

The article explores how tree rings serve as natural archives, offering valuable insights into climate, ecology, and Earth surface processes. Each year, trees add a new layer of growth beneath their bark, creating rings that reflect the environmental conditions of that time. By studying these patterns, we can reconstruct past climates, track ecological changes, and understand how landscapes have evolved over centuries. This approach has helped uncover ancient droughts, temperature fluctuations, and even the impacts of volcanic eruptions. Tree rings also provide clues about forest health, wildfire frequency, and species responses to environmental stress making them essential tools in (palaeo)ecological research. Beyond climate and ecosystems, tree-ring data supports the study of erosion, landslides, and other earth surface processes, revealing how natural forces shape the land over time.

INTRODUCTION

Imagine a tree as a living book, with each ring marking a chapter of its life. Dendrochronology is simply the science of reading those rings to uncover the stories of the past. For centuries, trees have stood as silent witnesses to the variability of natural processes, their annual growth rings serving as an unparalleled archive of environmental change. From subtle shifts in climate to dramatic ecological events and the slow, relentless creep of geological forces, tree rings capture a wealth of information, offering scientists a unique window into the past. These living archives provide invaluable long-term perspectives that extend far beyond instrumental records, allowing us to understand natural variability, assess human impacts, and anticipate future environmental trends. In an era dominated by concerns about climate change and ecosystem health, the humble tree ring has emerged as a powerful tool, unlocking secrets of our planet's history and guiding our path forward.

What are tree rings?

At its core, a tree ring is a testament to a year of growth. Trees in temperate and boreal regions typically produce one growth ring annually, a process driven by the cambium, a thin layer of cells just beneath the bark. This annual increment comprises two distinct parts: earlywood and latewood. Earlywood, formed in spring and early summer, consists of large, thin-walled cells facilitating rapid water transport for new leaf growth. As the growing season progresses, latewood is produced, characterized by smaller, thicker-walled cells providing structural support. The sharp contrast between the dense latewood of one year and the porous earlywood of the next creates the distinct annual ring boundary. The width of these rings directly reflects the environmental conditions experienced by the tree during that growing season. Favourable conditions, such as ample moisture and warm temperatures, generally lead to wider rings, while stressful periods, like drought or extreme cold, result in narrower rings. This direct relationship between ring width and environmental factors forms the fundamental principle of dendrochronology.

Tree rings and climate: unlocking past climates (dendroclimatology)

Dendroclimatology, the study of past climates using tree rings, is a significant application of dendrochronology. The principle is straightforward: trees in climate sensitive regions, such as those at their latitudinal or altitudinal limits, exhibit ring-width variations primarily controlled by climatic factors like temperature and precipitation. By analyzing long tree-ring chronologies, sequences of tree-ring widths from multiple trees in a region, cross-dated for accurate annual assignment, dendrochronologist can reconstruct past climate conditions with remarkable precision.

One key strength of dendroclimatology is its ability to extend climate records far beyond the relatively short instrumental record (typically the last 100-150 years). Tree-ring chronologies often extend back hundreds, even thousands of years, providing invaluable insights into natural climate variability before significant human influence. For example, tree-ring data have reconstructed drought patterns in North America and Europe over the past 2,000 years, revealing severe megadroughts far exceeding anything experienced recently. These reconstructions are crucial for understanding the long-term context of current climate change and improving climate models.

Beyond ring width, other tree-ring properties also serve as climate proxies. Latewood density, for instance, often strongly correlates with summer temperatures, providing independent evidence for past thermal conditions. Isotopic composition of tree-ring cellulose (e.g. oxygen and carbon isotopes) can also provide information about past humidity, temperature, and atmospheric CO_2 levels. By combining these multiple proxies, dendroclimatologists build a comprehensive picture of past climate, helping differentiate between natural climate cycles and anthropogenic impacts.

Tree rings and ecology: Understanding ecosystem dynamics (dendroecology)

Dendroecology applies tree-ring analysis to address a wide range of ecological questions, providing a temporal dimension to our understanding of ecosystem dynamics. Trees, as long-lived organisms, record not only climate but also various ecological events impacting their growth. This makes dendroecology an indispensable tool for reconstructing past forest disturbances, population dynamics, and long-term ecosystem health.

One prominent application is reconstructing disturbance regimes. Tree rings reveal the history of events, such as wildfires, insect outbreaks, and avalanches. For example, fire scars – distinct marks left on tree rings by past fires – can be precisely dated, allowing scientists to reconstruct historical fire frequencies and severities. This information is vital for fire management and understanding fire's role in shaping forest landscapes. Similarly, periods of reduced growth or specific anatomical changes in tree rings can indicate past insect infestations or disease outbreaks, providing insights into long-term pest population dynamics and their impact on forest health.

Dendroecology also contributes to understanding forest development and succession, ecotone and treeline dynamics, and pollution impacts. By analyzing individual tree and stand growth patterns, researchers infer competition dynamics, stand age structures, and the timing of forest regeneration events. Studies at treelines, where tree growth is often temperature-limited, reveal how these sensitive ecosystems respond to climate warming or cooling. Furthermore, tree rings record environmental pollution history, as trees incorporate pollutants from the atmosphere and soil into their wood, providing a chronological record of contaminant levels over time.

Tree rings and earth surface processes: dating geomorphic events (dendrogeomorphology)

Dendrogeomorphology is a specialized field using tree rings to date and reconstruct past earth surface processes, particularly natural hazards. Geomorphic events, such as landslides, rockfalls, floods, and debris flows leave distinct imprints on tree growth, which can then be analyzed to determine the timing and magnitude of these events. The impact of a geomorphic event on a tree manifests in various ways. A tree partially buried by a landslide might exhibit a sudden growth release as competition is reduced, or a change in ring eccentricity as it attempts to reorient itself. Scars on tree trunks from impacts by falling rocks or debris can be precisely dated to the year of the event. Trees on unstable slopes might show tilted growth, leading to the formation of reaction wood (compression wood in conifers, tension wood in hardwoods), anatomically distinct and identifiable in tree rings.

By studying these tree-ring responses, dendrogeomorphologists build chronologies of past geomorphic events, providing crucial data for hazard assessment and risk management. This long-term perspective is particularly valuable in regions with limited historical records of natural disasters. For example, tree-ring studies have reconstructed the frequency and magnitude of debris flows in mountainous regions, helping identify prone areas and inform land-use planning. The ability to precisely date these events also aids in understanding their triggers and controlling factors, contributing to a more holistic understanding of landscape evolution.

The science behind the rings: methodology of dendrochronology

The power of tree-ring science lies in its rigorous methodology, ensuring the accuracy and reliability of reconstructed environmental records. The process typically begins with careful sample collection, followed by meticulous laboratory preparation and, most critically, crossdating.

Sample collection

Tree-ring samples are usually collected using an increment borer, a non-destructive tool that extracts a small, pencil-thin core from bark to pith, containing the complete sequence of annual growth rings. For living trees, two cores are often taken from opposite sides to account for localized growth anomalies. For historical timbers or archaeological

Figure 1. The annual growth rings of a tree where the variation in ring widths is response to the local climatic and ecological variability

wood, cross-sections or wedges may be taken without compromising artifact integrity. The location and context of each sample are meticulously recorded, including species, geographical coordinates, elevation, and relevant site characteristics. This contextual information is crucial for interpreting tree-ring data and understanding environmental factors influencing tree growth at that site.

Laboratory preparation

Collected tree-ring cores or wood samples are pre-processed in the laboratory. They are typically mounted in wooden holders, then carefully sanded and polished using progressively finer grits of sandpaper. This creates a smooth, flat surface where individual annual rings become clearly visible under a microscope. The distinct boundary between the dense latewood of one year and the lighter earlywood of the next is essential for accurate ring counting and measurement. Some samples may also be stained to enhance ring visibility.

Cross-dating: the cornerstone of dendrochronology

Cross-dating is arguably the most critical step in dendrochronology, transforming simple ring counting into a precise scientific dating method. It involves matching patterns of wide and narrow rings across multiple tree-ring samples from the same region, often from different trees and species. Because trees in a given area are generally subjected to the same climatic influences, they exhibit similar patterns of growth variability.

For example, a widespread drought in a particular year will likely result in a very narrow ring. In most trees in that region, while a year with abundant moisture might produce a wide ring. By identifying these unique patterns and matching them across numerous samples, dendrochronologists assign an exact calendar year to each tree ring, even in samples with missing or faint rings (a phenomenon known as a false ring or a locally absent ring).

This meticulous process allows for the construction of master chronologies – long, continuous, and

Figure. 2. Sample collection using an increment borer: (a) Boring into the tree stem, and (b) Retrieving the increment core using an extraction spoon.

accurately dated sequences of tree-ring widths spanning hundreds to thousands of years. Without cross-dating, tree-ring analysis would be merely ring counting, susceptible to errors from missing or false rings, and would lack the temporal precision that makes dendrochronology such a powerful tool for environmental reconstruction.

Applications across disciplines

The versatility of tree-ring science extends its utility across a multitude of scientific disciplines, offering unique perspectives and long-term data often unattainable through other means.

Climate science and paleoclimatology

As discussed, dendroclimatology is a cornerstone of paleoclimatology. Tree-ring data have been instrumental in reconstructing past temperature, precipitation, and drought patterns on regional and continental scales. These reconstructions are vital for understanding natural climate variability, identifying the frequency and intensity of extreme climate events (e.g. megadroughts or prolonged cold spells), and providing a baseline to assess recent anthropogenic climate change.

For instance, tree-ring records reveal that some recent droughts, while severe, are not unprecedented in the context of the last millennium, but their current intensity and widespread nature, coupled with rising temperatures, suggest a different underlying cause. This historical context is crucial for climate modeling and developing effective adaptation and mitigation strategies.

Ecological research and forest management

Dendroecology provides a powerful lens to examine long-term ecological processes. Beyond disturbance history, tree rings shed light on forest growth rates, stand dynamics, and competitive interactions. Researchers use tree-ring data to study the impacts of insect outbreaks, disease epidemics, and invasive species on forest health and productivity over centuries. This information is critical for sustainable forest management, allowing managers to understand the natural range of variability in forest ecosystems and develop strategies promoting resilience to environmental change.

For example, understanding historical fire regimes through dendroecology can inform prescribed burning practices aimed at restoring ecosystem health and reducing catastrophic wildfire risk.

Earth surface processes and natural hazard assessment

Dendrogeomorphology has revolutionized the study of earth surface processes by providing precise dating of geomorphic events. This sub-discipline is particularly valuable in mountainous regions prone to natural hazards. By analyzing tree-ring anomalies caused by events, such as landslides, rockfalls, debris flows, and floods, scientists reconstruct the frequency, magnitude, and spatial extent of these events over long timescales.

This historical data is essential for hazard mapping, risk assessment, and developing early warning systems. For example, dendrogeomorphological studies have identified areas with high recurrence of debris flows, allowing for better land-use planning and infrastructure development in vulnerable areas. The ability to precisely date these events also helps understand their triggers and controlling factors, contributing to a more holistic understanding of landscape evolution.

The future of tree-ring science

The field of dendrochronology continues to evolve, with new technologies and analytical techniques constantly expanding its capabilities. High-resolution imaging, X-ray densitometry, and stable isotope analysis provide increasingly detailed information from tree rings.

The integration of tree-ring data with other paleoclimate proxies, remote sensing data, climate models and machine learning models is leading to a more holistic understanding of Earth's systems.

Furthermore, the development of global tree-ring networks facilitates largescale climate reconstructions and enhances our ability to understand teleconnections and global climate patterns.

As the impacts of climate change become more pronounced, the demand for long-term environmental data will only increase. Tree-ring science, with its unique ability to provide annually resolved, precisely dated records of past environmental conditions, will remain an indispensable tool. These living archives will continue to help us unravel the complexities of Earth's past, inform our understanding of the present, and guide our efforts to build a more sustainable future.

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Hidden hazards: Palynomorphs as aeroallergens

Mohammad Firoze Quamar

PALYNOLOGY is the discipline in which we study about microscopic organic structures (especially the pollen grains and spores: palynomorphs), which are resistant to treatments with hydrofluoric acid (HF). As a matter of fact, pollen is a combined Greek and Latin words. It is derived from a Greek verb: palunō, which means I strew or sprinkle; palunein: to strew or sprinkle; Greek noun: pale- dust, fine meal; and Latin word: pollen- fine flour, dust; and Greak noun: logos- word, speech, to study (Pollen Analysis Circular no. 8, p. 6). Therefore, pollen grains are also known as "Golden Dust", "Wonder Dust of Nature" and the "Nature's Fingerprints of Plants".

Pollen grain is the immature male gametophyte or the first cell of male gametophyte, the primary function of which is to perform the vital task of sexual reproduction through production and transport of male gametes. It is formed in the anther of the flowers by the reduction division (meiosis) of the pollen mother cell. Initially, they are formed in tetrad. Most pollen is liberated as a single grain, but in some families such as Ericaceae, Orchidiaceae, Typhaceae, etc. the grains remain united in tetrads. Each plant produces pollen or spores that are distinctive from those of other plants; the uniqueness can sometimes only be seen at the Field Emission Scanning Electron Microscope (FESEM), Transmission Electron Microscope (TEM) and/or Confocal Laser Scanning Microscope (CLSM) level. Pollen and spores can usually be identified at the plant family, genus, and sometimes at the species level with light microscope (LM). Pollen, in fact, carries the male sex cells of flowering plants-phanerogams or spermophyta (angiosperms: plants bearing closed seed) and cone producing plants (gymnosperms: plants bearing naked seeds), whereas spores are the asexual reproductive bodies of cryptogams (algae and fungi-thallophyta, mosses-bryophyta, and ferns-pteridophyta). During pollination (transfer of male gametes/sperm cells from the stamen to the pistil of flowers of the angiospermous plants and/or female cone of the gymnospermous plants), pollen germinates and produces a pollen tube that transfers the sperm to the ovule and/or to the female cone. As a matter of fact, pollen is the carrier of genetic material from one generation to the other and is, thus, important units in the biological cycle of flowering plants.

Pollen grains after release from plants remain suspended in the air for extended periods due to wind and turbulence, and are transported by air currents. The pollen grains and spores of various plants, which vary according to the local flora, climate (temperature, relative humidity, wind velocity and rainfall), meteorological factors and the season, are regarded as a prospective cause of certain allergic disorders. Thus, the palynomorphs due to their aerial prevalence all the year round serve as aeroallergens, and belong to the plant taxa, such as *Madhuca indica*, *Holoptelea*, *Lannea coromandelica*, *Terminalia* spp., *Diospyros melanoxylon*, *Emblica officinalis, Aegle mermelos*, *Schleichera oleosa*, *Syzygium cumini*, *Eucalyptus citridora*, *Ailanthus excelsa*, *Morus alba*, *Grewia*, *Bombax ceiba*, *Bauhinia*, *Cedrela toona*, *Polyalthia longifolia*, *Putranjiva roxburghii*, *Prosopis juliflora* and *Prosopis cinearia*, Sapotaceae, *Casuarina equisetifolia*, *Flacourtia*, Anacardiaceae, *Acacia*, *Azadirachta indica*, *Melia azedarach*, *Dodonea viscosa*, *Tribulus terrestris*, *Argemone mexicana*, *Cocos*, *Pinus*, *Cedrus*, *Alnus*, *Ziziphus*, *Ricinus*, *Ephedra*, Tubuliflorae, Poaceae (grasses), Cheno/Am (now Amaranthaceae),

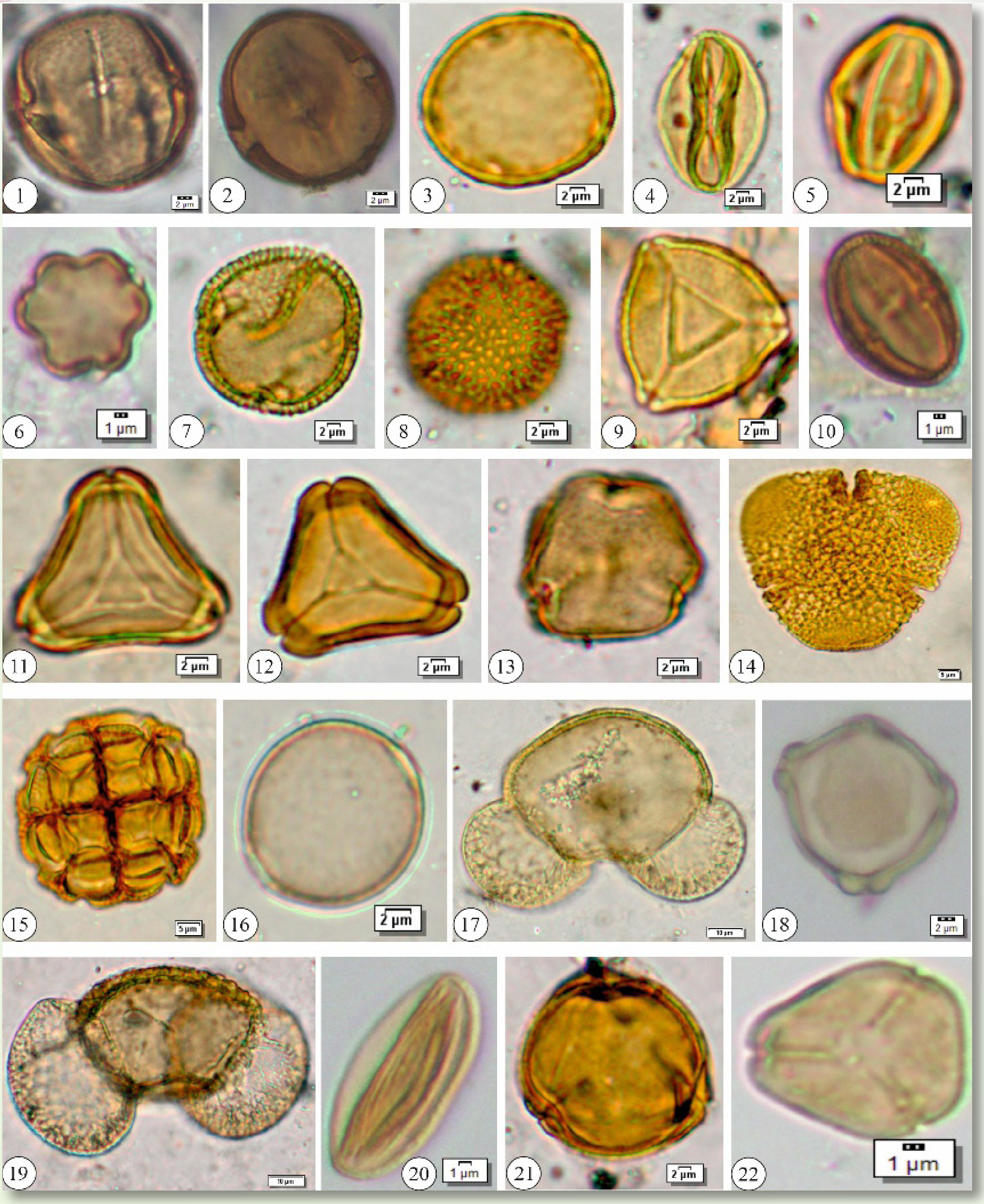

Figure 1. Key palynomorphs showing allergenicity in India. 1-2. *Madhuca indica*, 3. *Holoptelea integrifolia*, 4. *Lannea coromandelica*, 5-6. *Terminalia* spp., 7. *Emblica officinalis*, 8. *Aegle marmelos*, 9. *Schleichera oleosa*, 10. *Lagerstroemia parviflora*, 11. *Syzygium cumini*, 12. *Eucalyptus*, 13. *Ailanthes excelsa*, 14. *Bombax ceiba*, 15. *Acacia* spp., 16. *Morus alba*, 17. *Pinus* spp., 18. *Alnus* spp., 19. *Cedrus*, 20. *Ephedra*, 21. *Ricinus communis* , 22. *Ziziphus* sp.

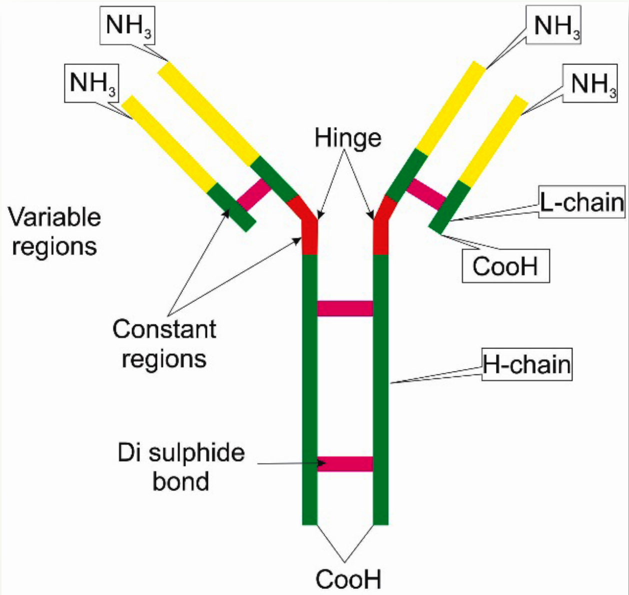

Figure 2. IgE antibody

Artemisia, Caryophyllaceae, *Cannabis sativa*, *Argemone Mexicana*, *Xanthium*, *Justicia*, *Capsicum frutescens*, Brassicaceae, Lamiaceae cf. *Pogostemon*, *Parthenium hysterophorus*, *Hyptis*, ferns, Cyperaceae (sedges), etc. Besides, algal spores, and good number of fungal spores, such as *Diplodia*, *Nigrospora*, *Curvularia*, *Cookeina*, *Alternaria*, *Helminthosporium*, etc. have also serve as aeroallergens (Fig. 1). The most common allergic disorders, caused by palynomorphs, are bronchial asthma, hay fever (allergic rhinitis/pollinosis), dermatitis and other disorders, such as naso-bronchial allergy and other respiratory disorders along with conjunctivitis, contact dermatitis, eczema, food allergies and other health hazards. The pollen grains release proteins (Ig E-binding proteins) that may be responsible for immediate hypersensitivity reactions in sensitive patients (Fig. 2).

Aeropalynology (an applied branch of science) deals with the study of pollen grains and spores present in the atmosphere, which transports to different places through air. However, aerobiology (an interdisciplinary science) deals with the study of air-borne biological particles (bioparticles) or biopollutants and chemicals that are passively suspended and dispersed, and which poses burden for the respiratory tract of humans. Aerobiology, besides pollen and spores, comprises algae and protozoans, animal danders, fungal spores, minute insects, such as aphids, mites, pollution gases and particles that exert specific biological effects. Aerobiological investigations have been carried out in different parts of the country to ascertain aerial concentration and seasonality of pollen and fungal spores. This science aims to understand mainly the spread of diseases in humans, animals, and plants, and thereby seek their prevention.

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A Lake That Remembered: Kondagai's Silent Chronicle of Climate and Civilization

Anand Rajoriya and Biswajeet Thakur

LONG before proper written records, before some of the known scripts, and even before the rise of early urbanism, a quiet oxbow lake along the Vaigai was already documenting everything. Layer by layer, year after year, the sediments of Kondagai Lake were storing stories of rain and drought, of flood, of forests and farms, of humans who came, settled, shaped the land, and eventually moved on. Today, more than 4,400 years later, those stories have been decoded (Fig.1).

A recent study has brought to light an extraordinary environmental history preserved in the sediments of this unassuming lake near Keeladi. Using a blend of stable isotopes, microscopic fossils, grain-size analysis, and radiocarbon dating, the researchers reconstructed a detailed timeline of climate rhythms and human

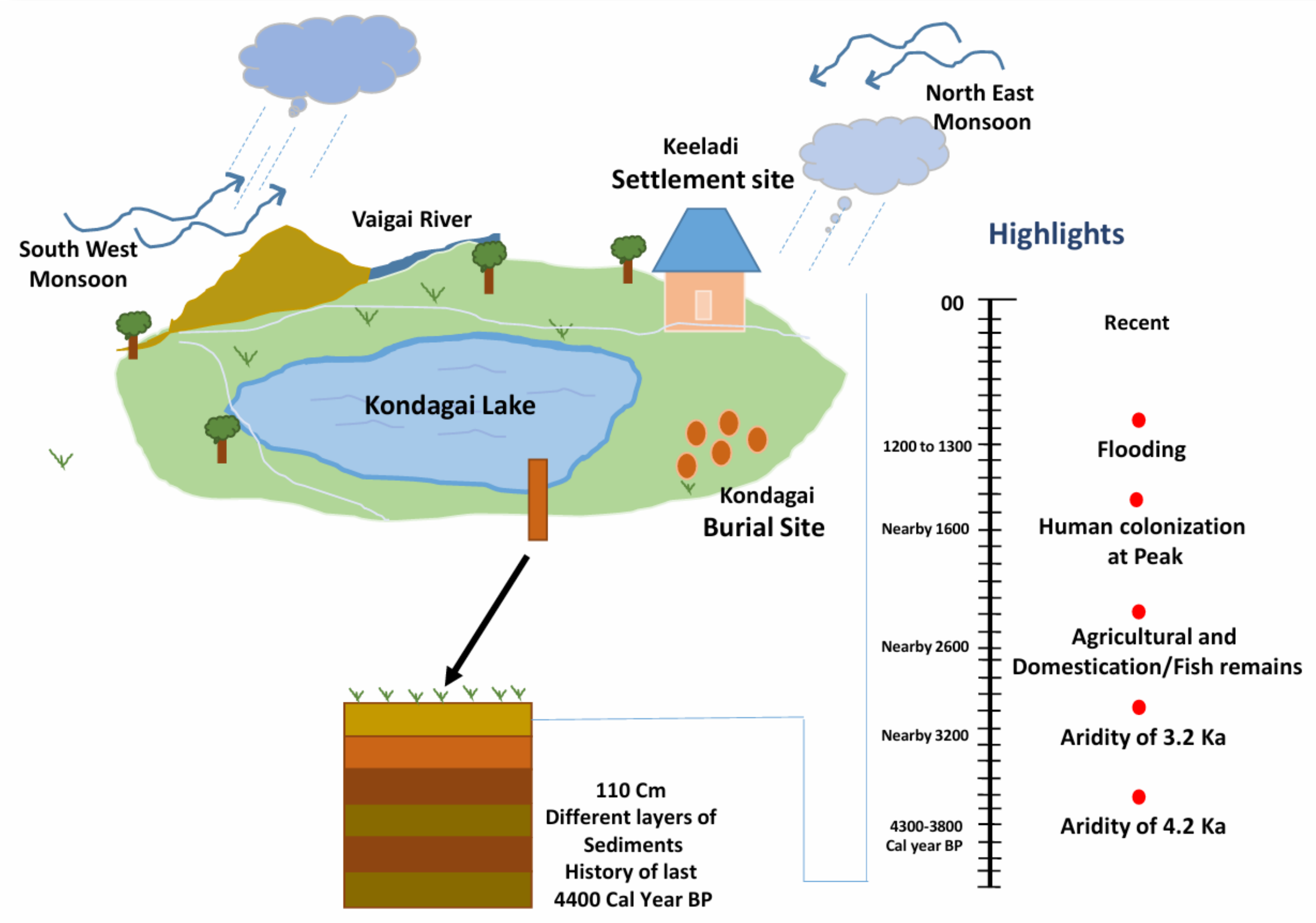

Figure 1. Study area.

activities over the last 4,400 years in the Sivaganga region (Fig. 2), an area that has become central to understanding South India's early cultural landscape.

What emerges is a narrative that feels almost cinematic. Around 4,200 years ago, a major climate event swept across several parts of the world, contributing to the decline of the Indus Valley civilization, Akkadian empire and weakening river-fed civilisations in West and South Asia. Tamil Nadu, too, felt its echo. The sediments from Kondagai reveal a sharp shift to drier conditions, reduced lake levels, and a surge in hardy C_4 grasses. Algal abundance dipped, microscopic fungal spores rose, and the lake's chemistry changed as rainfall faltered. The global 4.2 ka drought was not an isolated northern phenomenon, it reached deep into the peninsular part of south India.

Yet, this dry spell was punctuated by a brief, unexpected wet phase, like a single respite in a harsh season. The lake remembers this clearly: finer sediments, enhanced aquatic remains, and a slight recovery in moisture-loving plants. But the larger trend remained unmistakably arid. Centuries later, another major dry phase, around 3,200 years ago, left its imprint. This time, erosional signatures and coarse grains washed in from the catchment suggested shrinking vegetative cover and weakened monsoon activity. These episodes reshaped landscapes and likely influenced human movement across the Vaigai basin.

The lake's story becomes even more compelling as it intersects with the archaeology of Keeladi. As habitation intensified during the second phase of urban settlement, the lake sediments responded. Nitrogen isotopes, especially $\delta^{15}N$, rose sharply,

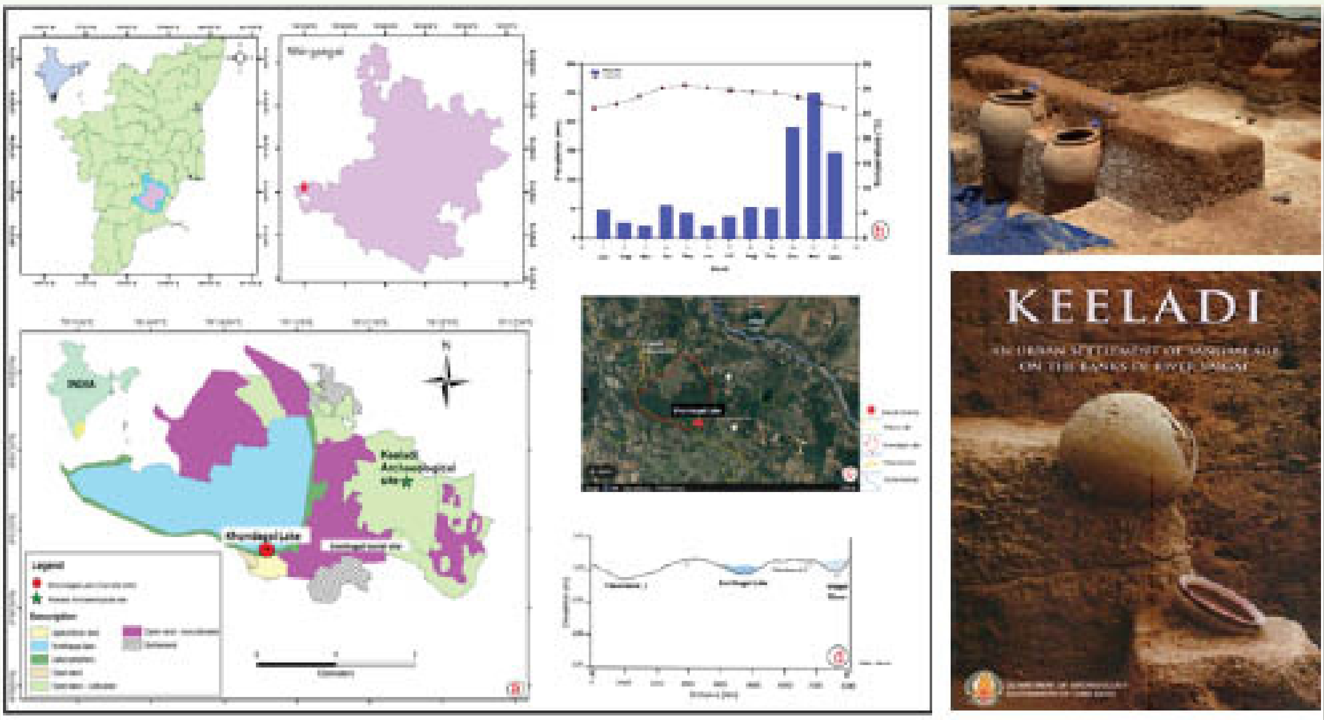

Figure 2. (a) Study map of the Khondagai Lake (KLD), Tamil Nadu, showing the profile location with land use and land cover in the vicinity of the study site. (b) The mean monthly precipitation in the Khondagai district, Tamil Nadu, from 1901 to 2020 AD was extracted online from the KNMI Climatic explorer https://climexp.knmi.nl/start.cgi. (c) Google Earth imagery showing the study site, the location of the paleochannels, and the Ox-bow lakes in the Vaigai River basin. (d) Cross section along KK', showing that T0 is the active channel and T1 is the river trace and the location of the paleochannels of river Vaigai. (e) Kondagai burial site.

signalling increased organic inputs associated with livestock, agriculture, and human-agricultural waste (Fig.3). It is a rare geochemical fingerprint of human presence, captured not in stone or pottery, but in the chemistry of mud. The timing aligns beautifully with archaeological records, making this one of the few environmental archives in South India that reflect human settlement so clearly.

More clues come from pollen and micro-remains. Cerealia grains whisper of cultivated crops. Aquatic algae speak of stable water bodies nurtured by human-managed landscapes. There are even biological hints of early fish culture and an ancient practice that rarely leaves a trace in the archaeological record. Together, they reflect a society that understood its waters, tended them, and possibly farmed them.

Curiously, the very reason Keeladi may have been chosen as a settlement becomes evident in the lake data. Unlike much of peninsular India, Kondagai receives rainfall from both the Southwest and Northeast monsoons. This dual monsoon advantage created a climatic buffer, ensuring water availability even during weakened phases of the summer monsoon. The ancient settlers may not

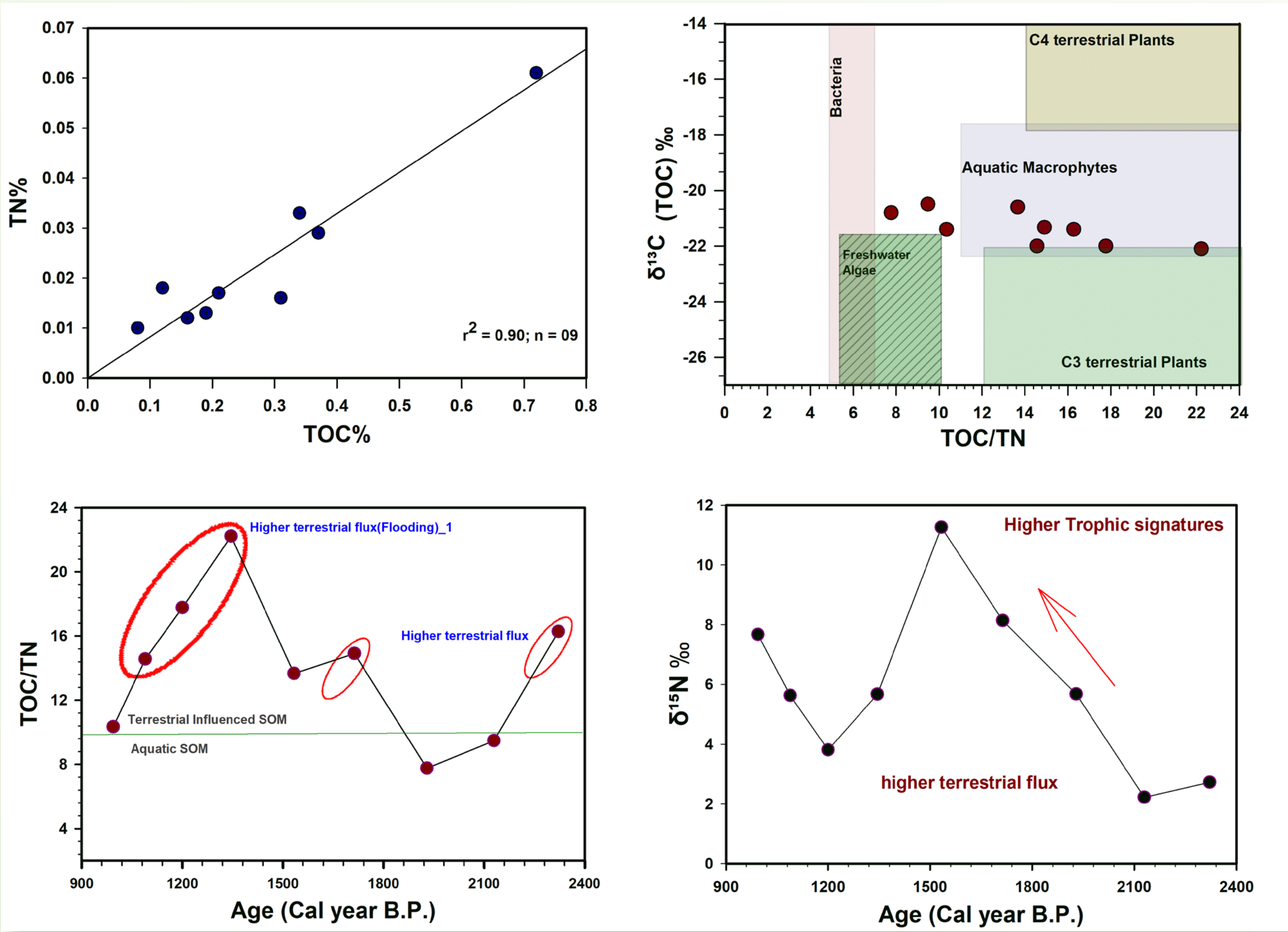

Figure 3. Different bi-plot of isotopes and elemental concentration used to infer; (a) This plot (TOC% vs TN %) shows the organic boundnace of the Nitrogen and carbon as the r score is nearly 01. (b) This plot (Delta ^{13}C Vs TOC/TN) shows the different sources of the organic matter. (c) This plot (TOC/TN ratio vs Age) shows the terrestrial flux loading at the study site during the specific time, marking the flooding. (d) Delta ^{15}N vs Age plot shows the changes in the tropic level during the higher colonization time around the study site.

have articulated this in hydrological terms, but they certainly understood it. The landscape itself offered security, resilience, and continuity, qualities vital for sustaining an urban settlement.

The lake's final act is an ode to global climate synchrony. Between 2,000 and 1,600 years ago, the Roman Warm Period left its imprint in Tamil Nadu too. Increased rainfall, a thriving aquatic ecosystem, and enhanced sediment influx marked this chapter. And around 1,300 years ago, during what climatologists call the Dark Age Cold Period, the lake recorded sudden terrestrial loading and a decline in nitrogen isotope values, likely triggered by regional flooding and shifts in land use.

To read Kondagai's sediments is to realise that local history is never truly local. It is tethered to global winds, wandering ocean currents, flickers of solar activity, and human choices made thousands of kilometres away. A drought in Syria, a shift in the Pacific, a cooling in Greenland, all find their faint reflections in a lake in Tamil Nadu (Fig. 4).

Perhaps the greatest triumph of this study is how it weaves climate into culture. It does not claim that climate dictated the fate of Keeladi or its surrounding settlements. But it shows, with rare clarity, how ancient societies negotiated a fluctuating monsoon system, adapted to environmental stress, and shaped their ecosystems in turn (Fig.5). Kondagai Lake becomes a bridge between archaeology and climate science, between what people built and what nature recorded.

In an era when climate concerns dominate our headlines, this ancient archive from Tamil Nadu reminds us that the relationship between humans and climate has always been intimate, and that resilience, adaptation, and environmental wisdom were as crucial then as they are today.

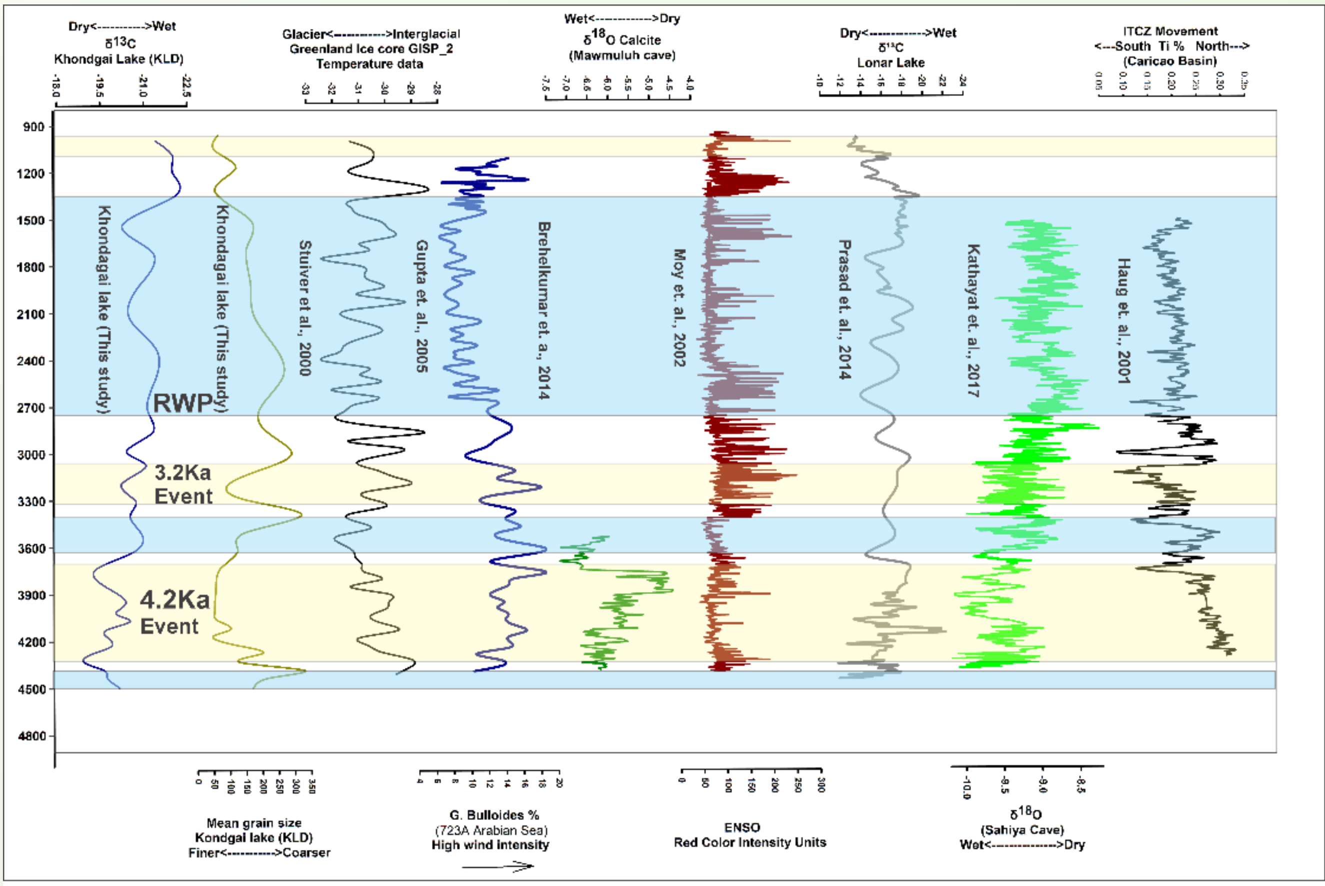

Figure 4. Comparison of the global records with the KLD Lake profile data.

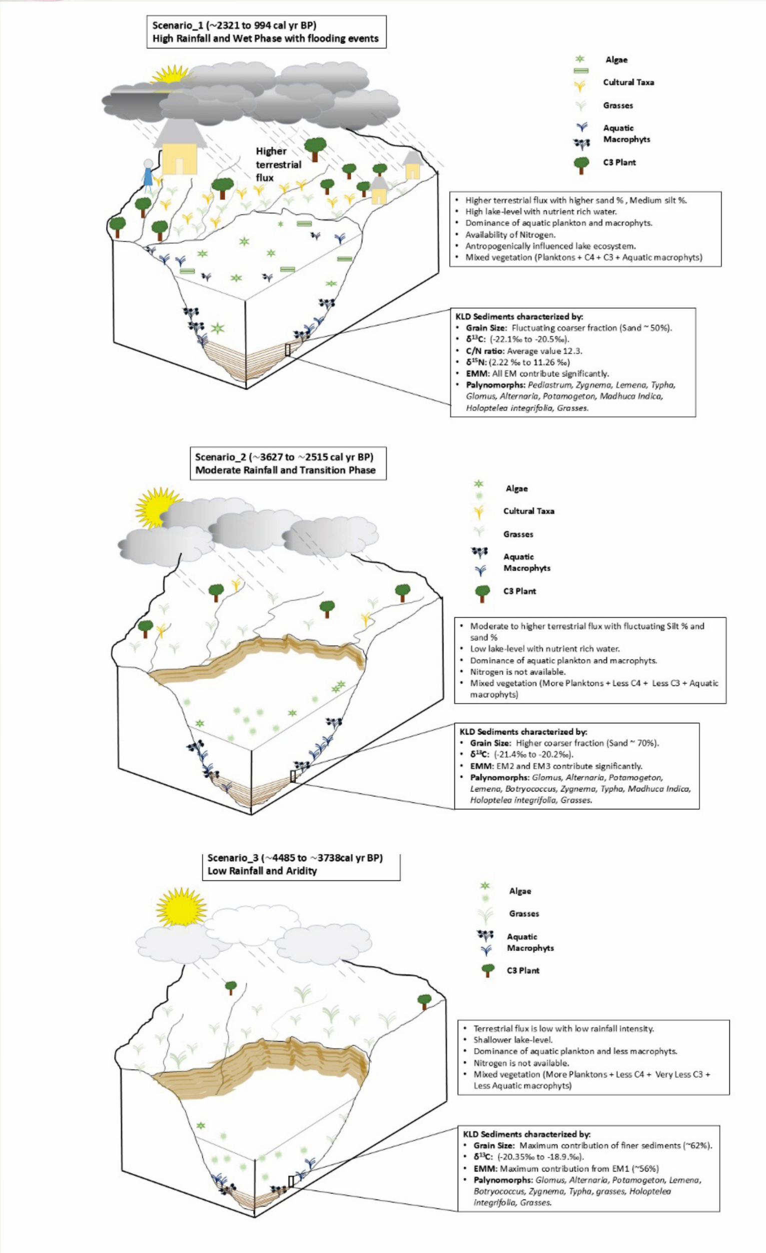

Figure 5. Schematic model of the different phases of the KLD Lake profile.

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Tracing Monsoon footprints during the Late Holocene in the Core Monsoon Zone, India

Nagendra Prasad and Mohammad Firoze Quamar

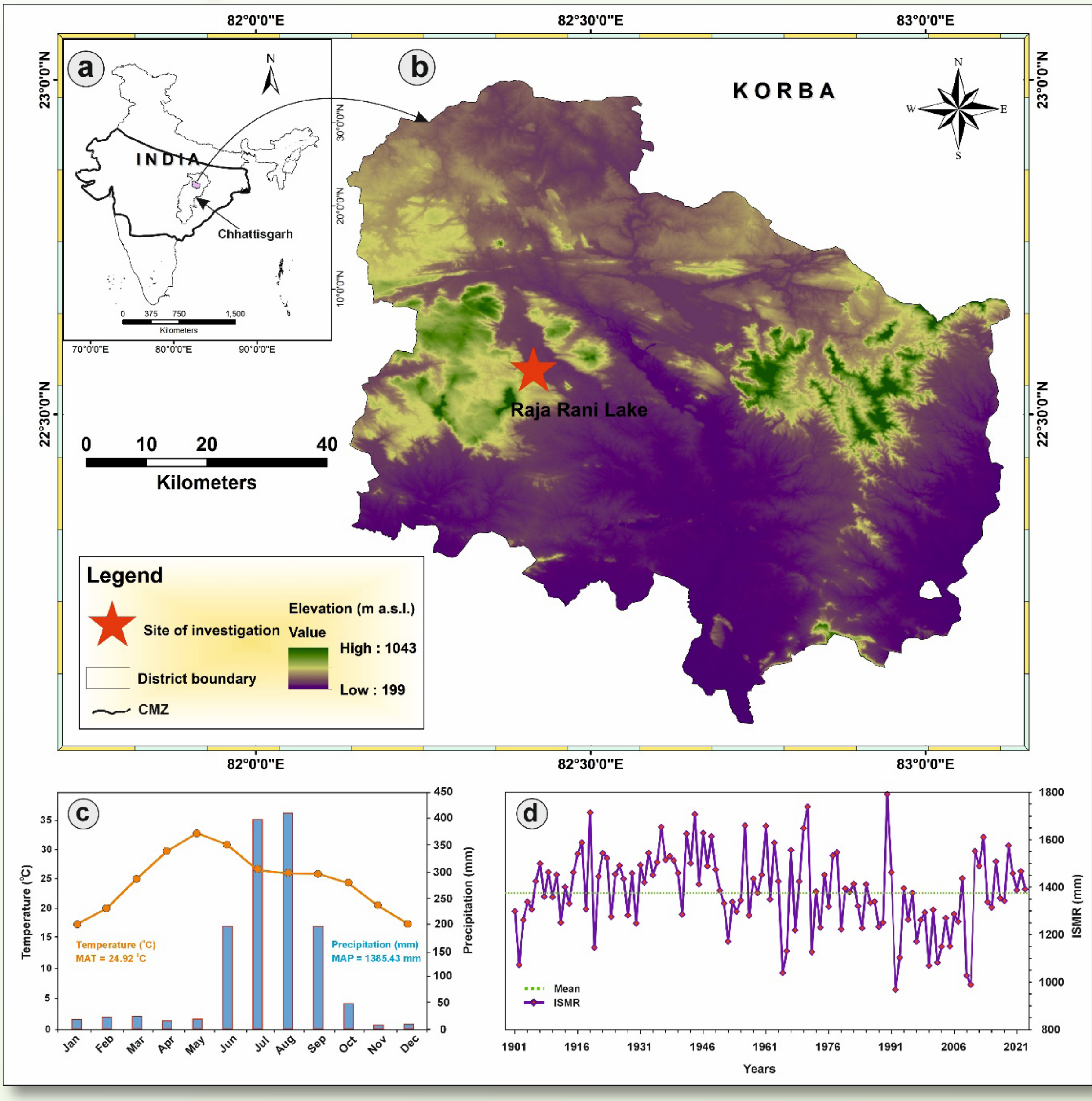

Figure 1. (a) Geographical map of India showing the Korba District, Chhattisgarh, CMZ, India (dark black and bold lines). (b) SRTM DEM of the Korba District, showing the site of investigation (red star). (c) CRU TS. 4.07, 0.5 × 0.5 gridded climate data point, 1901–2023, showing mean monthly temperature and precipitation around the study area. MAT = Mean Annual Temperature; MAP = Mean Annual Precipitation. (d) Annual Rainfall data (mm) of the last 123 years from the study area. Dotted green lines show the mean annual rainfall value.

The Indian Summer Monsoon (ISM) plays a pivotal role in shaping the climatic and socio-economic landscape of the Indian subcontinent. As a dominant component of the Asian Summer Monsoon system, it governs the seasonal transport of heat and moisture between the Indian Ocean and the Asian landmass, delivering nearly 80% of annual precipitation across most of the Indian landmass during June to September. This seasonal rainfall is not only vital for agriculture and water resources, but also influences the livelihoods of billions. Archaeologically, fluctuations in the ISM intensity have had profound impacts on human civilizations, particularly during abrupt climatic events, such as the 8.2 ka and 4.2 ka BP episodes. The latter, in particular, contributed to the decline of the Indus-Harappan Civilization, prompting eastward migration and a shift in agriculture. Understanding such variability during the Holocene is essential for contextualizing present-day climate perturbations and anticipating future trends.

Despite the significance of the ISM, high-resolution reconstructions from continental lake sediments in India remain limited. Marine records have dominated the literature, while terrestrial archives, especially from the Core Monsoon Zone (CMZ), are understated. The CMZ, which lies between latitudes 18°N and 28°N and longitudes 65°E and 88°E, is mainly sensitive to ISM variations and is considered a key region for identifying weak or intense monsoon phases. Pollen analysis was carried out from the Raja Rani Lake (RRL) (22º34'33.6" N latitude and 82º25'18.4" E longitude; elevation- 365 m a.s.l.) in the Korba District of Chhattisgarh State, central India (CMZ, India), a region characterized by tropical moist and dry deciduous forests (Figs. 1 and 2). Pollen extraction was followed by standard maceration protocols as suggested by Erdtmann (1952). Pollen and spore counts were conducted using a transmitted Light Microscope (Olympus BX50 Microscope with attached DP-26 camera for photography), using a 40X magnification, at the Quaternary Palynology Laboratory of the BSIP, Lucknow, India (Fig. 3).

The study indicates savannah vegetation around the landscape of the study area between ca. 3560 and 2860 cal yr BP. Terrestrial herbs were predominant with scattered tree taxa. The vegetation composition suggests a cool-dry climate indicating a reduced ISM rainfall. This was also suggested by the higher value of dry forest elements in comparison to the moist forest elements. An increase in forest taxa (both dry and moist forest elements) was recorded between ca. 2860 and 1960 cal yr BP, and the region experienced a transformation from savannah vegetation to wooded savannah in a warm and moderately humid climate, suggesting moderately strengthened ISM rainfall. The time period from ca. 1960 to 890 cal yr BP is marked by the appearance of new forest species and an increase in the pollen values of the existing wooded savannah vegetation.

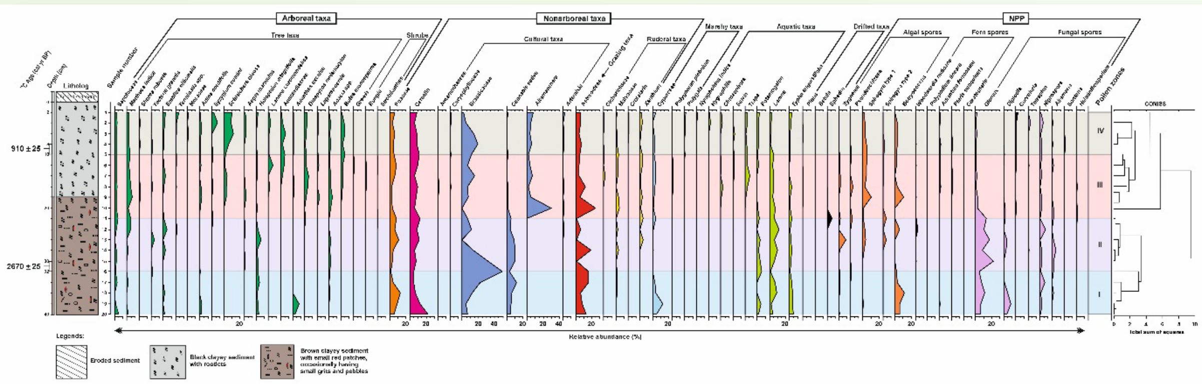

Figure 2. Pollen diagram of RRL core, showing the details of lithology, pollen assemblage zones along with ages, and vegetation distribution pattern since ca. 3560 cal yr BP.

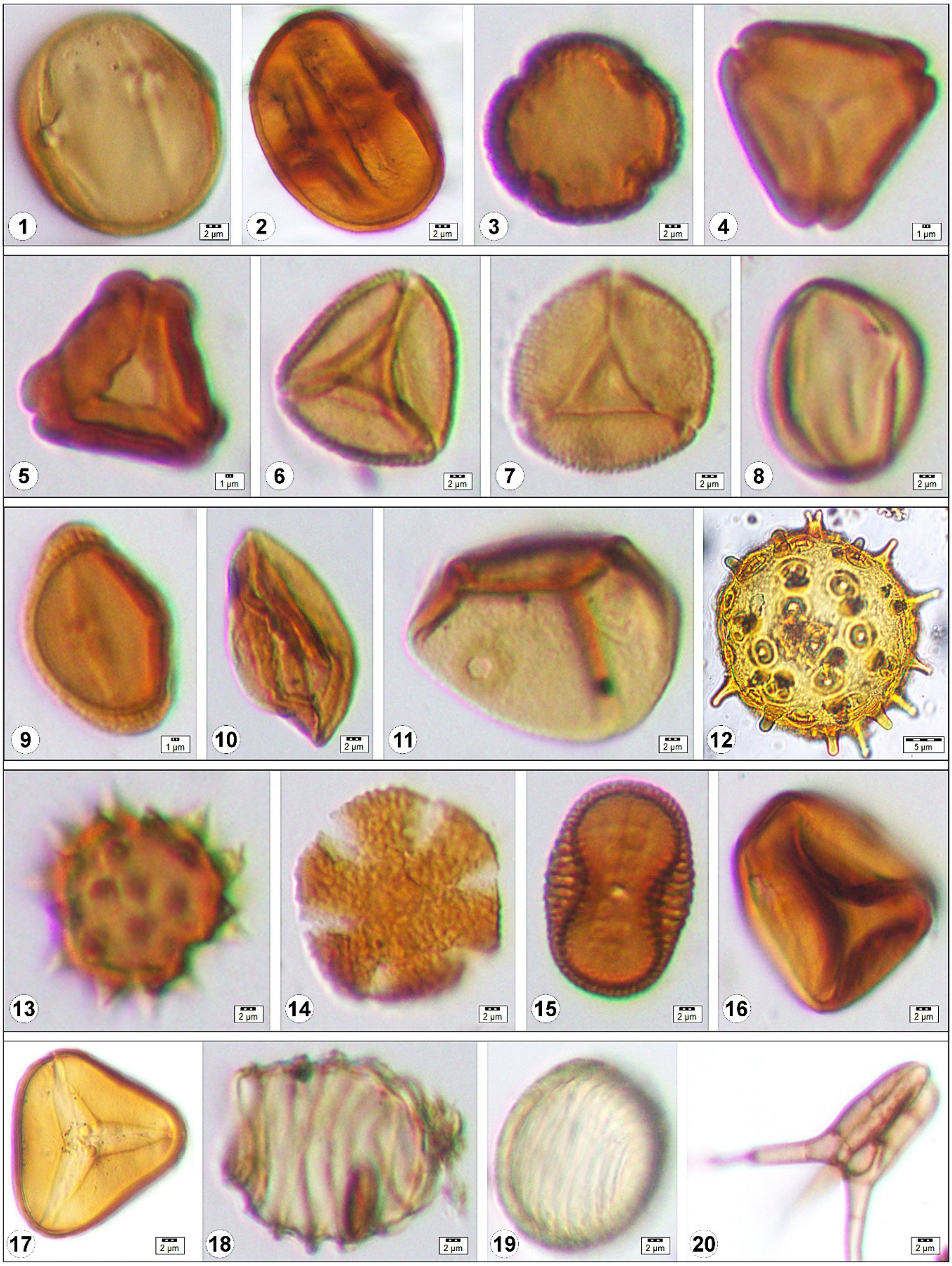

Figure 3. Pollen plate showing key palynomorphs recorded from the RRL core, Korba District (CMZ, India). 1 and 2. *Madhuca indica*, 3. *Emblica officinalis*, 4 and 5. *Syzygium cumini*, 6 and 7. *Schleichera oleosa*, 8. *Terminalia* spp., 9. *Lagerstroemia parviflora*, 10. *Diospyros melanoxylon*, 11. Cereal, 12. Malvaceae, 13. Asteroideae (Tubuliflorae), 14. *Ocimum* spp., 15. *Crotolaria*,16. Cyperaceae, 17. Trilete fern spore, 18. Nucule of *Chara*, 19. Pseudoschizea, 20. *Tetraploa.*

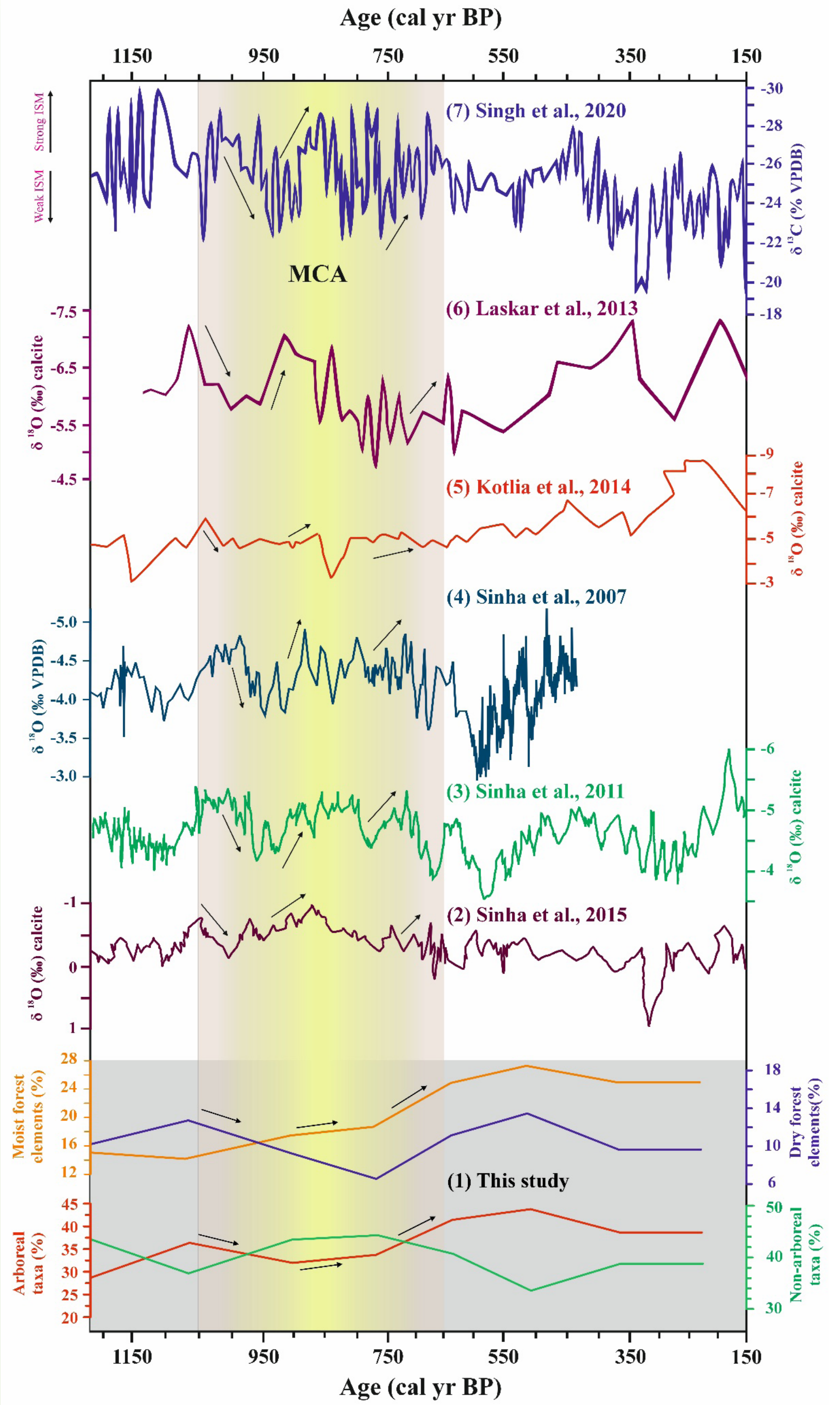

Figure 4. MCA records (yellow colour) from the various regions and correlated with the present study: 1. The present study shows the relative abundance of arboreal (moist and dry tropical deciduous forest elements) and non-arboreal taxa from the Korba District of Chhattisgarh State, central India; 2. from Sahiya Cave, Uttarakhand, lesser Himalaya (Sinha et al., 2015); 3. from Jhumar Cave, Jagdalpur, Chhattisgarh, central India (Sinha et al., 2011); 4. From Dandak Cave, Kanger Valley National Park, Chhattisgarh, central India (Sinha et al., 2007); 5. from Sainji cave, central Himalaya (Kotlia et al., 2014); 6. From Baratang cave, Andaman Islands (Laskar et al., 2013); 7. from Rewalsar lake, Mandi District, Himachal Pradesh, NW Himalaya, India (Singh et al., 2020).

The improvement in overall forest vegetation growth suggested that study area was occupied by mixed tropical deciduous forests in a warm-humid climatic condition. This change in climatic condition has occurred in response to the prevalence of increased ISM rainfall. A prominent increase in existing mixed tropical deciduous forests was recorded from ca. 890 to 225 cal yr BP (CE 1060-1725). During this period, the forest vegetation became more diversified with highly diverse moist forest elements compared to the dry ones in the vicinity and also in the adjoining areas of the investigated site. Thus, dense mixed tropical deciduous forests came into existence in the prevalence of intense warm-humid climate. This suggested that in the study area in CMZ, intense warm-humid climate with intensified ISM rainfall established during ca. 890 to 225 cal yr BP. The initial part (CE 1060−1400) of this phase corresponds with the global Medieval Climate Anomaly (MCA; CE 700−1400) (Figs. 2 and 4).

The ISM intensification during the MCA could be attributed to the northward shift of the ITCZ (Haug et al., 2001; Rehfeld et al., 2013). Bradley et al. (2016) were of the view that climate change during the MCA has been primarily attributed to natural factors, such as volcanic aerosols and solar variability. Cronin et al. (2003) suggested that the short warming phase of the MCA has been linked to changes in the strength of the thermohaline circulation in the North Atlantic, whereas Emile-Geay et al. (2007) proposed that the ENSO-modulated solar insolation played a role in enhancing the ISM. Other contributing factors include positive temperature anomalies, increased sunspot activity, and high solar radiation (Gupta et al. 2005). Additionally, enhanced wind strength in the Arabian Sea and wetter conditions over India coincided with this period (Haug et al., 2001; Gupta et al., 2003; Solanki et al., 2004; Mann et al., 2008).

Reference:

Prasad, N., Quamar M. F., Morthekai, P., Maneesha M. E.T., Tiwari, P., Thakur, B., Sharma, A., 2025. Late Holocene vegetation dynamics and Indian Summer Monsoon evolution from the Core Monsoon Zone, India. Review of Palaeobotany and Palynology. https://doi.org/10.1016/j.revpalbo.2025.105455

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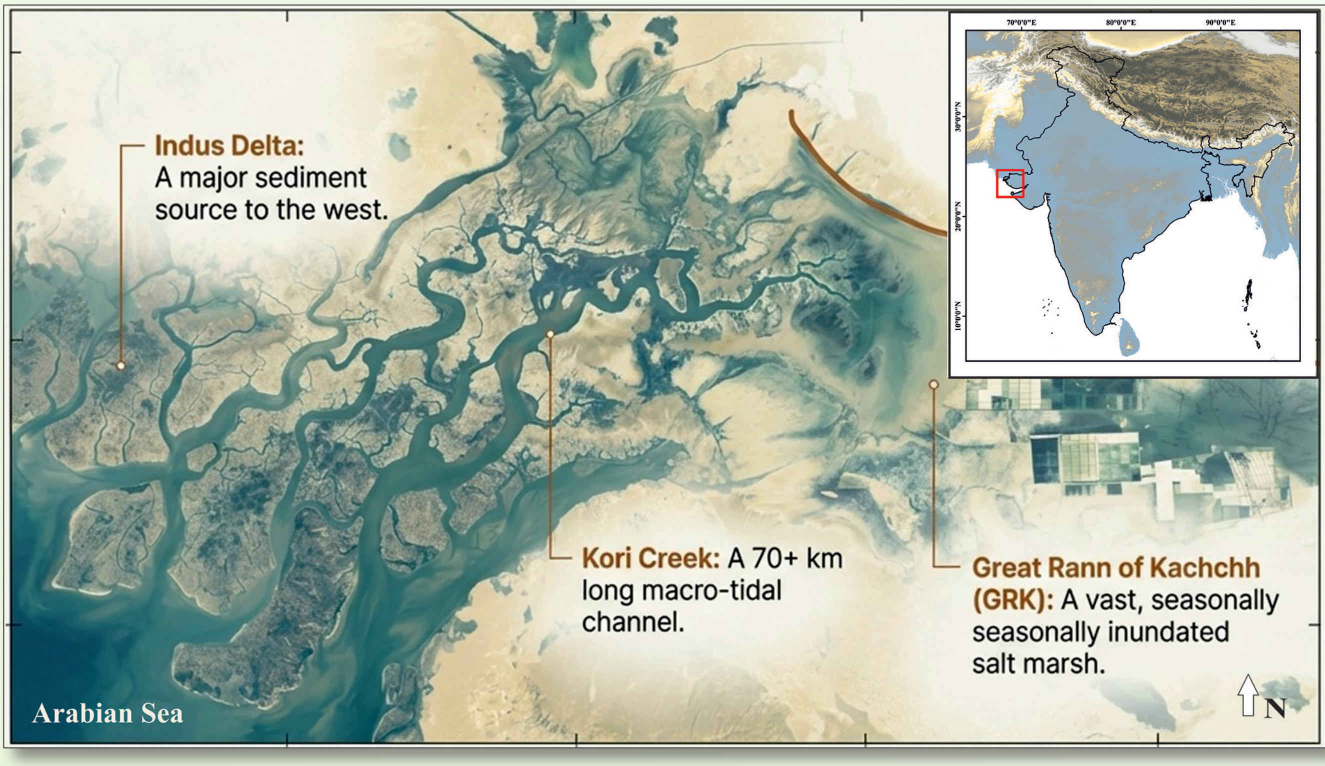
Rapidly Changing Landscape of Kori Creek and its Tidal Network

Jinamoni Saikia

FOR centuries, Kori Creek served as a quiet, but vital corridor linking coastal Gujarat to the Arabian sea. In the age before instrumental records, it was a navigable water route linking Kachchh to Sindh where boats once floated over lands that are now dry and cracked. The last forty years have seen this landscape evolve with surprising intensity. Using satellite imagery in accordance with technical advancements, and samples drawn from the earth itself, the researchers reveal how the creek has marched more than 30 kilometers inland, driven by the energy of tides, tectonic forces and the erosion that carves new pathways like veins through salt flats.

What is Creek? Creeks are one of the most dynamic morphological features of coastal environments, where freshwater and saltwater interact due to tidal stirring (Shirodkar et al., 2010). The tidal channels extensively form in macro-tidal settings by incising the tidal flats and salt marshes and undergo inundation/ drying cycles in intertidal regions (Wells et al.,1990). The tidal channels and creeks are branched and often form their interconnected network, however, the term "tidal channel" referred to large channels that are continuously submerged, whereas "tidal creeks" are small-scale features intersecting tidal flats and emerge out during low tides. This isn't just a creek it is a chronicle. And as recent research has shown, it is also an ever-evolving memory of tides, earthquakes, ancient rivers and human history written in sediments. The beauty of Kori Creek is not just geological it is historical too. British surveyors in the early 1800s described boats sailing deep into what is now salt flat



in this Great Rann of Kachchh. Earthquakes re-routed rivers, drowned ports and created new barriers. The 1819 quake was so strong that its effects were felt from Kathmandu to Pondicherry. In its wake, entire channels disappeared whereas Kori Creek surged ahead reclaiming ground. Travelers accounts from the 19th century mention rescue missions through floodwaters, abandoned forts and even sea routes that once connected this now-silent landscape to ancient trading ports.

At first glance, the Kori Creek appears barren a stretch of muddy saline wetlands dotted with the odd tidal stream and baked flats. But when it is zoomed out in a Google earth or satellite image something remarkable emerges. Using satellite images from 1984 to 2020 scientists have traced the dramatic reshaping of the creek and its tributaries. In just four decades the main channel of Kori Creek has forwarded over 30 kilometres inland. This is not a gentle shift. It is the result of active tectonics, earthquakes that tilt and crack the land and the forceful work of headward erosion where water chews back into the landscape carving out new channels.

The most significant changes occurred in between 1984-1994 and again from 2004 -2014, tidal fingers branched out across the land forming new channels and widening old ones. These were not random acts. The landscape responded to movements deep below specially near the Allah Bund fault a fingerprint of the 1819 earthquake that raised entire tracts of land and drowned others.

The Kori Creek now stretches its arms toward what used to be the Nara River threatening to reconnect with the ancient riverbeds, it once knew. A team of Indian researchers led by Dr. Niteshkumar Khonde recently studied this region using a unique blend of satellite imagery, sediment analysis and geochemical studies. What they found is starling: over the past 40 years alone the creek has shifted more than 30 kilometers inland reshaping the land with a restless kind of purpose.

While satellite images draw the map of change, the true voice of the land lies buried in its sediments. To understand how this shifting landscape works, the researchers dug deeper. They extracted six short sediment cores along a north-south transect each roughly half a meter deep.

Inside the sediments tell a story with alternating bands of fine silt and coarse sand, faint layers of salt from summer floods that later evaporated and changing mineral compositions that reveal where the sediments came from. Sand, silt and clay are sediment particles divided on the basis of sizes of grain diameters where sand (0.0625 mm-256 mm) is the highest in size and clay (<0.0039 mm) is the lowest with silt (0.0039-0.0625mm), the medium grain size. These cores are like time machines: layers of silt, clay, salt and sand revealing the cycles of flooding, drying and tidal intrusion over the past several decades. Some layers whisper of stagnant waters that stayed too long under the sun, others roar of monsoon tides.

As the team traced the changing textures, they could see the dominance of either tides or channels in shaping the sediment. In some places water had flowed steadily depositing fine muds in tranquil silence. In others, the fingerprints of fast-moving floods or tidal backflow left their mark in coarse grains and jumbled pattern.

The northernmost core KC-1 taken near the main creek channel reveals distinct salt layers intermixed with fine-grained mud and silt. These salt bands some thick, some faint reflect the seasonal drying and flooding cycle typical of this intertidal zone. As one moves further southward into the basin the nature of sediments changes. Towards southward the layering is more subdued, suggesting quieter, more protected environments.

The sediments shift from being dominated by channel flows to being shaped by tidal movements, their textures alternating between mud and sand-silt mixes. The deepest parts of some cores even show signs of stagnant water conditions thick salt layers that form when evaporation outgrows flow, hinting at periods of climatic dryness or geomorphic isolation. But there is more.

The mineral composition of the clay itself hints at distant origins. The four major players of clay particles illite, smectite, chlorite and kaolinite, each bring a story of origin. Illite and chlorite are more local associated with the arid mainland of Kachchh and the Great Rann basin. Smectite, however, is the signature of the distant Indus, the river that once poured vast sediments into the Arabian Sea carved its own mighty path through what is now Pakistan and western India. Today even though the Indus no longer flows directly into Kachchh its sediments still find their way here.

Tidal currents specially during the monsoon carry microscopic traces of the Indus across the sea depositing them along the Kori Creek. It is as if the river's memory lives on not in flowing water, but in grains of clay. As one moves from the sea toward the inland edge of the creek the mixture of clays changes. The study finds a trend from the north (near the open sea) to the south (inland) Smectite becomes more prominent showing a signal that Indus sediments are making their way in. But farther inland, its influence fades replaced by the old local signature of the Great Rann of Kachchh, a massive salt desert, hinting at a complex interplay between geography, hydrodynamics and sediment supply.

To deepen their understanding, the team also studied the chemistry of Rare Earth Elements (REEs) those wonderful atoms that act like mineral barcodes or invisible markers that help trace the origin and journey of sediments.

The researchers measured REEs and showed a consistent pattern pointing to felsic rocks, such as granite and hinted a well-mixed stable sources. No sudden disruptions, no chaotic inputs, just the long slow mixing of earth's particles by water, wind and time. But one element Europium appeared in lower amounts than expected, an indication of ancient rock processes where feldspar minerals were stripped away leaving behind a unique fingerprint.

What we are getting from this study is not just a dataset or a sediment profile, it is a narrative of transformation. The Kori Creek is not a static feature. It is a shifting. One striking trend is the north-northeast push of the tidal channels coming closer to the ancient pathways of the Nara River.

It may be preparing to reconnect with the Nara River long since lost to uplift and tectonics. If that happens, the sea could once again flood inland along an ancient path reclaiming its old corridors. The maps are already changing as the tidal network grows more complex by the year. Branches bifurcate, gullies deepen into creeks and the land softens under the pressure of coastal processes.

Between 1984 and 2020, not only did the main channel extend significantly, but new branches appeared particularly in the north and west, while some older pathways stabilized or vanished. These changes are driven by a mix of tectonic adjustments, rising sea levels and sediment availability. If Kori Creek eventually merges with this paleochannel it could reshape regional drainage patterns and even may rejoin ancient water corridors once used for navigation and trade, responding to pressures from below (earthquakes), above (rain and wind, climate) and from a far (sediments from rivers like the Indus). In a world where climate change, rising sea levels and extreme weather are becoming a major concern, regions like Kori Creek are more than academic interests. They show us how land responds when pushed by natural forces or human hands.

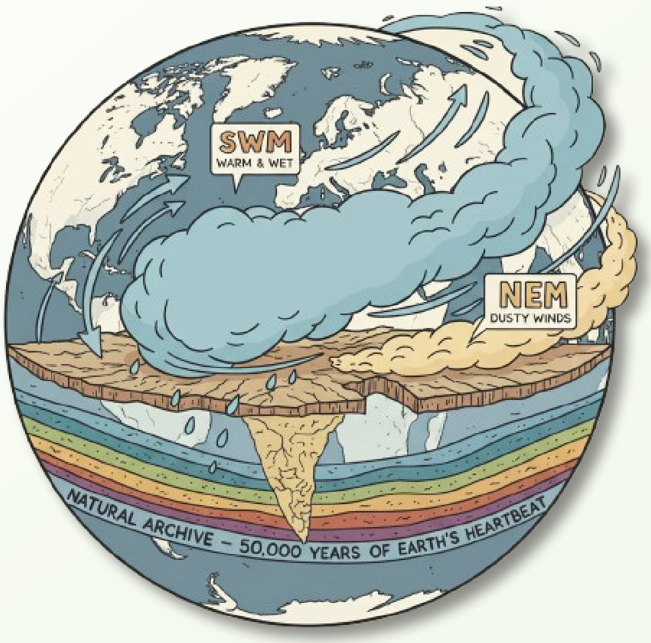
Kori Creek is not a place most people will ever visit. It is remote, salty and often submerged. They remind us that even the most unassuming landscapes can hold profound stories. Through the work of Dr. Khonde and his team we offered not only scientific insights, but also an invitation to observe, to listen and to respect the quiet wisdom written in earth and time. It is a reminder that the world is still changing beneath our feet and the quietest places often have the loudest stories to tell.

About author

Ms. Jinamoni Saikia is a Junior Research Fellow at the Birbal Sahni Institute of Palaeosciences, Lucknow. Her research focuses on the Holocene land-sea interactions and palaeoenvironmental changes in Rann of Kachchh, western India.

The sea that remembered the monsoon

Adhra Renny, Manoj M.C, Srinivas Bikkina and Binita Phartiyal



FIFTY thousand years ago, long before humans began writing their histories, the **southeastern Arabian Sea** was already writing one of its own. Its script was not ink on paper, but fine layers of settling sediments.

Every year, two mighty winds shaped its waters: the **Southwest Monsoon** (SWM), warm and wet, bringing rain from the ocean to the Indian land; and the **Northeast Monsoon** (NEM), cool and dry, carrying dust from deserts back toward the sea. Together, they turned the Arabian Sea into a vast natural archive, layer by layer, year after year, storing the rhythms of the planet's heartbeat.

THE SCIENTISTS AND THE CORE OF TIME

Fast forward to the present day. A team of scientists set out on an expedition. Their goal was to extract a piece of this natural archive from deep under the sea. On a research vessel floating 1,689 meters above the seafloor, they pulled up a 4.4-meter-long sediment core, named SK-257/02. To the naked eye, it was just layers of mud of brown, grey, and yellow colour. But to trained eyes, it was a timeline stretching across 50,000 years of climate history.

SEDIMENT THAT HOLDS CLUE

Each grain in that sediment carries their written history which is pointing to their origin story. When washed from rivers, these grains are fine and smooth; when blown by desert winds, they are slightly coarser and mixed with dust. By measuring their "fingerprints", scientists can tell whether a layer formed in a rainy time or a dusty one.

The team used environmental magnetism, a technique that treats sediments like a magnetic compass, which shows the true direction, and **end-member modelling analysis (EMMA)**, a statistical way to separate mixed sediments into their key components, which worked as a torch to light the path shown by the environmental magnetism. What we found was that the core contained **three voices of the Earth's past**, each representing a unique process.

THE THREE VOICES OF THE SEA

1. The River's Whisper (EM1 – 4.3 µm)

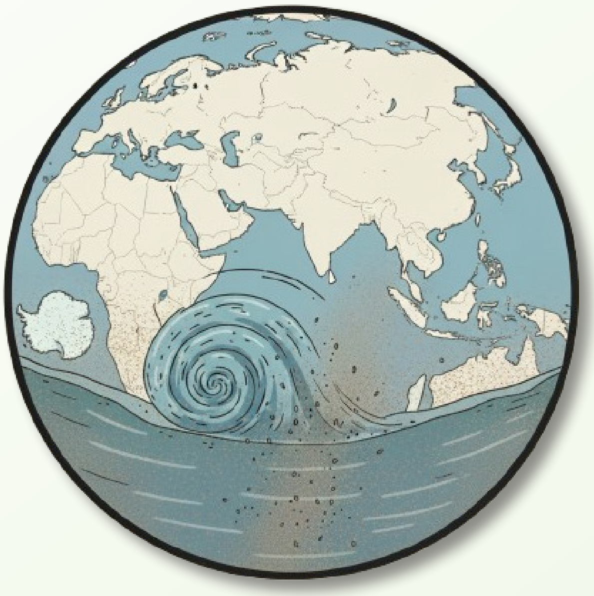
THE finest fraction, made of clays and very fine silts, spoke of powerful rivers bringing sediment from the Western Ghats and Indian plateaus into the sea during strong **Southwest monsoons.** These were the **green phases** of history, times of warmth and life when India's rivers swelled, forests flourished, and monsoon rains reached far inland.

2. The Desert's Breath (EM2 – 5.9 µm)

THE slightly coarser grains were the **dust** of distant lands carried by dry **Northeast Monsoon** winds from Arabia, Persia, and India's own deserts. They mark the **brown phases**, the colder glacial times like the **Last Glacial Maximum** (about 21,000 years ago), when the Indian Summer Monsoon weakened, deserts expanded, and winds howled over bare earth.

3. The Ocean's Pulse (EM3 – 11.2 µm)

THE third voice was coarser still, particles stirred and resettled by deep ocean currents. This "resuspension" told stories not of the atmosphere but of the **deep ocean**, when strong undersea flows connected the **Southern Ocean** to the Indian Ocean. It hinted at global connections: when Antarctica cooled, its bottom waters surged northward, altering the circulation in the Arabian Sea.



THE RULING PERIOD

When the Rivers Roared Back:

As Earth warmed and ice sheets melted, the **monsoon revived**. Around **11,000 years ago**, sunlight over the Northern Hemisphere increased, the Indian Ocean heated up, and monsoon rains returned with force. Rivers flooded again, and fine fluvial clays (EM1) surged into the sea. The magnetic signals from this time show an abundance of fine-grained minerals, a clear fingerprint of stronger rainfall and erosion on land.

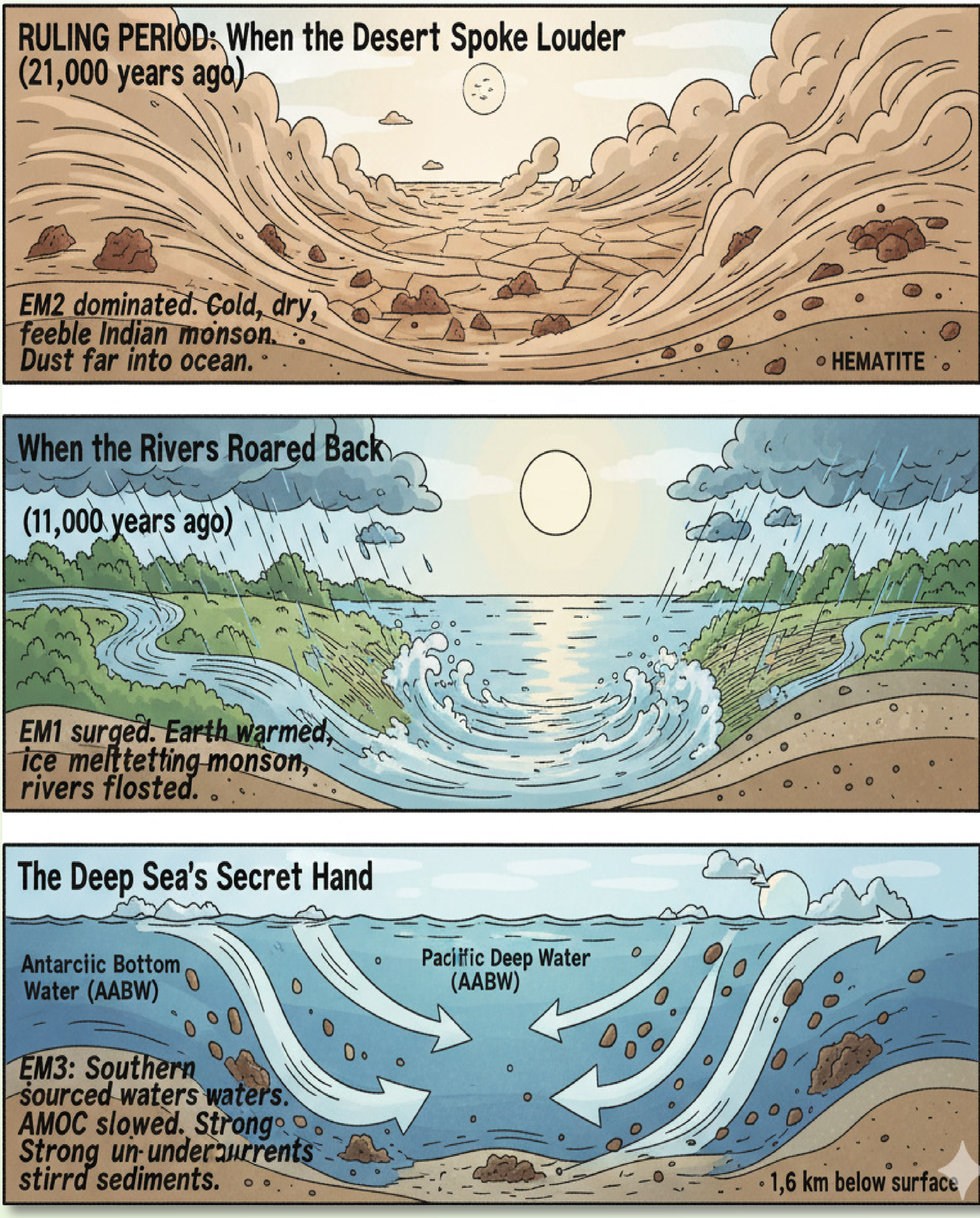
When the Desert Spoke Louder:

Around **21,000 years ago**, during the **Last Glacial Maximum**, the dust component (EM2) dominated. The world was colder, sea levels lower, and the Indian monsoon feeble. Winds from the northeast blew dust far into the ocean, which was written in the grains that still rest in the sediment core today. Magnetic tests revealed more hematite, an iron mineral linked to desert dust, confirming these were the driest, dustiest centuries in the record.

***The Deep Sea's Secret Hand*:**

But the story wasn't only about wind and rain- the **deep ocean** was quietly rewriting the script. The coarsest sediment fraction (EM3) corresponded with times when southern-sourced waters, like the **Antarctic Bottom Water (AABW)** and **Pacific Deep Water (PDW),** surged into the Indian Ocean. When the Atlantic Meridional Overturning Circulation (AMOC) slowed, as **during glacial times**, these southern waters filled the deep basins of the Indian Ocean. The result: stronger undercurrents that stirred up and re-sorted sediments even 1.6 km below the sea surface. This pattern aligned perfectly with changes in **neodymium isotope data** from other Indian Ocean sites, proof that shifts in deep-water circulation had a global reach, linking the poles through the ocean's "conveyor belt."

Every layer in that 4.4-meter-long core captures the way the Indian monsoon and the global oceans danced through ice ages and warm periods, their shifting rhythms quietly recorded in the sediments of the Arabian Sea.


RULING PERIOD: When the Desert Spoke Louder
(21,000 years ago)
EM2 dominated. Cold, dry, feeble Indian monson. Dust far into ocean.
HEMATITE
When the Rivers Roared Back
(11,000 years ago)
EM1 surged. Earth warmed, ice melttetting monson, rivers flosted.
The Deep Sea's Secret Hand
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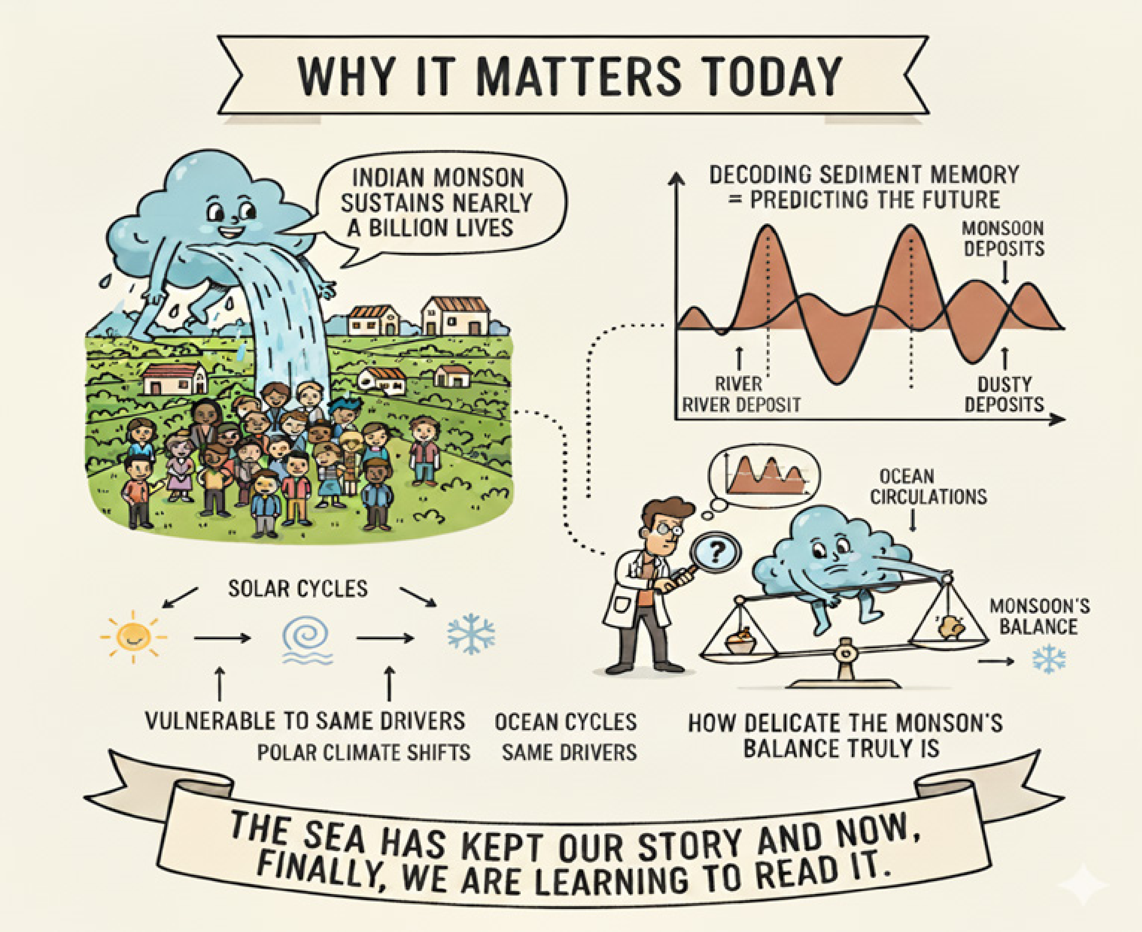


About authors

Ms Adhra Renny is a DST-INSPIRE SRF in Ocean and Polar Group of the BSIP, Lucknow. Her research focused on the reconstruction of the late Quaternary monsoon variability and associated sediment provenance, productivity, and water masses from the Arabian Sea.

Dr Manoj M.C is a Scientist- D, Ocean and Polar Group of the BSIP, Lucknow. His research integrates sedimentological and geochemical approaches to reconstruct palaeoclimatic and palaeoceanographic evolution across diverse environmental regimes, including terrestrial, marine, and polar domains.

Dr Srinivas Bikkina is Scientist-F and Head of Ocean and Polar Group and Radiocarbon Lab, BSIP, Lucknow. His research focus is to understand the role of atmospheric input of nutrients, trace metals and organic compounds to the surface ocean in order to better assess their geochemical budget and impact on ocean biogeochemistry.

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

Mountains, Climate Shifts, and Forgotten Forests of Kashmir Valley (India)

Harshita Bhatia and Gaurav Srivastava

IMAGINE standing on the forested slopes of Kashmir, not in the crisp, pine-scented air of today, but some four million years ago. Instead of snow-draped peaks and biting winds, you would find yourself immersed in a lush, subtropical paradise. Tall trees towered above, vibrant forests stretched across the landscape, and summer rains nourished a rich diversity of plant life. This is not fiction, it's a story told by fossilized leaves entombed in the ancient sediments of the Kashmir Valley, India.

Around four million years ago, the Kashmir Valley (Fig. 1) looked strikingly different from today's snowy mountains and cold winters. It was a warm, humid, and life-filled region, shaped by a monsoonal climate that brought abundant summer rainfall. But that world began to change dramatically with the rise of the Himalayas. The uplift of these mighty mountains, particularly the Pir Panjal Range, set into motion a transformation that would forever alter Kashmir's climate—shifting it from a monsoonal haven to the Mediterranean-type climate it experiences today.

Karewa group from where fossil leaves were excavated

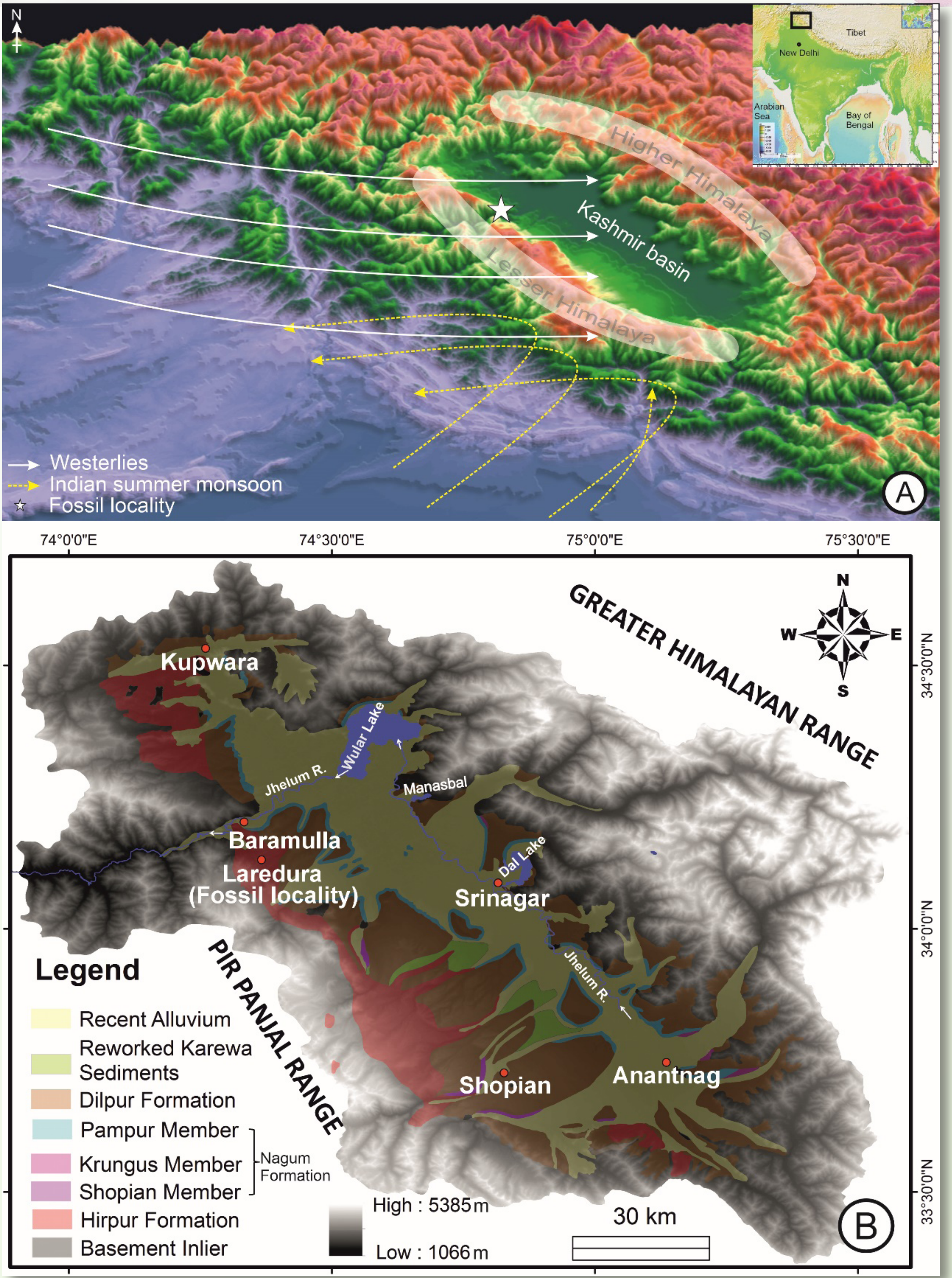


Figure 1. Map showing the location of the fossil locality situated in the Kashmir Valley (after Bhatia et al., 2025).

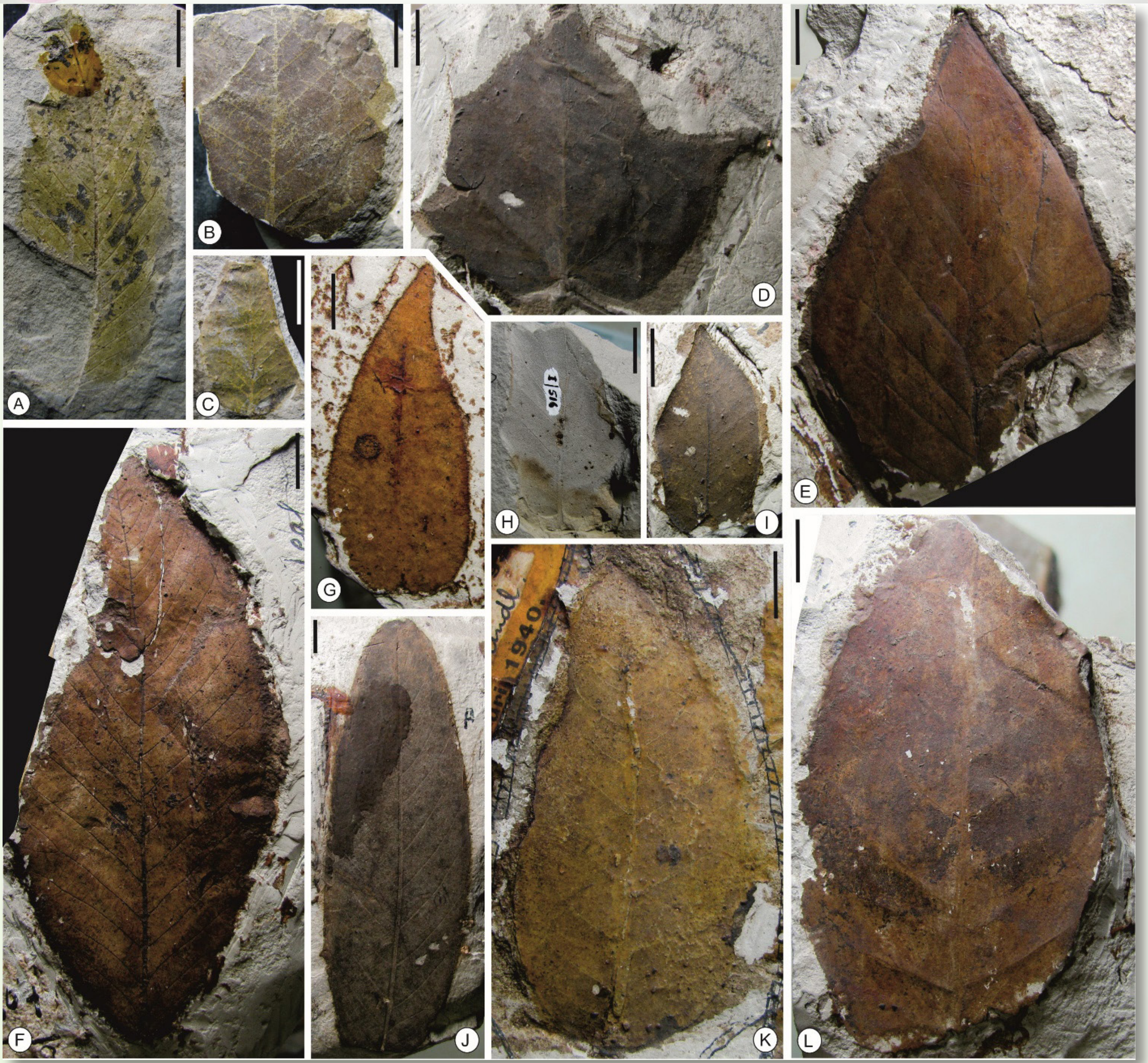
Figure 2. Fossil leaves excavated from the Kashmir Valley belonging to ~4 million years in age (after Bhatia et al., 2025).

Cradled between the Pir Panjal and Greater Himalayan ranges, the Kashmir Valley is a bowl-shaped basin formed by powerful tectonic forces. Around four million years ago, the continued collision of the Indian and Eurasian plates uplifted the Pir Panjal Range. As the range gradually rose, it acted like a natural dam, blocking rivers and leading to the formation of a vast lake that once stretched across thousands of square kilometers. Over time, layer upon layer of mud, sand, and organic material accumulated on the lakebed, eventually forming the Karewa sediments. Today, these Karewa deposits, reaching up to 1300 meters in thickness, preserve a remarkable archive of fossilized leaves (Fig. 2), a natural diary chronicling climate changes across millions of years.

To decode these ancient climate stories, paleobotanists employ methodologies like the **Climate Leaf Analysis Multivariate Program (CLAMP)** and the **Coexistence Approach (CA)**. While CLAMP interprets climate through the morphology of fossil leaves, CA infers past environmental conditions by comparing the fossils with their modern botanical relatives.

What emerges from these analyses is a climate narrative far removed from the Kashmir of today. In the ancient past, the region experienced a mean annual temperature of nearly 18°C, with a growing season that spanned 9 to 10 months. High humidity and intense summer rains supported a flourishing subtropical forest—an environment vastly different from the wet winters and dry summers that now define the valley.

Section exposed from where fossil leaves were excavated



Fossil leaves studied

SO, WHAT CAUSED THIS DRAMATIC CLIMATIC SHIFT?

The answer lies in the relentless ascent of the Pir Panjal Range. As these mountains grew taller, they began to block the southwesterly monsoon winds that had long brought summer rainfall to the valley. Gradually, the region transitioned from a humid, monsoon-dominated climate to one shaped by winter precipitation, a defining feature of the Mediterranean climate.

This tectonic reconfiguration marked the onset of a major climate transition. Kashmir moved from being a lush subtropical region with abundant summer rainfall to a landscape where winters became the primary season of precipitation, while summers grew increasingly dry and warm.

But the fossil record reveals more than just changes in temperature and rainfall, it tells a story of ecological upheaval. Many plant species that once thrived in the valley have since vanished. Trees like *Prunus cerasoides* (wild cherry blossom), emblematic of the valley's earlier climate, are now absent, signaling a profound shift in habitat and ecological conditions.

The Karewa Basin stands today as a silent witness to these monumental changes. Once a fertile cradle of biodiversity, fed by monsoon rains, it was gradually reshaped by geological forces. As mountains rose and the climate shifted, the lush vegetation of the past gave way to more resilient species capable of withstanding wet winters. Rainfall became more seasonal and less abundant, and the valley's ecosystem adjusted accordingly.

Buried deep within the Karewa sediments lies a powerful message: mountain ecosystems are incredibly sensitive to both tectonic and climatic forces. The Himalayas, still rising today, continue to influence regional weather systems and biodiversity.

The evolution of a Mediterranean-type climate in the Kashmir Basin is a striking example of the intricate relationship between geology and climate. The ancient fossil leaves, pressed into the earth like forgotten letters, reveal how the rise of mountains can alter the rhythm of the sky, and the life that depends on it.

In today's world of rapid climate change, these ancient records offer more than a glimpse into the past. They offer a lesson. They remind us that change is an ever-present force on Earth, but also that understanding our planet's deep history can help us prepare for the future. The Earth remembers, and it adapts.

Reference:

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Dr Gaurav Srivastava is a Senior Scientist (Scientist-E) at the 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.

Medicinal and aromatic plants for natural healing

Jyoti Marwah

THE DEEP-TIME EVIDENCE: SEEDS IN SOIL, STORIES IN STONE

LANDSCAPE, people, and climate have always been interconnected, forming the basis of the human–plant relationship since the end of the Ice Age. Early humans depended on plants for survival—food, shelter, and firewood. Beyond these practical needs, plants shaped spiritual beliefs and cultural identity. The five senses, particularly smell and taste, guided humans in discovering medicinal, aromatic, and sacred plants. Observing animals heal themselves by consuming herbs inspired humans to experiment with herbs and spices for digestion, preservation, and medicine. Ritual practices, such as burning aromatic substances evolved from practical utility into symbolic acts of worship and healing.

Ancient Indian texts reflect this growing awareness. The *Rigveda* mentions 67 plants, the *Yajurveda* 111, and the *Atharvaveda* nearly 300, showing a remarkable expansion in botanical

knowledge. This knowledge shaped not only survival, but also perfumery, healthcare, and spiritual practices.

EVIDENCING PLANT AROMAS IN PERFUMERY

Archaeobotanical and ethnobotanical studies reveal the deep history of fragrance in human culture. Excavations at Mohenjo-Daro uncovered faience vessels used for perfumes, incense, and powders, evidence that aromatics were integral to luxury, ritual, and social identity.

Primitive perfumery began with the burning of herbs and resins, followed by the application of fragrant pastes made from flowers, bark, and leaves. These practices expanded into perfumed waters and oils used for ceremonies. Prof. Birbal Sahni emphasized the importance of connecting palaeobotany with archaeology, showing that Indian and Chinese cultures shared botanical knowledge through trade routes across the Himalayas. His research demonstrated that the Himalayas were not barriers, but cultural bridges where silajit and other materials traveled, enriching both societies.

ARCHAEOBOTANY AND PALAEOBOTANY

Plant fossils, impressions, and carbonized seeds provide direct evidence of ancient human–plant interactions. Techniques, such as flotation allow archaeologists to recover delicate grains, fruits, and charcoal. These remains reveal both subsistence crops and aromatic plants used for ritual.

Excavations at Kunal in Haryana uncovered seeds of fenugreek, ephedra, sesame, linseed, and lemon fragments, indicating that early farmers cultivated both food and medicinal species. Similarly, excavations at Sanghol revealed fire-altars containing charred remains of *amla*, *haritaki*, *tulsi*, black pepper,

and sacred woods like sandalwood, deodar, and palash, highlighting the role of plants in ritual sacrifice.

Even utilitarian materials reveal botanical stories. Mud plaster fragments showed impressions of *munja* reeds used in construction, while coprolites and wood charcoal provide insights into ancient diets and spiritual practices. These findings demonstrate that plants were central to everyday life, culture, and belief systems.

ARCHAEOLOGY: SEALS, SCULPTURE, AND DISTILLATION

Harappan and post-Harappan cultures left behind rich visual evidence of botanical significance. Seals depict trees, such as pipal, neem, and acacia—plants that remain culturally significant today. Many seals and figurines portray ritual acts involving plants, such as offerings or tree marriages, underscoring the sacred role of flora.

Archaeological findings also provide evidence of advanced technology. Terracotta vessels excavated at Mohenjo-Daro resemble distillation equipment for producing perfumed waters and oils. This suggests that distillation was practiced in India nearly 5,000 years ago, centuries before Arab traditions of perfume distillation. Such discoveries position India as a cradle of perfumery science.

INSCRIPTIONS AND LITERATURE: PLANTS IN TEXTS AND ART

Ancient literature, inscriptions, and art provide parallel evidence of the role of medicinal and aromatic plants. Buddhist and Jain texts emphasize the spiritual value of flora, while bas-reliefs from Sanchi and Bharhut stupas depict sandalwood, champa, mango, fig, lotus, and other species. These motifs reflect cultural reverence for plants in religious and daily life.

Ayurvedic classics describe therapies based on fragrance. The *vamanopaya* technique used powdered *Madanaphala* placed on a lotus flower; patients inhaled the aroma to induce purification. Epigraphic sources, such as the Deopara Inscription (5th century CE), mention sandalwood, musk, and camphor, confirming their continued use across centuries.

PALAEOBOTANICAL EVIDENCE: SACRED PLANTS ACROSS MILLENNIA

Excavations at Ahirua-Rajarampur and Siyapur unearthed remains of tulsi (*Ocimum sanctum*), highlighting its role in Buddhist and Jain rituals. Pollen analysis from Lahuradewa in the Ganga plain identified bael, arjun, mahua, rosewood, and acacia, showing that medicinal and aromatic trees thrived between 8700–5700 BP.

These palaeobotanical records mirror living traditions. Tulsi remains central to Indian households, sandalwood continues in rituals, and neem has been rediscovered for modern agriculture. The continuity of these practices across thousands of years demonstrates the resilience of cultural memory.

BUDDHIST TRAILS: CONNECTING INDIA WITH CENTRAL ASIA, TIBET, AND CHINA

The spread of Buddhism facilitated the movement of plants and botanical knowledge across Asia. Himalayan trade routes carried ephedra, sandalwood, and silajit from India to Tibet, Central Asia, and China. Archaeological work in Xinjiang revealed bunches of ephedra in ancient graves, connecting the plant to the legendary *Soma* of the Rigveda.

Buddhist iconography reinforced botanical symbolism. Tara and Avalokiteshvara are often depicted seated on lotus flowers, while Chinese manuscripts record the use of aromatics in healthcare and rituals. The lotus, revered in India and Tibet, also appeared in Egypt as a symbol of rebirth, showing the universal role of plants in spiritual life.

CONCLUSION

Archaeological, palaeobotanical, and literary evidence collectively demonstrate the foundational role of medicinal and aromatic plants in shaping India's health traditions, rituals, and cultural identity. Seeds, pollen, seals, and inscriptions confirm that plants were not just resources, they were sacred companions, healers, and cultural symbols.

India's pioneering role in perfumery and medicinal plants use, from early distillation to Ayurvedic therapies, showcases an advanced heritage that continues to influence global practices. The persistence of tulsi, sandalwood, and neem in everyday life proves that this heritage is not a relic, but a living tradition.

At a time of biodiversity loss and climate crisis, the ancient ethos of reverence for plants provides vital lessons. By honoring the wisdom preserved in soil, seeds, and stone, we reaffirm the enduring power of palaeoscience to connect the past with a sustainable future.

About author

Dr. Jyoti Marwah, retired Principal and Head, Dept. of History, ICLES College, Navi Mumbai is an accomplished researcher with major projects for SAARC and UGC on history and uses of plant fragrances. At present, she is the Director of HimSurabhi Aroma Museum and Mussoorie Fragrance & Flavours Institute, Uttarakhand.

From Whispers of the Past through the Algorithms of the Present: Elephants, A Mammoth Task for Conservation

Brigitte Uttar Kornetzky

TODAY, our planet's majestic giants–elephants–face unprecedented threats from poaching, habitat loss, and human-wildlife conflict. In a fascinating twist of modern innovation, one of our most advanced technologies, Artificial Intelligence (AI), is emerging as a critical ally in their survival. Furthermore, this same technology is unlocking secrets from their ancient past, creating a powerful feedback loop between paleontology and contemporary conservation.

A wild elephant enjoys a meal in a rice field in Nagaon, Assam © Brigitte Uttar Kornetzky, 2023

This leads us to a pressing question, posed by Prof. Mahesh G. Thakkar: How can paleoscience contribute to today's most pressing issues, climate resilience, biodiversity conservation, and ecosystem restoration?

To explore this, we must ask: how do we understand ecosystem-climate shifts? Rising temperatures are contributing to extreme weather events worldwide, displacing communities, compromising safety, and increasing health risks. The past holds the key to understanding these changes.

When we see flesh around a skeleton, we see a living being. A skeleton alone takes us back in time. The puzzle becomes even more complex when we find only fossil fragments or chamber fillings scattered across different geological layers. It is our task to assemble this evolutionary jigsaw puzzle.

Places like the Department of Palaeontology at the Natural History Museum in Vienna are gateways to the past. Here, Earth's memory is numbered, registered, and stored in boxes, with reconstructions of dinosaurs, mammoths, and other ancient creatures reaching for the ceiling, millions of years of history locked in bones, reconstructed bodies, mummies, and fossils.

Today, equipped with stunning technologies, we sit at our modern desks, trying to decode our past from these fragments to understand our present. And that present is defined by a critical challenge: what is being done for endangered elephants and other species? What will their future be if we do not act now?

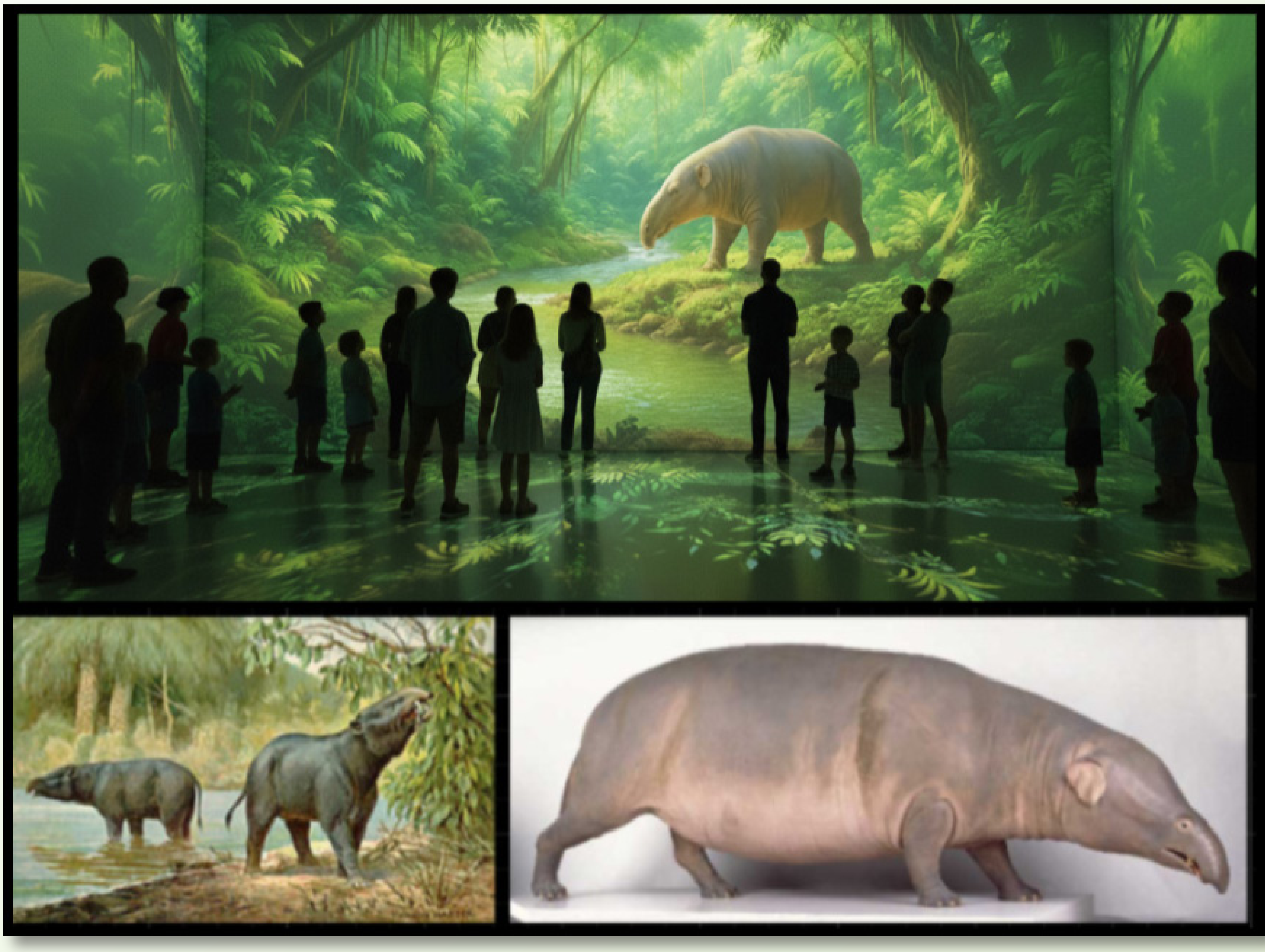
This urgency forces us to reflect: Do we truly need everything we produce? Could a major shift in our habits make a significant contribution to sustainability? One thing is certain: we must protect the remaining elephant species on both the African and Asian continents.

A CLOSER LOOK

The discovery of deep-frozen mammoth proteins that have survived for thousands of years in the ice is not, in itself, surprising. But it raises deeper questions about evolution.

Why do some species diverge dramatically from their mammalian counterparts, while others remain loyal to their lineage? For instance, mammoths and mastodons are similarly related to modern Asian and African elephants, while manatees, rock hyraxes, and aardvarks, though demonstrably descending from the same ancestral giants, have taken a different evolutionary path.

Basing such findings on a 40,000-year-old protein may seem adventurous, challenging traditional arguments based on similarities in teeth and tusks. Drawing hypotheses from fossil materials over 50 million years old broadens our kaleidoscopic horizon of knowledge. We can now study molecular evolution using both living and extinct species.



The Coryphodon, a gentle giant of the Paleocene, was not the direct ancestor of elephants, but it shared their spirit. It roamed swamps and tropical forests—a massive body built for calm movement, an herbivore's appetite, and a life shaped by water and vegetation. It resembles an early sketch of what nature would later perfect with the Proboscideans. © Benigno Perez, 2025

This progress even raises the fascinating, and perhaps dangerous, possibility of reviving extinct species from frozen carcasses. The cloning of a mammoth, for example, by implanting a viable mammoth egg cell (which has not yet been found due to permafrost damage) into a living elephant, raises serious conservational and ethical concerns. Such an act could undermine species conservation with unforeseeable consequences.

Creating an elephant with long eyelashes, a mammoth-like tail, or back hair does not mean the mammoth has been reborn. We would be creating a new, hybrid species. Its viability and adaptability to existing ecosystems are highly questionable. Would a newborn individual possess the necessary biogenetic substance to survive, reproduce, and establish a continued existence?

AI AS A CONSERVATION ALLY

The use of Artificial Intelligence (AI) in conservation is transforming how we protect elephant populations in real time.

DETERRING POACHING WITH PREDICTIVE PATROLS

AI now analyzes vast datasets, historical poaching incidents, weather patterns, animal movement data

The Deinotherium, a Miocene giant, belonged to the same family as modern elephants, though its lineage vanished two million years ago. Recognizable by its downward-curving tusks on the lower jaw, it roamed the forests of Africa and Eurasia in search of roots and foliage. Powerful yet peaceful, it represents a forgotten branch in the evolution of the great proboscideans. © Benigno Perez, 2025 from collars, real-time satellite imagery, and aerial drone surveillance. By processing this information, AI can predict where poachers are most likely to strike. This allows conservation organizations to proactively deploy rangers to high-risk areas, shifting from a reactive to a preventative model. It is a high-stakes chess game, and AI provides the decisive next move.

SILENT SENTINELS: AI-POWERED IMAGE RECOGNITION

Camera traps are invaluable for wildlife observation, but sifting through millions of images is a monumental human task. AI-powered image recognition models, trained on thousands of elephant photographs, can now analyze this data in minutes. They identify individual elephants based on unique characteristics like ear patterns, tusk shape, tail cracks, and trunk pigmentation. This allows researchers to track individuals, monitor population health, and understand social structures with unprecedented precision.

ACOUSTIC MONITORING FOR INSTANT ALERTS

Networks of acoustic sensors placed in forests continuously listen for danger. AI algorithms can be trained to distinguish between natural forest sounds and the specific noises of gunshots or chainsaws. Upon detection, the system can immediately alert ranger stations, enabling a rapid response to poaching or illegal logging, potentially preventing tragedy.

EARS AND VOICE: AN AI STRATEGY FOR DETERRING ELEPHANTS

Rising human-elephant conflicts, driven by habitat loss, agricultural expansion, and climate change, require innovative solutions. Artificial intelligence is now being deployed to address these challenges directly.

By analyzing the complex vocal repertoire of elephants, AI can interpret their rumbles, squeaks, and trumpets to determine a herd's specific behavior—whether they are calmly foraging, mating, or, most critically, if they are agitated or issuing a warning. This allows for alerts, such as "agitated herd approaching village X," which is far more valuable than a simple "elephants detected."

Furthermore, AI can act as a deterrent by playing credible, unpredictable sounds like tiger roars or buzzing bees. This "surprise" element prevents intelligent elephants from becoming habituated to the warnings.

In summary, AI-driven acoustic monitoring provides the "ears" for an early-warning system, while bio-acoustic deterrence offers a "voice" to guide elephants away or to direct herds in a specific direction to prevent them from plundering the rice fields. Together, they form a promising, high-tech strategy for fostering peaceful human-elephant coexistence.

BRIDGING THE GAP BETWEEN PAST AND FUTURE

AI's ability to process gigantic data collections provides powerful access to the analysis of both current and historical paleontological data, a task beyond the capacity of the human brain alone. It bridges the gap between past and future, offering critical insights for modern conservation strategies.

Paleontologists use machine learning to analyze fossil pollen, plant microfossils, and isotopic data from mammoth tusks and teeth. AI recognizes complex patterns in this data that might elude humans, allowing for the detailed reconstruction of prehistoric landscapes and climates. By understanding the habitats that supported vast populations of ancient proboscideans, we can identify optimal habitats for their living relatives and work to conserve and restore similar ecosystems.

MAPPING MIGRATION AND EXTINCTION

Why did the woolly mammoth vanish? What caused the extinction of the Mediterranean dwarf elephants? The answers are complex. Was it climate change, human hunting, or a combination? Extinction can only be explained by complex changes in the interaction between species and their environment—

climatic shifts impacting food and water availability, temperature extremes, desert expansion, and more.

AI models can run complex simulations to test various extinction scenarios. By processing data from ice cores, the archaeological record of human arrival, and fossil distribution over millions of years, these models help us understand the dynamics of past population collapses. They provide both a cautionary tale and a predictive framework for assessing the vulnerability of modern elephant populations facing similar pressures. Whatever the reasons for the extinction of their ancient cousins, we must spare no effort to save our two remaining species: the African and Asian elephants.

MORPHOLOGICAL ANALYSIS AND EVOLUTION

How did the elephant get its trunk? AI-driven geometric morphometrics can analyze 3D scans of hundreds of fossilized skulls, jaws, and teeth from elephant ancestors. By algorithmically comparing these shapes, AI helps map the evolutionary trajectory of key adaptations, such as the development of tusks and the trunk. This deep understanding of their evolutionary biology highlights the unique and irreplaceable niche elephants occupy, revealing precisely what we would lose if they were to disappear.

AI can visualize these evolutionary bridges in clear, accessible steps, making this knowledge available to a wider public.

IS A SYMBIOTIC FUTURE POSSIBLE?

The relationship between AI, paleontology, and conservation is inherently symbiotic. Paleontology provides the long-term data that trains AI to understand the rules of ecology and extinction. AI, in turn, gives paleontologists powerful new tools to interpret the fossil record. Together, the insights they generate form a more informed, evidence-based foundation for conservation action.

Elephants have roamed the earth for millennia, leaving their footprints not only in the mud, but in the very fabric of our planet's history. We are no longer just trying to save elephants; we are using the entire history of their lineage to intelligently secure their future.

Yet the challenges are immense. Asian elephants, in particular, face severe habitat fragmentation, leaving small, unsustainable populations vulnerable to genetic impoverishment and local extinction. A complex web of persistent poaching, illegal activities, massive habitat loss, and climate change is not only reducing populations but also weakening them.

The central conflict is the competition for space and resources between a growing human population and a species that requires vast territories for its migration and sustenance.

Trophy hunting, which targets the largest bulls with the most impressive tusks, genetically deprives populations of their strongest individuals. This leads to population depletion and disrupts social structures, as the older, experienced bulls are removed before they can pass on their genes.

Successful elephant conservation in the 21st century, therefore, requires not only combating poaching, but, above all, finding solutions for human-elephant coexistence, protecting habitats, and addressing the economic needs of local people.

We must ensure that the mighty footsteps of elephants continue to resonate into the future.

About author

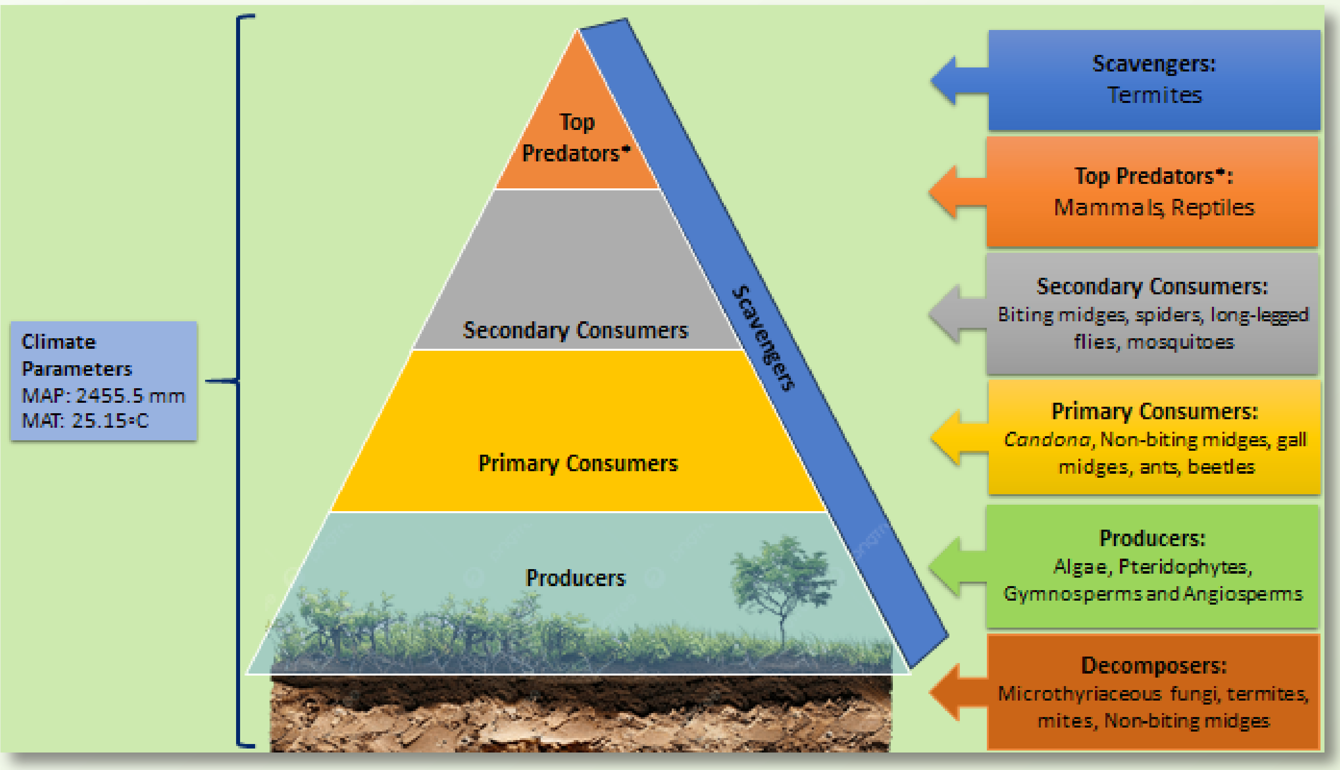
Ms Brigitte Uttar Kornetzky is a dedicated documentary film director, writer, and conservationist who has committed her life's work to the protection and understanding of elephants in India. Her work spans numerous publications, award-winning documentary films, and grassroots efforts to mitigate human-elephant conflict in Assam.

Eocene Amber: Nature's Time-Capsule Exposing the Secrets of Ancient Indian Rainforests

Shreya Mishra and Priya Agnihotri

MORE than 40 million years ago, India looked nothing like it does today. There were no crowded cities, no farms, and no dry summer heat. Instead, India was a giant island slowly floating north across the Earth's surface. It lay close to the equator, where the sun was strong and rain fell often. The land was covered by thick, green tropical rainforests, much like the jungles of Southeast Asia today. The air was warm and sticky. Big rivers flowed through the forests and spread into swampy wetlands. Tall trees stood close together, their branches forming a green roof above. Some of these trees produced a thick, sticky liquid called resin. When insects, pollen grains, tiny plants, or fungi come in contact with this resin, they got trapped inside. Over millions of years, the resin slowly hardened and turned into amber. This amber became a tiny time capsule, safely locking away pieces of ancient life.

Today, scientists have found this amber in the lignite (coal) mines of the Kutch Basin in Gujarat.

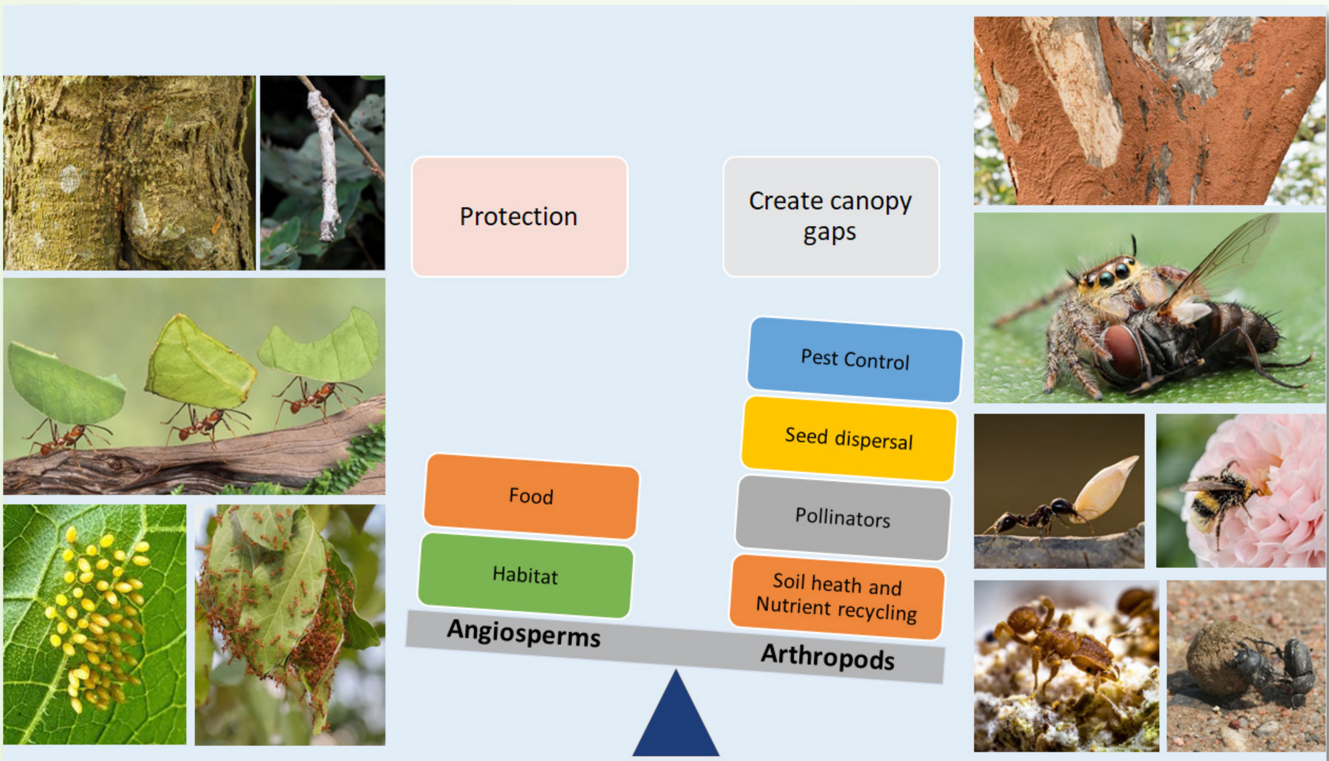


Ecological pyramid showing the distribution of biota recovered from the Umarsar Lignite Mine across different trophic levels.

Inside these golden pieces, they discovered one of the most detailed records of an ancient tropical rainforest ever found in Asia. The amber comes from the Middle Eocene period, a time when Earth was much warmer than it is now. The Eocene was like a global summer. There were no ice caps at the poles, and sea levels were high. Tropical weather stretched far across the planet. When India passed through this warm zone, its climate stayed stable for a very long time. This helped rainforests grow and spread easily. By studying fossil pollen trapped in amber and comparing it with plants living today, scientists found that western India had an average temperature of about 25°C and received nearly 2.5 metres of rain each year. The land stayed wet throughout the year, with rivers, swamps, and evergreen forests everywhere.

Amber is special because it preserves life in three dimensions. Unlike fossils pressed flat in rocks, amber keeps insects and plants almost exactly as they were. In the Umarsar Lignite Mine, amber pieces are found in layers formed from ancient peat swamps. Each small piece of amber is like a frozen moment from the past. Scientists studied hundreds of these pieces and found over 800 fossil insects and other arthropods, belonging to many different groups. They also identified more than 100 types of pollen and spores. Ants, termites, beetles, flies, spiders, mosquitoes, and mites were common. Some lived on tree bark, others in the forest canopy, and many near water or on the forest floor. There were even stingless bees, parasitic wasps, and insects that fed on fungi. This showed that the forest was not simple—it was busy, crowded, and full of interactions.

The ancient landscape itself had many zones. Near the coast, mangrove forests grew along shallow shores. Just beyond them were freshwater swamps filled with



Reconstruction of plant–insect interactions in a Middle Eocene tropical rainforest, showing major ecological relationships such as pollination, herbivory, decomposition, and nutrient recycling based on amber studies.

palms and ferns. Farther inland stood tall tropical rainforests, dominated by huge resin-producing trees similar to today's dipterocarps of Southeast Asia. These forests had layers: giant trees at the top, a thick canopy below, and smaller plants growing in the shade. Each layer was home to different insects and animals. Life in this forest was closely connected. Some insects ate plants, others hunted smaller creatures, and many helped plants reproduce by carrying pollen. Ants and termites lived in large colonies, shaping the soil and breaking down dead wood. Fungi and tiny insects recycled nutrients on the forest floor. Even mosquitoes played a role, showing that birds, reptiles, or mammals must have lived nearby.

Why was this rainforest so rich in life? Scientists explain it using the Energy–Stability–Area–Time idea. Tropical regions get lots of sunlight (energy), have stable climates, cover large areas, and last for long periods of time. During the Eocene, India had all these advantages. As an island, it was also partly isolated, allowing new species to evolve. Later, as India moved closer to Asia, these plants and animals spread to other regions. In this way, India became both a birthplace and a bridge for tropical life.

This ancient rainforest survived in a warmer world because all parts of the ecosystem worked together. Every plant, insect, and microbe played a role. The amber from Gujarat reminds us of this deep connection. Today, as modern rainforests face climate change and destruction, this story from the Eocene carries an important message. Life can survive in warm conditions, but only when ecosystems stay healthy and connected. The amber does not just preserve insects. It preserves a lesson from the past: protecting nature means protecting the relationships that hold life together.

Reference

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About authors

Dr. Shreya Mishra is a Scientist-C at the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow, specializing in Permian to Cenozoic palynology, biostratigraphy, paleoecology, and plant evolution.

Dr. Priya Agnihotri is a Birbal Sahni Research Associate the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow is a palaeoentomologist specializing in Eocene arthropods preserved in amber from the Kutch and Cambay lignite deposits of Gujarat, western India.

Founders' Day Celebration

THE Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow, celebrated its Founders' Day on November 14, 2025, marking the **134th birth anniversary of Professor Birbal Sahni**–the visionary scientist whose pioneering work laid the foundation of this globally renowned institute dedicated to fossils and allied geoscience disciplines. The programme began with a solemn tribute to Prof. Sahni's monumental contributions, followed by the **inauguration of the BSIP Annual Report** by dignitaries on the dais: Prof. Mahesh G. Thakkar, Director, BSIP; Dr. L. S. Rathore, Chief Guest and Former Director General, IMD; Dr. S. S. Rathore, Guest of Honour, Department of Geology, J.N.V. University, Jodhpur; Dr. S. C. Mathur, Special Guest, Department of Geology, J.N.V. University, Jodhpur; Prof. Murray Gingras, Special Guest, University of Alberta, Canada; Dr. Anupam Sharma, Seniormost Scientist, BSIP; and RDCC members.

Delivering the **67th Sir A. C. Seward Memorial Lecture**, Chief Guest Dr. L. S. Rathore spoke on "Climate Change: Mitigation and Adaptation." He highlighted the significance of the IPCC's First Assessment Report, which provided unequivocal evidence of the enhanced greenhouse effect and shaped global climate mitigation strategies. He highlighted the significant rise in greenhouse gas concentrations due to human activities and noted that by 2005, atmospheric CO_2 levels exceeded their natural range over the past 650,000 years. He also pointed out that India's forest and tree cover has steadily increased to 25.17% of its geographical area, creating an additional 2.29 billion tonnes of CO_2-equivalent carbon sink between 2005 and 2021.

Prof. Murray Gingras, University of Alberta, Canada, delivered the **55th Birbal Sahni Memorial Lecture** entitled "From Footprints to Facies: The Practical Power of Ichnology." He discussed ichnology (the study of trace fossils), and further explained how ancient organisms interacted with sediments, providing insights into behaviours, such as feeding, dwelling, escaping, and movement.

Nine best field photographs selected from the Annual Report were showcased, and the contributing scientists were felicitated. Awards were also distributed to winners of various competitions–including debate, essay writing, typing, poster presentation, etc., organized as part of Hindi Fortnight.

Inauguration of INQUA-2027 Conference Website at the BSIP, Lucknow

Prof. Mahesh G. Thakkar, Director, BSIP, who presided over the ceremony and addressed invited dignitaries and participants, formally inaugurated the official website of the INQUA-2027 Congress www.inquaindia2027.in on 3rd December, 2025 at the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow.

During the event, Prof. Thakkar, announced that the online abstract submission portal would open on 15th December, 2025, marking the commencement of the first major phase of scientific participation by national and international researchers.

The 22nd International Union for Quaternary Research (INQUA) Congress is going to happen for the first time in the Indian Subcontinent, expecting the participation of 3000-5000 delegates from all over the world at Indira Gandhi Pratisthan, Lucknow, in January 2027.

Prof. Thakkar further affirmed that the BSIP is fully prepared to adhere to the operational timelines and organizational requirements for hosting the global Congress.

The program concluded with a formal review and appreciation session, recognising the collective efforts of BSIP scientists, technical, administrative staff, and the organizing team in advancing preparations for the INQUA-2027 Congress.

Curtain Raiser Event of the 11th edition of India International Science Festival (IISF) 2025

THE Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow (an autonomous institute under Department of Science & Technology), successfully organized a Science Outreach Program on 21st November 2025 as part of the curtain-raiser activities for the 11th edition of the IISF 2025, which was held from 6–9 December 2025 at Panjab University, Chandigarh. The theme of IISF 2025 — "Vigyan Se Samruddhi: for Aatmanirbhar Bharat" — reflects its mission to celebrate and promote science-led growth for a self-reliant and prosperous India. It aims to bring together scientists, innovators, educators, students, industry leaders, science communicators, and policymakers on a common platform to foster collaboration, creativity, and knowledge exchange. The Chief Guest, Dr. G. K. Goswami, Director, Uttar Pradesh Institute of Forensic Science (UPSIFS), Lucknow, and former ADG of Police, delivered an inspiring address on the expanding role of forensic science. He described forensic science as a vision-oriented discipline rooted in the search for truth and emphasized the crucial link between science and law. He urged students to develop strong foundational knowledge, essential for excellence in any field.

BSIP Lucknow Shines at India International Science Festival 2025

BIRBAL Sahni Institute of Palaeosciences (BSIP), Lucknow, participated in the India International Science Festival (IISF) 2025, held in Panchkula from December 6 to 9, 2025. The event was inaugurated by the Union Minister of Science and Technology (Independent Charge), Dr. Jitendra Singh along with the Haryana State Minister and secretaries from DST, DBT, MoES, and CSIR.

The BSIP team, led by Director Prof. M.G. Thakkar, highlighted the institute's work on fossil studies and palaeosciences to visitors, including students, teachers, and faculty members. The team members, Dr. Shilpa Pandey, Dr. Sanjai Kumar Singh, and Mr. Dhiraj Kumar, explained the significance of palaeosciences and the institute's research to the visitors.

Prof. Thakkar delivered a keynote speech in one of the sessions and chaired two sessions at the festival. He also participated in panel discussions at the Young Scientist Conclave and Vision Sansad, alongside esteemed panelists, including Dr. V. Narayanan, ISRO Chairman, and Dr. Ranjana Aggarwal, Director, NIScPR.

The BSIP's participation in IISF 2025 highlights the institute's commitment to promoting science and technology and its applications in addressing societal challenges. The event provided a platform for BSIP to share its research and expertise with a wider audience and engage with the scientific community commitment to promoting science and technology and its applications in addressing societal challenges.

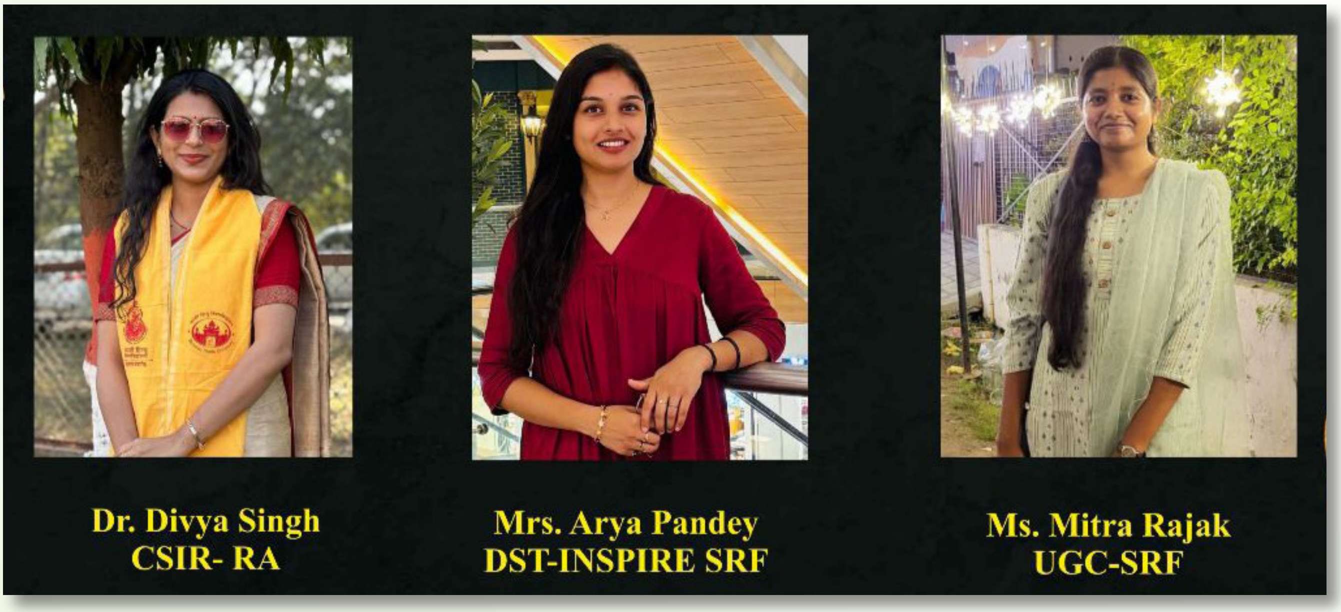
INSA SCIENCE WEEK CELEBRATION-DELHI 2025

DR. Swati Tripathi attended the INSA Science Week Celebration–Delhi 2025 at Amity University, Noida, on December 2, 2025 as an INSA Young Associate–2025. She delivered a lecture and actively participated in a round-table discussion with INSA Fellows, Young Associates, and faculty members of Amity University on ‘Environment, Sustainable Development, and Climate Change Issues’.

INSA ANNIVERSARY GENERAL MEETING & INDUCTION CEREMONY 2025

DR. Swati Tripathi attended the Anniversary General Meeting of the Indian National Science Academy (INSA) at Jawaharlal Nehru University (JNU), New Delhi, on December 3, 2025, for her induction and felicitation as an INSA Young Associate–2025.

AGU STUDENT TRAVEL GRANT RECIPIENT - 2025 OF OUR INSTITUTE



AGU Student Travel Grant:

American Geophysical Union (AGU) Student Travel Grants provide funds to assist students with a combination of costs associated with attending the AGU Annual Meeting. AGU Student Travel Grants assist students in paying costs associated with attending the event, both in-person and virtually.

AGU25:

Every year, AGU's Annual Meeting convenes 25,000 attendees from 100+ countries to share scientific findings and make connections. Researchers, scientists, educators, students, policymakers, exhibitors, journalists and communicators attend AGU's Annual Meeting to better understand our planet and environment, and our role in preserving its future. It is a results-oriented gathering rooted in celebrating and advancing positive individual and collective outcomes. The Meeting will be held on 15-19 December, 2025 in New Orleans, Louisiana, USA.

Know the Scholars

Dr. Divya Singh is a CSIR-RA working with Dr. Santosh K Pandey. Her postdoctoral research focuses on integrating a paleontological and geochemical dataset to resolve long-standing age inconsistencies in the Bhander Group of the Vindhyan Supergroup (Son Valley).

Mrs. Arya Pandey is a DST-INSPIRE SRF working with Dr. Swati Tripathi on the climate-induced Holocene vegetation response and anthropogenic impact on the upper Brahmaputra valley of Assam.

Ms. Mitra Rajak is a UGC-SRF working with Dr. Sheikh Nawaz Ali on the topic of changes in the glacier dynamics and climate change-induced glacier hazard of the Indian Central Himalaya.

The Rajbhasha Magazine *Puravigyan Smarika* Receives First Prize

IT is a matter of great pleasure to share that the Rajbhasha magazine ***Puravigyan Smarika*** of the Birbal Sahni Institute of Palaeosciences has been awarded the **First Prize** for the second consecutive year by the Town Official Language Implementation Committee (Office–3), Ministry of Home Affairs, Government of India.

This honour is the result of the visionary leadership and continuous encouragement of our Director, Prof. Mahesh G. Thakkar; the dedication of the editorial team (Dr. Poonam Verma, Dr. Swati Tripathi, Dr. Neelam Das); and the collective and consistent contributions of all colleagues.

This achievement not only underscores the Institute's commitment towards the Official Language (Hindi) but also stands as a testament to its high editorial standards and strong team spirit.

Platinum Jubilee Conference of the Palaeontological Society

The Platinum Jubilee Conference of the Palaeontological Society of India witnessed significant scientific participation from the BSIP under the theme "Fossils as Earth's Timekeepers" held during October 29–31, 2025, at the National Institute of Oceanography, Goa, The conference brought together leading researchers, academicians, and young scientists across the country to share insights into the vital role of fossils in unraveling Earth's history.

AWARDS

Heartiest congratulations to Drs. Swati Tripathi, Shreya Mishra, Suyash Gupta, and Pooja Nitin Saraf for receiving awards in different categories at the Platinum Jubilee Conference of the Palaeontological Society of India.

Their commendable achievements reflect BSIP's unwavering commitment to excellence, innovation, and leadership in Palaeontological research, inspiring the scientific community and strengthening the institute's legacy in the field.

Dr. Swati Tripathi, Scientist-E, BSIP, has been honoured with the **PSI–Mani Shankar Shukla Gold Medal 2024** for her exceptional contributions to the field of Palaeontology. The award was presented during the Platinum Jubilee Conference of the Palaeontological Society of India, held from 29–31 October 2025 at NIO, Goa.

Dr. Shreya Mishra, Scientist-C, BSIP was awarded with the **PSI–Sharda Chandra Gold Medal 2024** for her excellent research work.

Dr. Suyash Gupta, BSRA, BSIP has been honoured with the **PSI–S K Singh Medal-2023** for his best research publication in the Journal of the Palaeontological Society of India (JPSI).

Dr. Pooja Nitin Saraf, SRF, BSIP was awarded with the **PSI–S K Singh Medal-2024** for her best research publication in the Journal of the Palaeontological Society of India (JPSI).

Adieu, A Kind Adieu!
In Memory Of Birbal Sahni

R. R. Sreshta

From dawn to dark and dawn the hours are slowly drawn
Another and another day so goes since he is gone
Each season bears its name, the months their weeks proclaim
And as before seems everything, but nothing is the same

No more will April be a welcome month to me
And of all moons is April moon the saddest moon to see
For it was on a night when such a moon was bright
That his bright life did suffer sudden eclipse and darkened quite

No more does summer please, nor summer's show release
The melancholy mind from grief and give it a poor ease
No more does evening upon her quiet wing
For all her instant glory aught of former rapture bring

All things that once were fair are no· more what they were
A joy has vanished thence and left no comfort anywhere
Nature has yet her art to calm or else dispart
The weeping sky, the wailing wind, but not the moaning heart

The few whom the world rates above its loves and hates
Know him beloved of the Gods and envied of the Fates
His life the Gods did crown with worth and high renown
The Fates untimely in his height, alas! did cut him down

Seekers the wide world through of knowledge old or new
Who Learning's steep and arduous paths with single mind pursue
To this my doleful song, whose strains my dole prolong
Attend, and judge what hideous hurt the Fates have done, what wrong!

They, by a horrid hap, have ventured to affrap
A Being bright and beautiful, and caused a gloomy gap
Mankind has lost, O hear! a man without a peer
Science her prince has lost, and Truth her own preux chevalier

His country mourns his loss, his fame his country's was
Sahni, a name that India's made esteemed the globe across
Let all on Learning's quest, men of goodwill, attest
In serving Science loyally he served his Country best

In vain does Youth desire the voice that could inspire
The eye that cheered, the hand that led, and fed the sacred fire
For he possessed his theme, how complex so it seem
Expounding or exploring it with elegance supreme

Skilled to investigate and patient to await
The infinitely small unfold the infinitely great
Vision he had and tact the secret to extract
From Earth's most ancient signs, and seize the myth become a fact

Were it not lacking him the world were not so dim
A faultless friend, a manly man Nature herself did limn
In each his lineament each trait did well present
Greatness of mind, beauty of soul, and rightness of intent

Communion half-divine and shared delight were thine
O Comrade of his happy years, who made his home a shrine
At whose fair portal Care was bidden to forbear
Within whose guarded threshold dwelt a joy beyond compare

As whirling stars round sun, round axle spokes that run
Around his fixed memory my waking thoughts are spun
O might these fallen tears, or even this broken verse
Outlast the rocks, outlast the seas, a million million years!

I cannot seek him here, he cannot come anear
Until I meet and greet him in some far-removed sphere
No Shade of pallid hue but a Radiant Shape to view
Adieu, I say; adieu, sweet friend; adieu, a kind adieu!

Editor's Note:

This obituary was penned by Prof. R. R. Sreshta, who was then Professor of English at University of Lucknow and a compatriot of Prof. Birbal Sahni. It was originally published in 1952 in Volume 1 of the journal The Palaeobotanist. (Palaeobotanist 1: 475-476, 1952, now renamed and published as Journal of Palaeosciences). The original text is reprinted here verbatim; only the formatting is contemporary. Mrs. Savitri Sahni, the then Head of Birbal Sahni Institute of Palaeobotany (now Birbal Sahni Institute of Palaeosciences), had invited eminent persons from various spheres of life to write an obituary of Prof. Birbal Sahni for the inaugural issue of the journal The Palaeobotanist. This obituary was selected by Mrs. Savitri Sahni as the first obituary to be printed in a long list of obituaries.

This obituary is unique because it is not written in prose, but in poetry. Only a professor of English can achieve such a feat!

About author:

Prof. R. R. Sreshta†, M.A. (Cantab.), Professor of English, Department of English and Modern European Languages, University of Lucknow, Lucknow

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

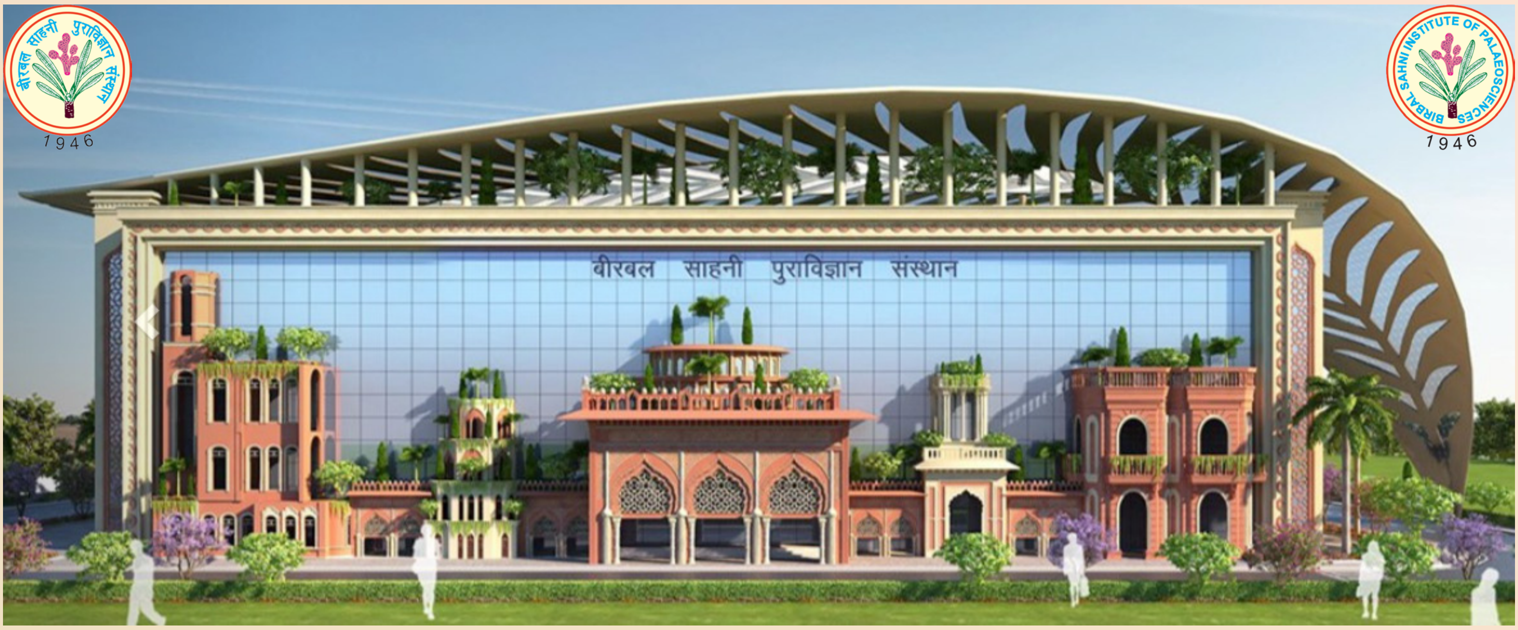
1. **Audience First:** Write for non-specialists. Avoid jargon; where unavoidable, explain in simple terms.
2. **Narrative Style:**
   - Begin with a strong hook (a question, fact, or anecdote).
   - Use storytelling, analogies, and real-world connections.
   - Keep paragraphs short and flow logical (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*



BIRBAL SAHNI INSTITUTE OF PALAEOSCIENCES (BSIP)

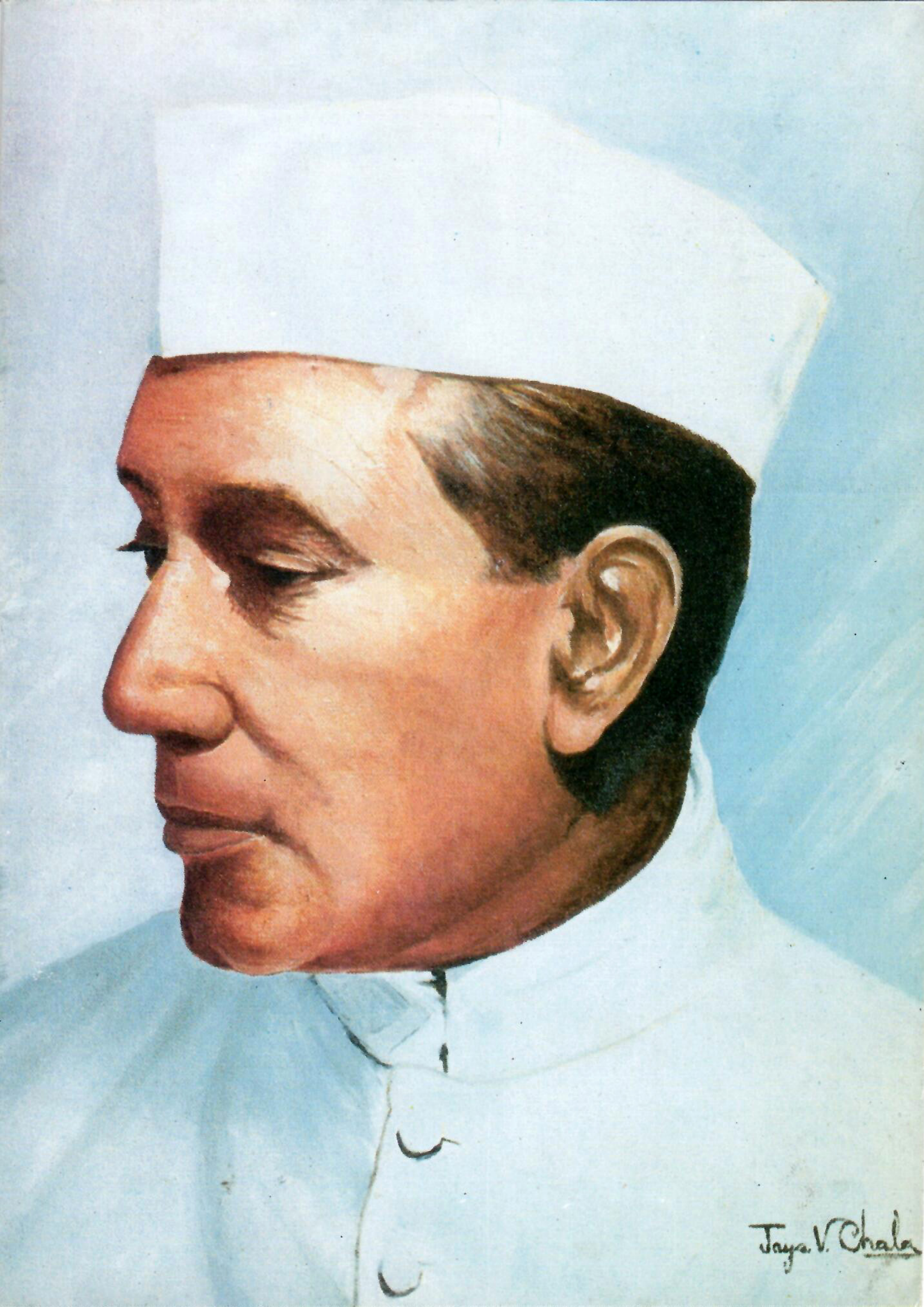
An Autonomous Institute under the Department of Science & Technology, Govt. of India
53, University Road, Lucknow - 226007

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


Jaya V. Chala