PALAEOSCIENCE TODAY

Tracing Time, Telling Stories

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From the Chief Editor's Desk

ECHOES FROM THE RAJMAHAL CHERTS:

PROF. BIRBAL SAHNI, THE PENTOXYLEAE, AND THE VISION BEHIND BSIP

WITH great pride and scientific responsibility, I welcome you to the inaugural issue of ***Palaeoscience Today***. This magazine is more than a publication; it is a platform for dialogue between deep geological time and the urgent environmental and cultural questions we face today. Our mission is to connect the past and future through science, history, and insight from Earth's ancient records.

In 1948, just a year after India's independence and at a moment of national renewal, Professor Birbal Sahni published what would become his final scientific paper, introducing a new and mysterious group of fossil seed plants, the Pentoxyleae. Based on fossils from the Rajmahal Hills in eastern India, Sahni's discovery marked a milestone not only in Indian palaeobotany, but also in global science.

A recent article by Peter R. Crane (2025) in the International Journal of Plant Sciences, entitled "Birbal Sahni Introduces the Pentoxyleae" revisits this seminal moment. His re-evaluation reminds us not only of the scientific enigma these fossils present, but of the bold intellectual tradition from which they emerged.

THE PENTOXYLEAE: A FOSSIL PUZZLE STILL UNSOLVED

Sahni's 1948 paper described a unique combination of fossilized structures: five-ribbed stems (*Pentoxylon*), strap-shaped leaves (*Nipaniophyllum*), seed-bearing heads (*Carnoconites*), and pollen organs (*Sahnia*). While individually intriguing, Sahni proposed, based on careful anatomical study, that they belonged to a single extinct plant group, previously unknown. This was a leap not just in taxonomy, but in scientific synthesis. And it came from Indian strata at a time when Indian science was beginning to define itself with confidence and autonomy.

Even today, the Pentoxyleae defy easy classification. Elements of their morphology hint at cycads, conifers, Gnetales, and Bennettitales, but never conclusively. As Crane notes, these fossils "*cannot be placed in any single known group of gymnosperms without stretching the definition… in important respects.*"

A VISION BIGGER THAN SCIENCE ALONE

To Sahni, the discovery of Pentoxyleae was not just a scientific milestone, but it was a part of a broader vision for Indian science. Educated at Cambridge and influenced by global mentors, he returned home to forge an indigenous scientific movement that was rigorous, modern, and nationally anchored. In 1946, Sahni established the Institute of Palaeobotany in Lucknow. Remarkably, this was not a state-funded initiative, but a personal effort, supported by him and his wife, Mrs. Savitri Sahni, who would go on to safeguard his legacy after his death.

The Institute's foundation stone was laid on 3rd April 1949. Just seven days later, Prof. Sahni passed away. But the Institute lived on with the untiring work of his wife, Smt. Savitri Sahni. Eventually the institute rechristened to Palaeosciences (BSIP), now a national centre of excellence under the Ministry of Science and Technology.

THE SCIENTIFIC RELEVANCE OF PENTOXYLEAE TODAY

Crane's re-examination in 2025 serves as both tribute and challenge. While over seven decades have passed since Sahni's paper, many questions remain unanswered. The vascular structure of *Pentoxylon* is without parallel among living plants. The reproductive structures lack typical protective bracts, raising debates about whether Pentoxyleae represent primitive gymnosperms, an evolutionary offshoot, or a now-extinct lineage.

Fossils like *Nataligma* and *Lindtheca* from southern Africa suggest that Pentoxyleae had a Gondwanan distribution, giving further weight to Sahni's early support of continental drift - a controversial stance in his day. In this light, the Pentoxyleae are more than fossils; they are windows into evolutionary innovation and the complexities of deep-time plant relationships.

WHY PENTOXYLEAE STILL MATTER

Crane's review demonstrates that the Pentoxyleae are not just historically important; they remain biologically and philosophically provocative. Their morphology contains traces that echo Gnetales, Bennettitales, and conifers—raising the fundamental question: how do we define major plant lineages in light of extinct forms?

Are the seeds of *Carnoconites* primitive or derived? Do they represent a unique integumentary system, or are they surrounded by bracts akin to Gnetalean envelopes? These are not idle academic questions. They strike at the heart of how we reconstruct phylogeny and understand the origins of floral morphology and plant reproductive strategies.

Crucially, Sahni's interpretations still guide the debate. As Crane notes, Sahni speculated that the reproductive structures of *Carnoconites* lacked bracts, unlike Bennettitales. This has led some researchers to view them as a possible precursor lineage, while others suggest, based on newer fossils that Pentoxyleae may share closer affinities with Gnetales, pointing toward a broader Gondwanan radiation.

These debates underscore the lasting relevance of Sahni's 1948 paper, it was not a conclusion, but a compelling invitation to future generations of palaeobotanists.

FROM FOSSILS TO A BROADER SCIENTIFIC MISSION

What began with palaeobotany has expanded into a multidisciplinary enterprise. Today, BSIP's research spans: Palaeoclimate modelling, geochemistry, isotopic, and radiometric and luminescence dating, ancient DNA and archaeobotany, micropalaeontology, Quaternary climates, present sea-level and climate change, and sedimentary systems.

This reflects a growing recognition that the past is not passive, it is an active partner in understanding the Earth's future.

OUR MANDATE IN THE PRESENT

As the BSIP prepares to enter its eighth decade, and as we launch *Palaeoscience Today*, we are guided by the same questions that animated Sahni's life:

- How do we translate fossil evidence into evolutionary insight?
- How do we ensure palaeoscience contributes to today's most pressing questions – the climate resilience, biodiversity conservation, and ecosystem restoration?
- And how do we train future scholars to approach these questions with both rigour and imagination?

This magazine, beginning with this issue, is one answer. Palaeoscience Today will bring scholarly reviews, popular science essays, heritage perspectives, and field reports into the public domain, ensuring that our work connects not only with scientists, but with students, educators, policy-makers and non-science intellectuals.

A CALL TO INQUIRY AND CONTINUITY

In honouring Crane's thoughtful reassessment of the Pentoxyleae, we also celebrate a tradition of critical engagement with the past, not just the geological past, but the intellectual past of palaeobotany in India. We are reminded that **Prof. Birbal Sahni was not only a scientist of fossils; he was a fossil of science in the best sense,** his life has become a reference point, a marker of how science can grow from place, vision, and individual passion.

Let this magazine - like the Pentoxyleae themselves - remain a puzzle worth solving, a record worth revisiting, and a legacy worth living.

Welcome to ***Palaeoscience Today,*** where deep time meets urgent relevance.

Warm regards,

Prof. Mahesh G. Thakkar
Chief Editor

Reference:

Crane, P. R. (2025). Birbal Sahni Introduces the Pentoxyleae. International Journal of Plant Sciences. https://doi.org/10.1086/737470

Editorial

PALAEOSCIENCE encompasses the disciplines of palaeobotany, palaeozoology, palynology, paleoclimatology and palaeobiogeography, offers long-term perspectives on Earth's environmental dynamics. These insights help us understand the causes and consequences of past climate variability, ecosystem shifts, and societal resilience and/or collapse. By studying what happened in the past, we can learn how nature and humans dealt with changes before, and how we can prepare for what lies ahead. The true potential of these findings, however, can only be realized when they inform public discourse, policy frameworks, and community action.

Science should not be just for scientists. It should be for students, teachers, inquisitive minds, science enthusiasts, and also for the benefit of the society. A disconnect, however, often persists between academic research and societal application, despite the depth of knowledge palaeoscience provides. The scientific results are frequently confined within journals, inaccessible to non-specialists, especially students, teachers, educators, farmers, planners and policy-makers. They don't get to see how this knowledge can help them. This detachment can stifle the transformative impact our work is capable of achieving. That is the gap we are trying to bridge. It is high time to call upon researchers to engage beyond traditional academic boundaries, as in an era defined by rapid climate change, biodiversity loss, and environmental uncertainty, the relevance of palaeoscientific research has never been more vital. We wish to make palaeoscience open, useful, and relevant. Through this Magazine – *Palaeoscience Today*, it is believed to bridge the divide by shared responsibility that demands communication, collaboration, and creativity. We are, in fact, guided by a solo motto "*Bridging the Gap between Science and Society*: *The Role of Palaeoscience in a Changing World*" to meet this demand.

Let this be a call of action: let us write not just for our peers, but also for our societal relevance. Let us bring science and society closer together.

In the very first issue, articles on the biography Prof. Birbal Sahni, FRS, founder of the BSIP, and his contribution, Shifting of the major Rivers in India, and their impact on Civilization, Palaeoscience and Society, Proxies of palaeoclimate, Origin and evolution of Life, Fossils of India, Micro- and mega-fossils and their significance, Palaeobiogeography, Permian Palaeofires, Palaeoclimate, Basics of the Indian Monsoon, Herbivory and Pastoraslism in Western Himalaya, as well as Infrastructure Development at the BSIP, Awards/Honours and Recognition, News and Events were incorporated under various heads, such as Feature Articles, Research Shorts, Lab Spotlight, etc.

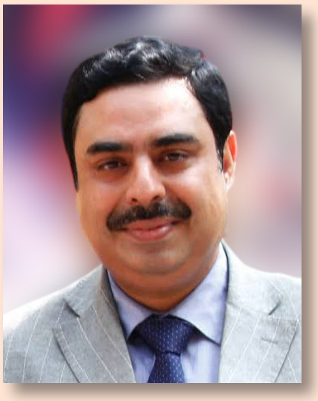
I hope you all will get benefitted by the scientific content incorporated in this magazine.

With best wishes,

Md. Firoze Quamar
Editor

From the Coordinating Editor's Desk

FROM FOSSILS TO FUTURES: PALAEOSCIENCE MUST SPEAK TO SOCIETY



WHEN you hold this inaugural issue of *Palaeoscience Today* in your hands, you are part of a journey that is much larger than a magazine. It is, in fact, a mission to connect science with society, past with present, and knowledge with responsibility.

The very preamble of our Constitution reminds us of this responsibility. Article 51A(h) underscores the fundamental duty of every citizen of India: *"to develop scientific temper, humanism and the spirit of inquiry and reform."* These words are not just constitutional obligations—they are guiding principles for institutions like the Birbal Sahni Institute of Palaeosciences (BSIP), Asia's only research centre exclusively devoted to the study of the Earth's deep past.

Yet, as I write these lines, a very simple and sobering incident comes to mind. Just this morning, two students of Class 11 and their teacher—who also happens to teach French—visited BSIP. They came enthusiastically to seek information about their upcoming school science exhibition. Out of curiosity, I asked them what they knew about palaeosciences and about BSIP. To my surprise, and somewhat to my disappointment, their faces went blank. Neither the word *palaeoscience* nor the name of our institute evoked any recognition.

This small exchange is a powerful reminder of why *Palaeoscience Today* must exist. It reflects the very communication gap that we, as scientists, educators, and science communicators, must strive to bridge. If bright, inquisitive young students and their teacher in Lucknow—the very city where BSIP stands tall—are unaware of our work, then the challenge of reaching the wider society across India becomes even more urgent.

WHY PALAEOSCIENCE MATTERS

Palaeoscience is not a luxury subject. It is not a museum curiosity meant for fossils locked in glass cases. It is, in fact, a living, breathing discipline that informs how we understand our climate, our ecosystems, and even our future survival on this planet. From fossils of ancient plants that tell us about atmospheric carbon millions of years ago, to sediment layers that warn us about past climate shifts, to biomarkers that trace the chemistry of ancient oceans—palaeoscience offers answers to questions that humanity cannot afford to ignore.

Climate change, biodiversity loss, environmental degradation, and natural hazards are not merely global buzzwords; they are challenges that affect every Indian household, every farmer, every student. To tackle them wisely, we need to know not just the "now" but also the "then." We must learn from Earth's memory. That memory is precisely what palaeoscientists safeguard, interpret, and share.

And yet, this treasure of knowledge has largely remained within the walls of academia. The language of research papers, specialized journals, and scientific conferences has not always translated into a language that the general public, schoolchildren, or even policymakers can easily understand.

THE BIRTH OF SCOPE AND THIS MAGAZINE

Recognizing this gap, BSIP launched the Science Communication for Public Engagement & Partnership (SCoPE) initiative under its newly conceptualized academic thrust area – *Media*. The vision is simple but powerful: to empower scientists to communicate their research in ways that are accessible, relatable, and meaningful for diverse audiences.

Palaeoscience Today is one of the flagship activities under this initiative. Conceived as a quarterly newsletter-cum-magazine, it will serve as a bridge between researchers and readers. Every issue will bring you stories of ancient life, rocks, fossils, and climates—but told in a language that sparks curiosity, not confusion. Our aim is to take you on a journey from the lab to the land, from excavation sites to everyday life.

This first issue is not perfect—no inaugural issue ever is—but it is a sincere attempt. It is a promise. A promise that from here on, palaeoscience will no longer remain hidden behind technical jargon or locked in laboratories. It will walk into classrooms, living rooms, and public spaces where people seek to make sense of their world.

BUILDING BRIDGES: FROM LOCAL TO GLOBAL

BSIP is not just an institute; it is a legacy. Established in 1946 and named after the visionary scientist Prof. Birbal Sahni, the institute has for decades contributed to global knowledge about plant fossils, stratigraphy, palaeoclimates, and evolutionary processes. Few people realize that our findings contribute directly to oil and coal exploration, groundwater mapping, and climate modelling—sectors that fuel India's economy and safeguard its environment.

But the impact of BSIP must not remain confined to research papers and academic collaborations. It must reach the citizen who asks, "Why should I care about a fossil?" To that citizen, our answer must be: *because the fossil holds the story of your future climate, your food security, your water availability, and the biodiversity you depend on.*

This magazine, therefore, will not just be about fossils and rocks. It will be about people. It will be about how science connects to their lives. It will showcase our collaborations with national and international partners, our role in global debates on sustainability, and our commitment to nurturing the next generation of scientists.

THE ROAD AHEAD

In the upcoming issues, readers can look forward to feature articles that explain complex topics such as palaeoclimatology, sedimentology, or amber fossils in simple and accessible language. These issues will also include rich visual stories with photographs and illustrations that make science engaging and relatable. First-hand accounts from scientists working at excavation sites, in laboratories, or in collaboration with farmers and local communities will provide unique insights from the field. Special sections for youth engagement will allow school and college students to share their questions, ideas, or art inspired by palaeoscience. Additionally, global perspectives will highlight how India's palaeoscience research contributes to the international understanding of Earth's systems.

In parallel, BSIP will expand its outreach through podcasts, short films, workshops, and competitions. Together, these initiatives aim to create a culture where science is not distant or abstract, but deeply integrated into everyday life.

A CALL TO THE READER

Dear reader, this magazine is for you—the student curious about why dinosaurs vanished, the teacher seeking to explain climate change effectively, the policymaker making decisions about resources, and the citizen who wonders how Earth became what it is today. The students and teacher I met today reminded me that our work is unfinished; knowledge, no matter how profound, has little value if it does not travel. Through *Palaeoscience Today*, we invite you to read, question, share, and engage.

We also warmly welcome contributions from researchers, teachers, students, and science enthusiasts. By sharing articles, research findings, experiences, or creative science-related content, you can help enrich this platform and make it a vibrant forum for scientific engagement. Your active participation will strengthen our collective effort to bring palaeoscience closer to society.

May this magazine ignite curiosity, foster understanding, and nurture the scientific temper envisioned by our Constitution. Welcome to *Palaeoscience Today*—a journey where the past guides the future.

I would also like to extend my heartfelt thanks to Prof. M. G. Thakkar, Director, BSIP, whose vision and guidance led to the creation of the *Media* academic thrust area and this magazine. Without his support, approval and foresight, the Science Communication for Public Engagement & Partnership (SCoPE) initiative—and the launch of *Palaeoscience Today*—would not have been possible.

Dr Nimish Kapoor
Coordinating Editor

Contents

Prof. Birbal Sahni: The Greatest Indian Palaeobotanist

Swati Tripathi

PROF. Birbal Sahni, often hailed as the Father of Palaeobotany in India, made groundbreaking contributions to the study of fossil plants, with a special emphasis on the flora of the Indian subcontinent. He was born on 14th November, 1891 at Behra, a small town in the Shahpur District (now in West Punjab, Pakistan). He was the third child of Mr. Ruchi Ram Sahni and Mrs. Ishwar Devi. His father, Ruchi Ram Sahni, was a passionate educationist, a committed patriot, and a devoted social reformer, known for his independent thinking and progressive outlook. Prof. Sahni exhibited academic brilliance from an early age. Among his many achievements were securing the top position in Sanskrit during his matriculation and earning provincial distinction in Intermediate Science. After completing his graduation in 1911, he pursued higher studies at Cambridge University. He earned a B.Sc. degree from the University of London and began his research under the supervision of esteemed botanist Sir Albert Charles Seward, whom he deeply admired and considered his mentor.

In 1919, the University of London awarded Prof. Birbal Sahni the prestigious Doctor of Science (D.Sc.) degree in recognition of his outstanding research in the field of palaeobotany. Upon his return to India, he briefly served as Professor of Botany at Banaras Hindu University, Varanasi, and later at Punjab University. In 1921, he was appointed the first Professor and Head of the Botany Department at Lucknow University—a position he held with distinction until his death. Under his leadership, the department flourished and became a prominent center for botanical studies in India. Prof. Sahni was also the visionary founder of the Palaeobotanical Society. On 10th September, 1946,

Prof. Birbal Sahni while delivering a speech on the occasion of laying down the foundation stone of BSIP.

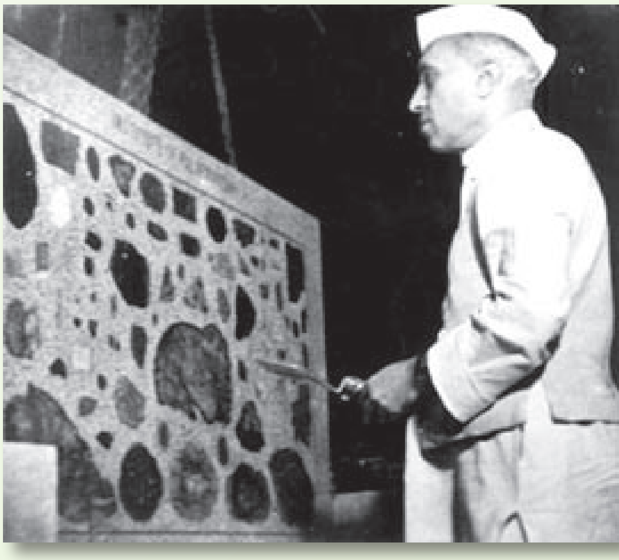
the Society established the Institute of Palaeobotany, initially operating from the Botany Department of Lucknow University. In 1949, the institute shifted to its dedicated premises at 53 University Road, Lucknow, where it continues to serve as a leading center for palaeobotanical research.

On 3 April 1949, the Prime Minister of India Jawaharlal Nehru laid the foundation stone of the new building of the institute. Prof. Sahni in his welcome speech said:

> "the foundation stone symbolizes: A great fact of the antiquity of plant life on the globe, the intellect of man ever trying to bring that fact more and more clearly to light, revealing different stages not only in the evolution of the plant kingdom in more and more orderly and understandable sequence, but also the evolution of his own poor understanding of these truth. The very construction of it, the flaws and imperfections in its entire make up, the labour that has gone into its preparation are all but symbols of our imperfect and helpless efforts at constructing something new, something worthwhile."

He was instrumental in establishing what would become the Birbal Sahni Institute of Palaeobotany, which, in recognition of its broadened research scope, was renamed in 2015 as the Birbal Sahni Institute of Palaeosciences (BSIP). Today, BSIP stands as a premier research center dedicated to fossil science and the study of ancient life and environments.

He was also involved in the establishment of Indian science education and served as the president of the National Academy of Sciences, India and as an honorary president of the International Botanical Congress, Stockholm. During his stint in England, Sahni joined Professor Seward to work on a Revision of Indian Gondwana plants (1920, Palaeontologica Indica). He made comprehensive studies on Indian Conifers. Later, he explored wealth of fossil plants from Rajmahal Hills. He studied *Ptilophyllum* and other elements and found that stem *Bucklandia*, leaf *Ptilophyllum* and flower *Williamsonia* belong to the same plant. He made reconstruction of *Williamsonia sewardiana*. He discovered petrified wood of *Homoxylon rajmahalense*, later, which was named as *Sahnioxylon rajmahalense*. He also described *Glossopteris angustifolia* Brongniart, *Palmoxylon*



Pandit Jawahar Lal Nehru laying the foundation stone of the BSIP (available for the visitors to witness in the BSIP museum). It comprises 77 fossil specimens.

Revered Professor Birbal Sahni's Statue

sundram a petrified wood, *Cocos* wood and a water fern *Azolla intertrappea*. This was followed by study of Gondwana plants of Salt Range, Karewa flora from Kashmir. He instituted a new plant group Pentoxyleae that attracted worldwide attention. His palaeobotanical studies had given support to continental drift theory. In addition, he dated some of the rocks of Salt Range to about 40-60 million years, and searched the Deccan traps in Madhya Pradesh and dated them as 62 million years, concluding they belonged to the Tertiary Period. During the following years, he not only continued his investigations, but also collected around him a group of devoted students from all parts of the country and built up a reputation for the university, which soon became the first Center for botanical and palaeobotanical investigations in India.

In 1920, he married Savitri Sahni, who also took an interest in his work and was a constant companion. She cherished his dream of establishing an Institute of palaeobotany single handedly after his premature demise. For Prof. Sahni work was worship, his last thoughts were not for him or for his family, but

Prof. Sahni on his desk, studying fossil plants

for the newly founded institute. He expressed his intense feeling to his wife before passing to eternal sleep "nourish the institute". Sahni was interested in music and could play the sitar and the violin. At Oxford, he used to play tennis for the Indian majlis. In 1936, he examined some coins and moulds dating to 100 BC from a dig in Khokra Kot and wrote on the possible methods involved in the casting of the coins. The collection is now at the National Museum at New Delhi.

Prof. Sahni received number of awards and prizes for his significant contributions. He was the recipient of the Barclay Medal of Royal Asiatic Society of Bengal in 1936, the Nelson Wright Medal of the Numismatic Society of India in 1945 and the Sir C. R. Reddy National prize in 1947. He was elected fellow of Geological Society of Great Britain. He also served the editorial board of the Botanical Journal Chronica Botanica. He was elected vice president of the 5th and 6th International Botanical Congress in 1930 and 1935 held at Cambridge and Amsterdam, respectively. In 1936, he was elected as Fellow of Royal Society of London (FRS). He was general President of the Indian Science Congress in 1940. He was a founder fellow of the National Academy of Sciences, India (NASI). The University of Cambridge had recognized his researches and awarded a Sc. D. in 1929. The American Academy of Arts and Sciences elected him as its foreign honorary member in 1948. However, in 1950 destiny prevented him to preside as Honorary President in International Botanical Congress, held at Stockholm as he passed away on 10 April, 1949.

The **Birbal Sahni Gold Medal** for postgraduate students of botany, Lucknow University was instituted in his memory. He has devoted his entire life to the field of Palaeobotany and emerged as a gem and master of this field, representing India globally and making the whole nation proud.

About author

Dr Swati Tripathi is Scientist-E at the Quaternary Palynology Laboratory of the BSIP, Lucknow. Her research focuses on Quaternary vegetation dynamics and climate change, with an emphasis on integrating biotic and abiotic proxies for palaeoenvironmental reconstruction, mainly in North-East India.

POPULAR SCIENCE ARTICLE

When Rivers Shift: How Nature Redrew the Map of Indian Civilizations

M. G. Thakkar

PROLOGUE

RIVERS are often perceived as enduring and immutable elements of the landscape. In the Indian subcontinent, major river systems, such as the Ganga, Yamuna, Narmada, Cauvery, and Sindhu (Indus) have served not only as crucial sources of water, but also as foundational pillars of cultural identity, historical development, and civilizational continuity. However, geological and climatic evidence reveals that these river systems have undergone significant shifts in their courses over millennia, frequently triggered by abrupt climatic changes and tectonic or seismic disturbances. These fluvial transformations have had profound implications—shaping settlement patterns, fostering the emergence of urban centers, prompting the decline or abandonment of ancient habitations, and altering the religious and socio-cultural fabric of the region. This article critically examines the role of paleoclimatic fluctuations and tectonic dynamics in governing river course changes, with a special focus on the Sindhu-Saraswati civilization. It also explores the transformative impact of a major historical earthquake in the tectonically sensitive Kachchh Basin, highlighting its consequences for regional geomorphology and socio-economic structures.

INTRODUCTION

RIVERS, often perceived as eternal and unchanging, have long served as the arteries of civilization—sustaining life, enabling agriculture, and fostering cultural and spiritual practices. In the Indian subcontinent, river systems, such as the Ganga, Yamuna, Narmada, Cauvery, and Sindhu (Indus) hold profound historical and cultural significance, deeply interwoven with the rise and continuity of human settlements. These watercourses, however, are far from static. Over millennia, they have exhibited remarkable dynamism, frequently altering their courses in response to natural forces, particularly climatic fluctuations and tectonic or seismic disturbances.

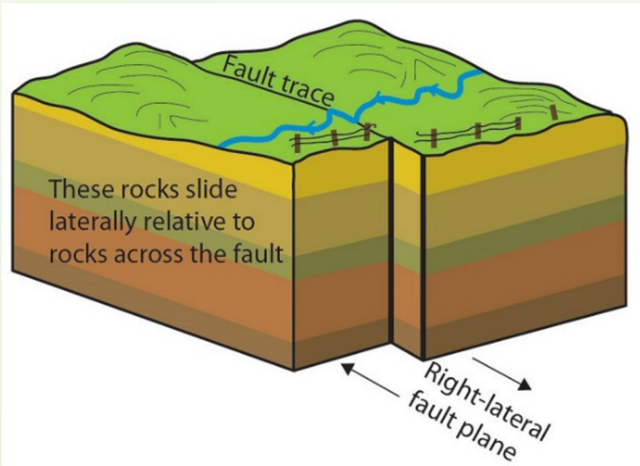


Figure 1. Diagram showing tectonic faulting (here-strike slip type of fault) changes a river course. See the displacement of fencing indicates right lateral fault.

Several tributaries of the Ganga—such as the Gandak, Ghaghara, Gomti, Kosi, and Chambal—have demonstrated persistent instability, shifting channels across historical and modern periods. These fluvial transformations have left an indelible mark on the geography and chronology of Indian civilization. The emergence of urban centres like Harappa, Mohenjo-daro, Ganweriwala, Kalibangan, and Dholavira along ancient riverbanks underscores the dependency of early societies on stable hydrological regimes. Conversely, the abandonment of these settlements often coincided with major river migrations or the desiccation of key channels.

This article explores the complex interplay between geomorphic processes and human settlement patterns, with a focus on how climatic variability and tectonic activity—particularly earthquakes—have influenced river dynamics and, consequently, the

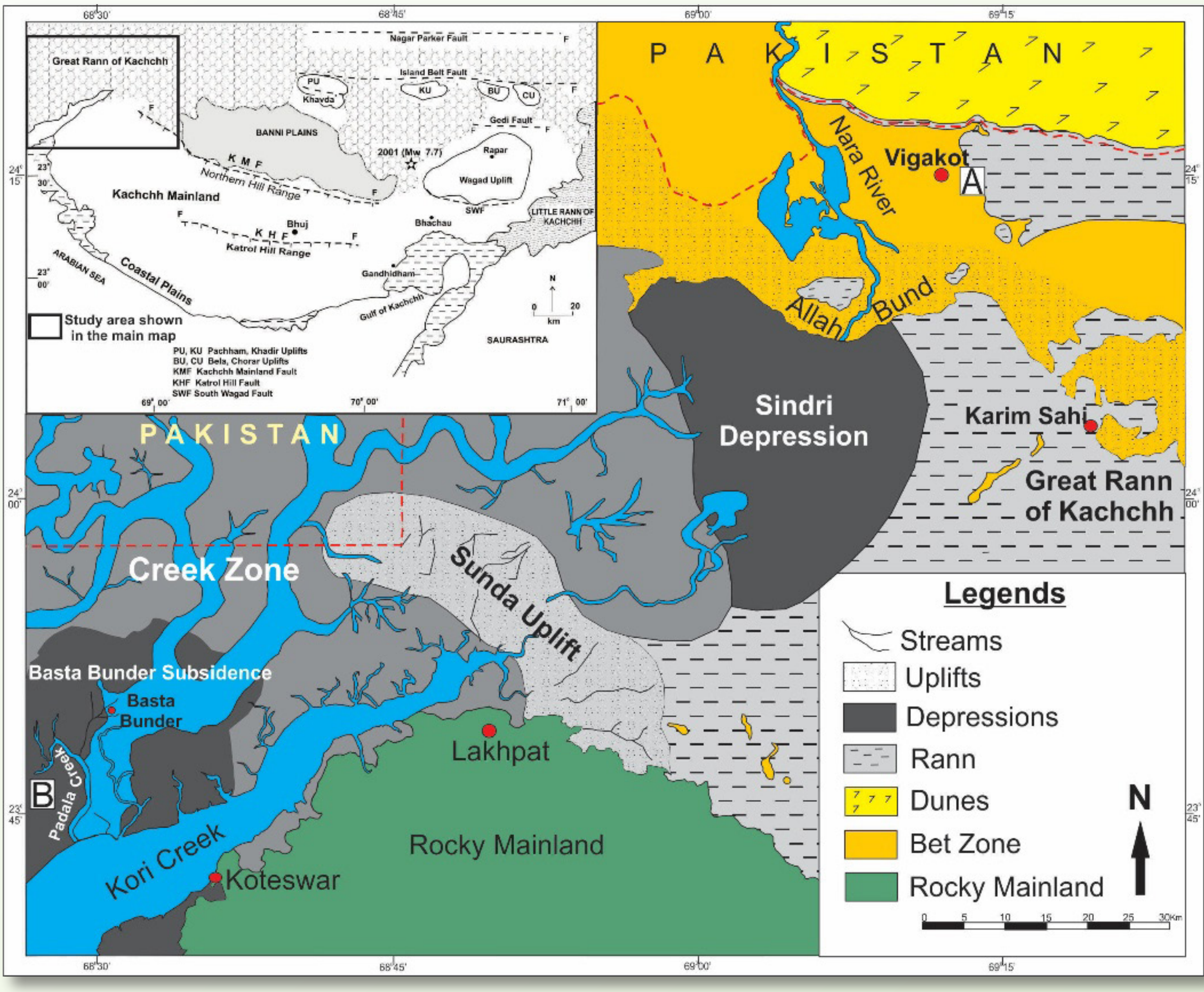


Figure 2. Location and physiographic map of the Allah bund area showing a part of the western Rann of Kachchh that was affected by the 1819 Kachchh earthquake and generated large-scale co-seismic features that modified the topography of the Rann and the western creek area of Kachchh. Note a channel of Indus known as Nara River abuts at the co-seismic uplift of Allah Bund. Sunda is an upwarped region between two co-seismic depressions of Sindri in the northeast and Basta Bunder in the southwest.

trajectory of civilization. Emphasis is placed on the Sindhu-Saraswati domain, where evidence suggests that natural processes, including a major historical earthquake in the tectonically active Kachchh Basin, drastically altered topography and socio-economic configurations. A case in point is the Kosi River, a Ganga tributary, which has shifted its course multiple times over the last century due to intense erosion and sedimentation cycles—earning it the epithet "Sorrow of Bihar."

By examining such cases through a scientific lens, this article seeks to unravel how nature's powerful forces have, time and again, redrawn the physical and cultural map of the Indian subcontinent.

HOW AND WHY DO RIVERS CHANGE THEIR COURSES?

TECTONIC ACTIVITY

Devastating earthquakes, and subsequent uplift, subsidence or faulting of land can alter the slope or elevation of river valleys drastically. Rivers then respond to the modification of the slope by changing their directions, abandoning old channels, or cutting new paths (Fig. 1). Earthquakes are one of the most powerful natural forces, capable of transforming entire landscapes in seconds. When the ground shakes, it doesn't just crack roads and topple buildings, it can also change the flow of rivers and create new waterbodies.

Figure 3. Google imagery showing the part of the western Great Rann of Kachchh where the co-seismic Allah bund ridge has obstructed the Nara Channel, which subsequently formed a lake to the north of Allah Bund and a large depression to the south of it.

Allah Bund earthquake and associated geomorphic changes

One of the most remarkable tectonic events in the Indian subcontinent is the Great Allah Bund Earthquake, which struck the Kachchh Basin of western India on June16, 1819. Estimated at a magnitude of ~7.8, the earthquake generated a significant co-seismic uplift, forming the prominent Allah Bund—a ridge approximately 90 km long, 16 km wide, and up to 6 meters high—in the western Great Rann of Kachchh (Oldham, 1926; Rajendran & Rajendran, 2001). This surface rupture, still visible after more than two centuries, is among the most well-preserved earthquake-related geomorphic features globally (Bilham, 1999).

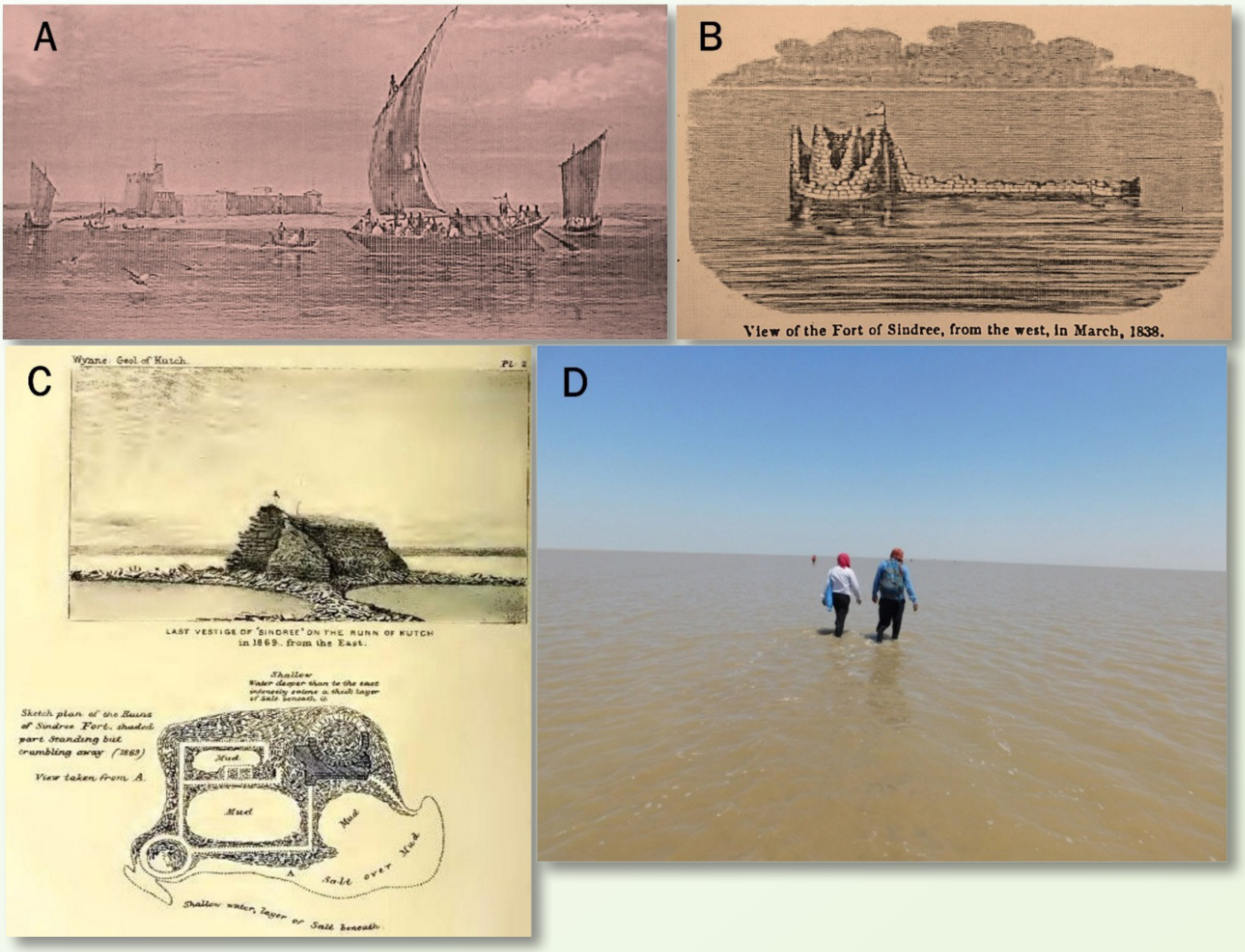


Figure 4. **(A)** In 1808 when Gridley visited the area and made a sketch of Sindri fort and its surroundings. A fort with 4 bastions and one spire with flag on it. It was an active revenue collection center under the King of Kachchh. Small country crafts used to sail and had an active inland navigation route to Ali Bunder to the north. **(B)** Fort Sindri in 1838 almost 19 years after the devastating earthquake. A few walls and almost collapsed main tower was seen but it was under the shallow lagoon water for years. **(C)** In 1869, almost 50 years after the earthquake when Dr A. B. Wynne visited and sketched from the east looks almost dry bed to the east. The abandoned fort and bastions are still seen. **(D)** In 2017, when our team (the author of this article and Kachchh University team along with Dr Navin Juyal of PRL and Dr P. S. Thakker, ISRO) visited the same site for the search of the Sindri fort but did not see the fort in the depression.

The uplift blocked the Nara Channel, a distributary of the Indus River, leading to the formation of a freshwater lake on its northern side (Fig. 2) (Burnes, 1833). To the south, a large depression formed due to subsidence, resulting in the Sindri Lake, which submerged a prominent castle and fort—a former customs and military post of the Kachchh Kingdom (Figs. 3 & 4) (Oldham, 1926; Bilham, 1999).

The earthquake caused a complex pattern of uplift and subsidence, extending from Allah Bund in the northeast to Busta Bunder – another custom collection and military post in the southeast, as shown in Figure 2 (Thakkar et. al, 2012; Rajendran & Rajendran, 2001; Biswas, 2005). Historical records provide striking corroboration of this geomorphic change. In 1808, eleven years before the earthquake, Captain Grindlay visited the region and recorded a well-maintained fortified settlement at Sindri – a fort and castle, served as the major military base and revenue centre along the channel of Nara flowing to south into the Arabian Sea via Kori Creek. Most cargo ships going to the north following the inland navigation used to stop here for custom duties. However, a post-earthquake account by James Burnes in 1838 described the same fort as collapsed ruins, confirming the destructive impact of the quake (Figs. 4A & 4B) (Burnes, 1833). Further documentation came from Dr A. B. Wynne, Director of the Geological Survey of India, who visited the site in 1869, about fifty years after the earthquake. He carefully sketched the remnants, noting dilapidated walls, scattered bricks, and structural debris, providing critical visual documentation (Fig. 4C) (Wynne, 1872).

In recent decades, the site was revisited by the author of this article, accompanied by Dr S. Bhandari, Dr Gaurav Chauhan (of KSKV Kachchh University), Dr N. Juyal (PRL), and Dr P. S. Thakker (ISRO). The team attempted to reach and document the submerged remains of the Sindri Fort within the depression, now known as Sindri Lake. However, the attempt proved unsuccessful and hazardous, likely due to continuous submergence, soft substrate, and the mud-brick architecture of the original structure (Fig. 4D).

Kosi River (Bihar and Nepal)

Several rivers in India have undergone significant course changes in recent history, with the Kosi River—often referred to as the *"Sorrow of Bihar"*—standing out as one of the most dynamic and hazardous examples. The Kosi is known for its frequent and unpredictable avulsions, which are primarily driven by a combination of tectonic uplift, intense sediment load, and monsoonal hydrology (Sinha, 2009; Wells & Dorr, 1987). A major geological factor influencing these shifts is the Main Frontal Thrust (MFT)—a tectonically active fault system along the Himalayan front that undergoes periodic reactivation, thereby impacting regional topography and fluvial gradients (Bilham et al., 2001; Lavé & Avouac, 2001).

A dramatic avulsion occurred in 2008, when the Kosi River suddenly breached its embankment at Kusaha in Nepal and shifted over 100 km eastward from its established channel, inundating large areas of Bihar and displacing over 3 million people (Sinha, 2009; Mishra, 2008) (Fig. 5). This event exemplified the river's natural tendency to seek lower-gradient paths across the floodplain when its elevated channel becomes unstable due to sediment buildup.

The Kosi River is a major tributary of the Ganga River, draining a vast Himalayan catchment that includes the Mount Everest region. Despite originating at high altitudes, the river meets the Ganga at just 25 meters above sea level, over a straight-line distance of approximately 300 km. This steep altitudinal gradient, combined with intense summer monsoon rainfall, results in aggressive erosion in the upper catchment and massive sediment deposition in the lower reaches (Goswami, 1985; Sinha et al., 2005). (Fig. 5)

Upon exiting the Himalayan foothills, the Kosi debouches into the Gangetic plains, forming the Kosi Megafan—one of the largest alluvial fans in the world, covering nearly 15,000 square kilometers (Sinha et al., 2005; Giosan et al., 2012). As the riverbed progressively aggrades due to high sediment load, it rises above the surrounding terrain, becoming prone to sudden channel avulsion. This behaviour has caused repeated shifts in the river's course, with historical records showing multiple channel positions between AD 1731 and 1963, as illustrated in Figure 5 (Goswami, 1985; Wells & Dorr, 1987) (Fig. 5).

ABRUPT CLIMATE CHANGE AND RIVER COURSE SHIFTS

Abrupt climatic events, such as cloudbursts, intense thunderstorms, and Glacial Lake Outburst Floods (GLOFs) can trigger extreme flooding, causing rivers to overflow and often carve out new courses (Worni et al., 2013; Allen et al., 2016). Conversely, prolonged droughts, glacial retreat, and monsoon failures can drastically reduce river discharge, resulting in channel shrinkage and rerouting (Clift & Plumb, 2008; Sinha et al., 2019). Glacial advances may also obstruct valleys, forcing rivers to form new pathways

Figure 5. Shifting courses of Kosi River channel from the year 1731 to 1963 AD. (Gole and Chitale, 1966).

or lakes, as seen historically with the Indus and its tributaries (Giosan et al., 2012; Clift et al., 2012a).

Increased rainfall can intensify discharge, leading to overbank flow and avulsion—a rapid and often permanent change in a river's course (Slingerland & Smith, 2004). On the other hand, reduced precipitation or aridification dries up channels, forcing rivers to migrate toward more stable or lower-gradient paths (Sinha & Friend, 1994). Long-term fluctuations in the Indian monsoon have caused ancient rivers, such as the Saraswati (now considered the Ghaggar-Hakra system) to become seasonal or extinct (Tripathi et al., 2004; Giosan et al., 2012) (Fig. 6).

Heavy rainfall combined with deforestation accelerates surface runoff, erosion, and sediment load, leading to aggradation—raising of riverbeds—which destabilizes channels and promotes shifting (Schumm, 1977; Valdiya, 2002). In sediment-rich conditions, rivers often form braided channels, whereas steadier flows encourage the development of meandering channels (Leopold & Wolman, 1957; Bridge, 2003). Vegetation plays a crucial role in stabilizing banks, however, climate-induced deforestation, especially

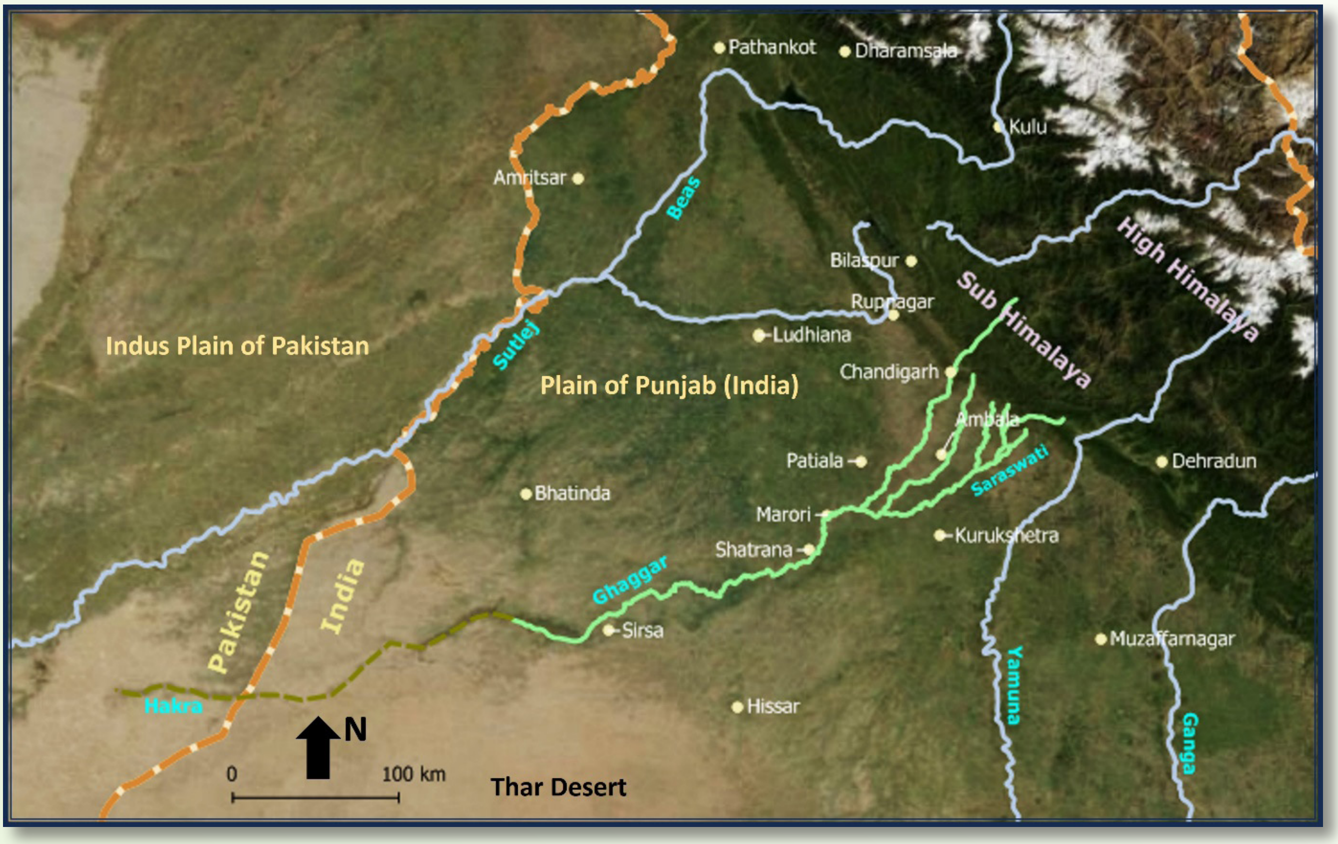


Figure 6. This satellite picture shows Thar desert of Rajasthan, fertile Indus basin of Punjab and Pakistan, plain of Haryana and eastern UP containing many paleochannels, Himalayan foot hills regions and higher Himalaya. Note the origin of Saraswati/ Ghaggar is in the sub-Himalayan region; and Yamuna River takes sharp turn from Kurukshetra. Also note that the Hakra channel meets Sutlej River to the west. According to the Rig-Ved the Saraswati was flowing between the Sutlej and the Yamuna. Hence the present day Ghaggar is known as the course of the Vedic Saraswati (After Suvrat Kher: https://suvratk.blogspot.com/2008/04/is-saraswati-still-flowing-underground.html)

during arid climatic phases, weakens bank stability and facilitates meander migration (Hooke, 2003; Knox, 2000).

Sea-level changes also influence river behaviour. During glacial periods, lower sea levels cause rivers to incise deeper valleys as they extend seaward (Stanley & Warne, 1994). In contrast, rising sea levels in interglacial periods result in delta shifting, backwater effects, and sediment deposition at river mouths, compelling rivers to alter their terminal courses (Blum & Törnqvist, 2000). Additionally, extreme weather events, such as cyclones, long-duration monsoon floods, and flash floods from cloudbursts can breach riverbanks and permanently alter river channels (Sati, 2013; Kale, 2003).

SHIFTING OF RIVERS IN INDIA AND THEIR IMPACT ON CIVILIZATIONS

THE INDUS AND THE VEDIC SARASWATI

The Indus Valley Civilization (IVC) – one of the world's earliest urban cultures—thrived around 2500 BCE along the Indus River and its tributaries. Many ancient sites are also found along the Ghaggar-Hakra River, believed by some to be the *Saraswati River* mentioned in the Vedas. Geological evidence suggests that this river was once glacial-fed, but due to tectonic shifts and drying climate around 2000 BCE, it lost its flow. This drying trend likely forced people to migrate eastward, contributing to the spread of settlements

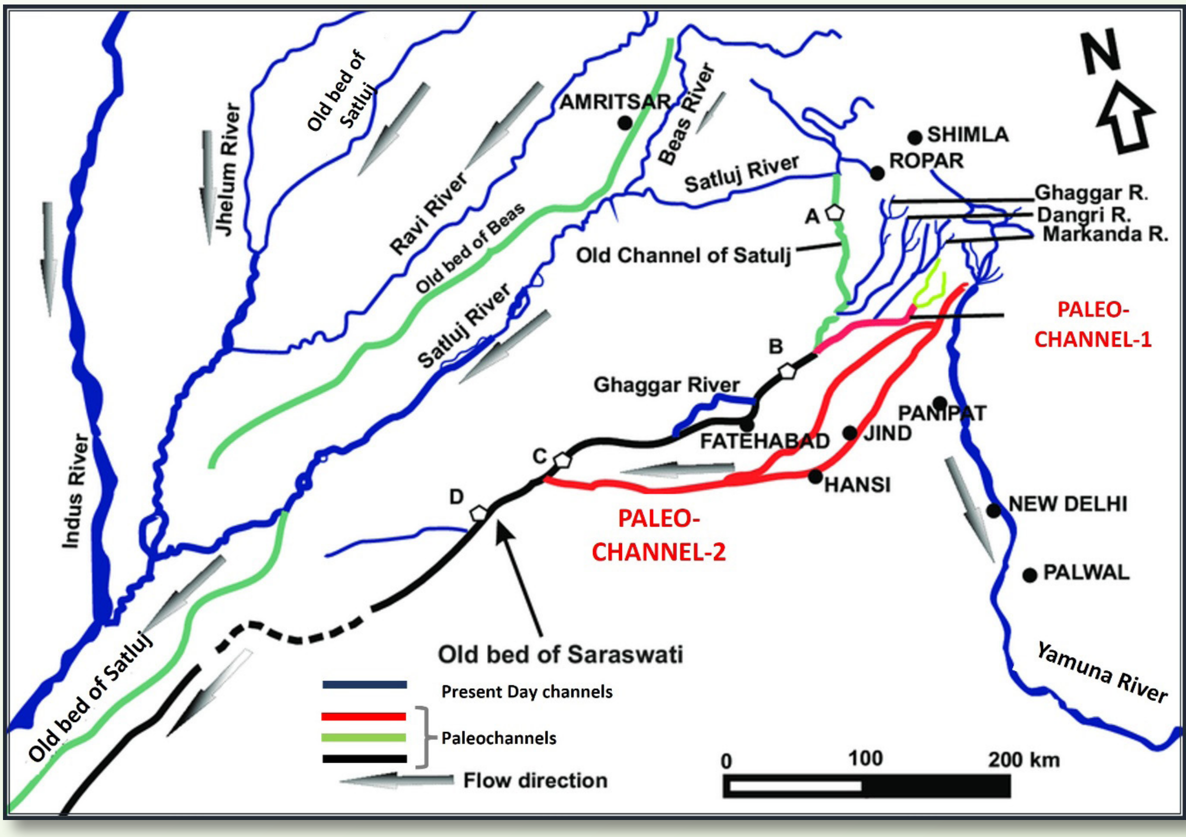


Figure 7. Drainage map of northwestern India showing present day channels/ rivers in blue colors and paleochannels between Indus River and Yamuna River in red, green and black colors. The red marked paleochannels are old courses of Yamuna while black colored are the paleochannels of Vedic Saraswati River which is largely occupied by modern Ghagghar River. Green ones are the old river beds of Beas and Satluj Rivers. The old connections with Satluj River and Yamuna River are also shown (After Yashpal, et al, 1980). Point 'A' to 'D' are the locations of OSL chronology indicating cessation of river flows (After Saini et al, 2020).

in the Ganga-Yamuna plains. The dynamic course changes in the Indus River and its tributaries have played a crucial role in shaping the rise and eventual dispersal of the Harappan Civilization (c. 2600–1900 BCE). This paper examines the paleogeographic evidence for fluvial migrations of the Indus and its tributaries, highlighting the role of regional tectonics and Holocene climate variability. Corroborated with archaeological and sedimentological evidence, the analysis supports a slow and regionally staged migration of Harappan populations in response to diminishing river flows, drying channels, and shifting floodplains. The civilization's sustenance was deeply intertwined with the hydrological stability of the Indus River system, which includes the major tributaries – Jhelum, Chenab, Ravi, Beas, and Sutlej (Fig. 7). Recent geological and paleoenvironmental studies suggest that significant shifts in river courses – driven by tectonic adjustments and climate change – led to profound societal transformations and eventual de-urbanization (Fig. 6 & 7).

SHIFTING COURSES OF THE INDUS AND ITS TRIBUTARIES

Paleochannels and tectonic control

The satellite imagery, remote sensing data, and sediment core analyses reveal numerous paleochannels crisscrossing the Indo-Gangetic plains and Thar Desert. For example: The Sutlej River, which now joins the Indus near Mithankot, once flowed along a more southeasterly course through the Ghaggar-Hakra-Nara alignment. Geological mapping by Clift et al. (2012) and Singh et al. (2017) shows Sutlej avulsion likely occurred around 8,000–5,000 years ago due to tectonic tilting. The Ghaggar-Hakra system, often equated with the Vedic Saraswati, is now ephemeral, but was once a mighty perennial river (Fig. 6 & 7). Remote sensing and OSL dating of fluvial sands (Saini et al., 2009; Ajit Singh et al., 2017) indicate significant flow in the mid-Holocene. Neotectonic uplift along the Himalayan Frontal Thrust (HFT) and active folding in the Siwalik region caused river deflections and abandonment of older channels.

Cholistan and Ghaggar-Hakra paleochannels

The Cholistan Desert, situated in southeastern Pakistan, is traversed by the remnants of the Ghaggar-Hakra palaeochannel, which is widely considered to be the continuation of the Ghaggar River in India. This now-dry channel system has been extensively studied using remote sensing, sediment coring, and archaeological data. Satellite imagery, particularly Landsat and Indian Remote Sensing (IRS) data, has clearly revealed the course of this palaeochannel across Rajasthan and into Cholistan.

Multiple core drilling studies have confirmed the existence of fluvial sandy deposits overlain by aeolian sands, indicating the channel once carried significant water flow (Clift et al., 2012b; Saini et al., 2009). Luminescence dating of these fluvial sequences has shown that active river flow along this channel occurred until around 2000 BCE. The decline in discharge and eventual aridification of the system corresponds temporally with the abandonment of Harappan settlements in this region (Giosan et al., 2012; Singh et al., 2017).

The Hakra River, possibly a separate tributary or extension of the Ghaggar system, is believed to have supported a dense network of Harappan settlements in the Cholistan Desert. Over 400 archaeological sites have been recorded along this dry course, attesting to a once-thriving river-dependent civilization (Mughal, 1997; Danino, 2010). The terminal desiccation of this river is widely thought to have been caused by a combination of monsoon weakening and tectonic reorganization of upstream tributaries (e.g., the Sutlej and Yamuna) (Figs. 6 & 7).

Sutlej and Beas migration

The rivers Sutlej and Beas, both originating in the western Himalayas, have undergone significant paleohydrological changes over the Holocene (last 11,700 years). The Sutlej River, which currently joins the Beas and later the Indus, is believed to have migrated northwestwards, abandoning its earlier flow into the Ghaggar-Hakra system (Clift et al., 2012) (Fig. 7). This shift may have occurred due to neotectonic activity, including uplift and tilting of the Himalayan foreland basin, which altered the regional gradient and redirected river courses. Sediment provenance studies using isotopic signatures and zircon dating have demonstrated that the Sutlej once flowed through the Ghaggar system, contributing Himalayan sediments. However, by around 1500–2000 BCE, the river had permanently shifted to its current course, thereby cutting off perennial water supply to the Ghaggar-Hakra channel (Clift et al., 2012; Giosan et al., 2012) (Fig. 7).

The Beas River, meanwhile, shows signs of eastward migration, likely due to fluvial dynamics and avulsion processes over the past 5,000 years (Sinha et al., 2012). These migrations reshaped the drainage landscape of northwest India and Pakistan, contributing to the hydrological instability that may have impacted the sustainability of Harappan urban centres, especially those located along now-inactive or seasonal river courses. In conclusion, it can be said that the Cholistan-Ghaggar-Hakra palaeochannel system represents a once-flourishing fluvial corridor that supported dense Harappan settlement until c. 2000 BCE, after which it dried due to climatic and tectonic shifts. The Sutlej and Beas rivers played crucial roles in shaping this landscape, their migrations driven by natural forces leading to lasting impacts on regional hydrology and ancient civilization patterns.

Climate-driven aridification

During the Holocene Climatic Optimum (c. 6000–2000 BCE), the northwestern Indian subcontinent experienced relatively humid conditions, largely supported by a strong Indian Summer Monsoon (ISM). This climatic phase was instrumental in sustaining large rivers like the Ghaggar-Hakra and supporting the flourishing of Harappan urban settlements across present-day Pakistan, Haryana, Rajasthan, and Gujarat. However, multi-proxy paleoclimate reconstructions from various lake and cave archives indicate a sharp and prolonged weakening of the monsoon after c. 2000 BCE. Sediment cores from lakes such as:

A. Lunkaransar (Rajasthan) showed transitions from fluvio-lacustrine to aeolian sedimentation, indicating desertification (Enzel et al., 1999; Singh et al., 1990).
B. Didwana and Riwasa lake beds provided pollen and isotope records that reveal a decline in vegetation and effective moisture, further supporting reduced monsoonal intensity (Sharma et al., 2004; Prasad & Enzel, 2006).
C. Speleothem records from caves like Dandak (central India) and Mawmluh (Meghalaya) show clear reductions in $\delta^{18}O$ values—evidence of diminished rainfall after 2000 BCE, interpreted as the onset of more arid conditions (Dixit et al., 2014; Kathayat et al., 2017).

This monsoon weakening led to a drop in groundwater recharge and river discharge, particularly affecting non-glacial rivers like the Ghaggar-Hakra. Eventually, these rivers became ephemeral or dried up completely, destabilizing the hydrological foundation upon which many urban Harappan settlements were built.

THE YAMUNA'S DRAMATIC DIVERSION: GEOLOGICAL, CLIMATIC AND CULTURAL IMPACTS

ANCIENT COURSE OF THE YAMUNA RIVER

Presently, the Yamuna River flows southeast from the Himalayas, joining the Ganga River at Prayagraj (Allahabad), and is one of its major tributaries. However, geomorphic, sedimentological, and archaeological evidence suggests that the Yamuna did not always follow this course. In the Early Holocene (c. 11,700–8200 years ago), the Yamuna may have flowed westward or southwestward, contributing its waters to the Ghaggar-Hakra (Saraswati) system, which once supported dense Harappan urban settlements in present-day Haryana, Rajasthan, and Cholistan (Pakistan). Satellite imagery and palaeochannel mapping have identified abandoned Yamuna-like channels west of its present course (Yash Pal et al., 1984; Sinha et al., 2009) (Figs. 6 & 7). These channels likely connected with the Ghaggar system near Hanumangarh and Kalibangan.

TECTONIC TILTING ALONG THE DELHI-HARIDWAR RIDGE

One of the primary factors influencing the Yamuna's course change is tectonic activity, particularly along the Delhi-Haridwar Ridge, a subsurface structural high aligned northwest – southeast that acts as a hydrological and geological divide between the Yamuna and Ghaggar basins (Roy and Jakhar, 2001). Studies have shown that tectonic tilting or uplift along

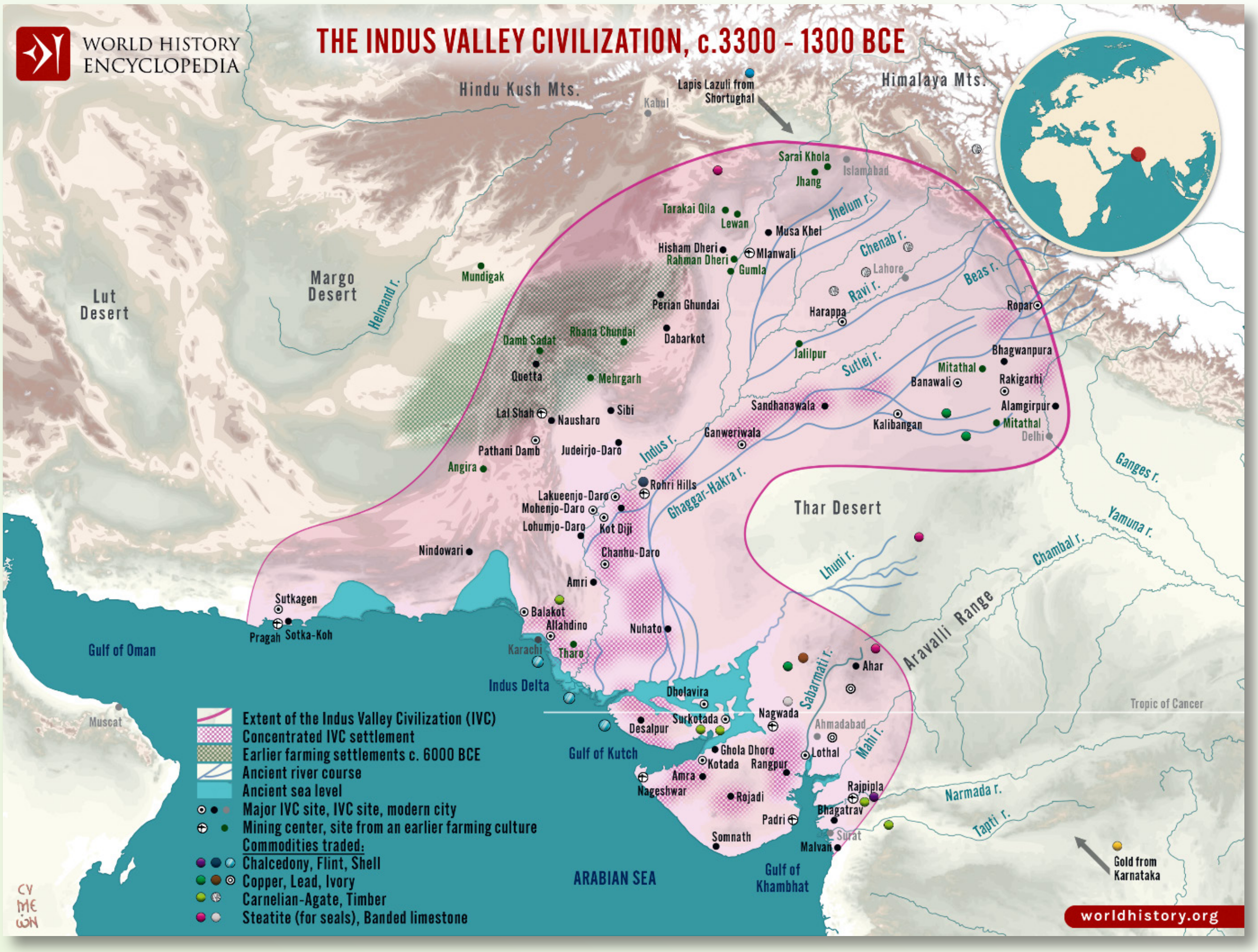


Figure 8. This map illustrates the extent and key urban centres of the Indus Valley Civilization (3300–1300 BCE). Spanning parts of modern-day Pakistan and northwest India. This civilization was notable for its large, well-planned cities, sophisticated infrastructure, and extensive trade networks. Often referred to as the Harappan or Sindhu-Sarasvati Civilization, it featured cities such as Harappa, Mohenjo-Daro, Kalibangan, Ganveriwala, Kot Diji and Dholavira that showcased grid-based layouts, advanced drainage systems, and standardized construction techniques. (Refer the link of World History Encyclopedia: https://www.worldhistory.org/Indus_Valley_Civilization/),

this ridge during the Mid- to Late-Holocene – roughly around 2000–1500 BCE – likely caused a gradual eastward deflection of the Yamuna River (Valdiya, 2002; Kumar et al., 2019). Seismic and geomorphic surveys, as well as borehole data, suggest vertical movements and faulting events that altered slope gradients, redirecting flow from the Ghaggar basin to the Ganga plains (Suresh et al., 2020).

This tectonic reorganization was likely influenced by the regional stress regime associated with the ongoing India-Eurasia plate collision, which continues to uplift the Himalayas and deform the adjacent foreland basin.

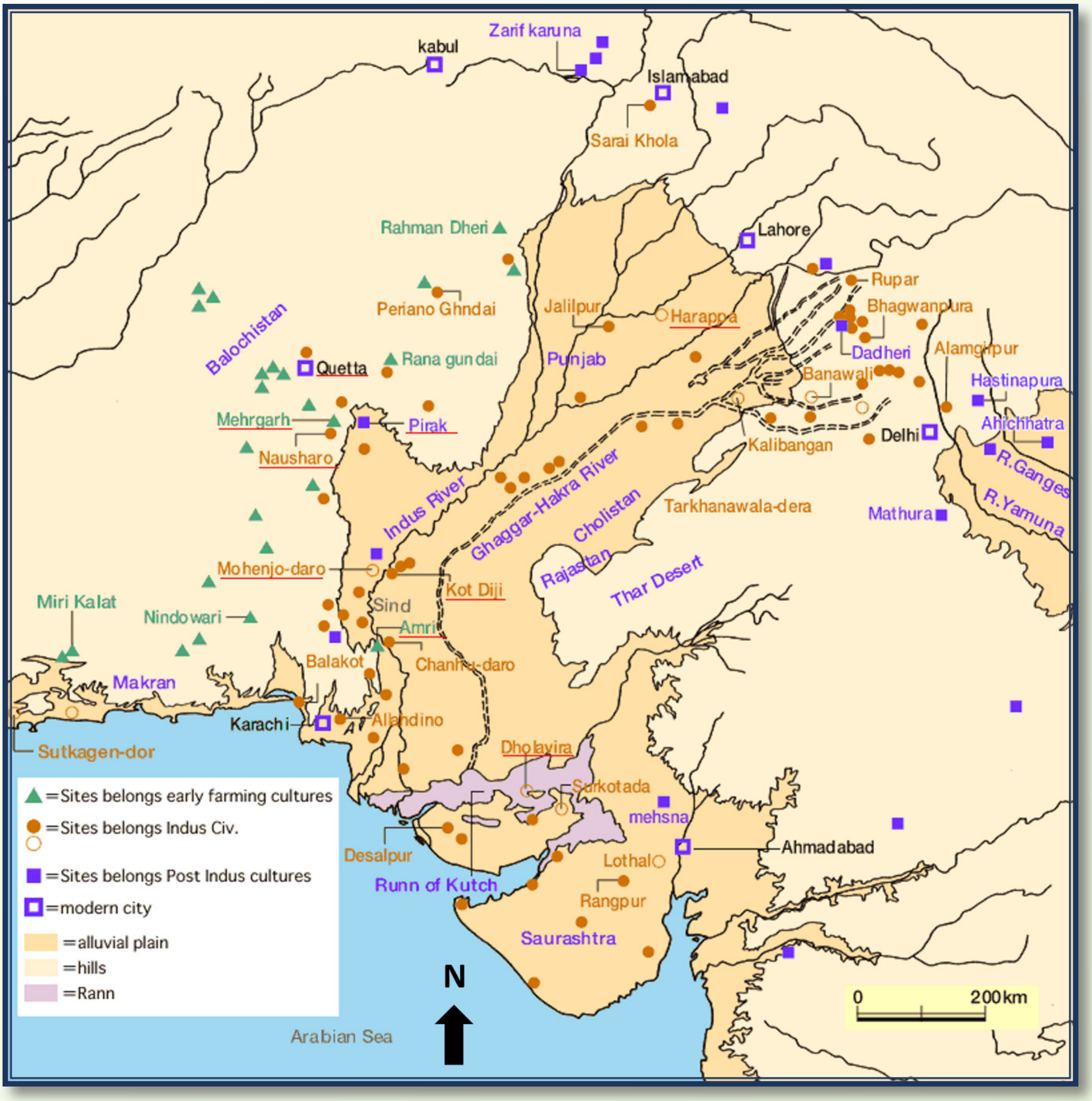


Figure 9. This map illustrates the sites belongs to early farming cultures, sites belong to Indus civilization, sites of post Indus cultures and also the modern cities. Note the early farming sites are concentrated in the west while the post Indus sites are clustered around Ganga and Yamuna rivers.

EVIDENCE OF HARAPPAN MIGRATION DUE TO RIVER SHIFTS

URBAN DE-URBANIZATION AND SITE DISTRIBUTION SHIFT

The Mature Harappan phase (c. 2600–1900 BCE) saw large, sophisticated cities, such as Mohenjo-Daro, Harappa, Dholavira, Kalibangan, and Rakhigarhi, which were strategically located near perennial rivers or active palaeochannels (Fig. 8). The reliability of water sources enabled urban growth, trade, intensive agriculture, and population density. However, as rivers such as the Sutlej and Yamuna were diverted (due to tectonics or avulsions) and as the Ghaggar-Hakra dried up, urban centres in Cholistan (Pakistan) and western Rajasthan saw a decline in occupation density, reduced building activity, and eventual abandonment (Giosan et al., 2012; Wright et al., 2008). Settlement data show a clear spatial shift in the Late Harappan phase (1900–1300 BCE): (a) Increased settlement concentration in eastern Punjab, the Upper Ganga-Yamuna plains, and northern Gujarat. (b) Cities like Kalibangan, Rakhigarhi, and Banawali, which were once major urban hubs, began to decline—evidenced by reduced structural complexity, decreased craft production, and diminishing long-distance trade.

This eastward and southward migration aligns with the availability of more stable monsoon-fed rivers (like the Yamuna and Ghaghara) and groundwater resources, showing a strategic relocation of populations in response to hydroclimatic stress (Fig. 9).

ARCHAEOLOGICAL AND CULTURAL TRANSITIONS

With urban de-urbanization came marked changes in Harappan material culture, suggestive of socio-political fragmentation and local adaptations:

A. The post-urban or Late Harappan phase is characterized by smaller, dispersed rural settlements, rather than large cities. These sites often lack monumental architecture or centralized planning (Possehl, 2002).

B. Ceramic typologies changed significantly: the appearance of more region-specific wares (e.g., Painted Grey Ware, Black-and-Red Ware) illustrates the breakdown of pan-Harappan cultural homogeneity (Kenoyer, 1998).

C. Agricultural practices adapted to changing climate. There was an increased emphasis on drought-resistant crops, such as millets, barley, and sorghum, replacing earlier wheat-dominated systems in some regions (Petrie et al., 2017).

D. Burial customs also diversified. There was a decline in standardized cemetery patterns, and increased local variation emerged in funerary practices, pointing to cultural pluralism and social reorganization.

These shifts reflect how communities adapted to environmental degradation and loss of riverine infrastructure—by becoming more resilient, mobile, and decentralized.

IMPACT ON THE GHAGGAR-SARASWATI SYSTEM

The loss of major tributaries like the Yamuna (and earlier, the Sutlej) had a profound effect on the Ghaggar-Hakra system: Without perennial water inputs, the river transitioned from perennial to ephemeral, supported only by monsoonal runoff or seasonal flow (Clift et al., 2012a; Giosan et al., 2012). This hydrological decline coincides with the abandonment or decline of key Mature Harappan sites, such as Kalibangan, Banawali, and Rakhigarhi, which were located along the now-defunct channels of the Ghaggar (Petrie et al., 2017) (Fig. 8).

STRENGTHENING OF THE GANGA BASIN AS A CULTURAL AND AGRICULTURAL HEARTLAND

As the Yamuna redirected its flow into the Ganga, it brought with it substantial water volume, sediment load, and fertile alluvium, contributing to the agricultural viability of the Middle Ganga

Plains. This redirection helped transform the Ganga-Yamuna Doab into a major cultural and settlement hub from the Late Harappan phase (c.1900 BCE) onward, eventually giving rise to Painted Grey Ware (PGW) and early Vedic cultures (Possehl, 2002; Chakrabarti, 1999). The eastward shift of settlement patterns, from drying western basins to the increasingly fertile Ganga Plain, represents one of the most significant population and cultural realignments in the subcontinent's prehistory. The diversion of the Yamuna River was a watershed moment in the environmental and cultural history of the Indian subcontinent. Controlled by tectonic uplift and associated with the weakening monsoon, this hydrological shift diminished the viability of the Ghaggar-Hakra system and enhanced the fertility of the Ganga plains, facilitating a civilizational pivot that laid the foundation for post-Harappan and Vedic cultures.

CONCLUSION: CLIMATE, TECTONICS, AND CIVILIZATION RESPONSE

Rivers are storytellers of deep time. Their changing courses have not only redrawn maps but have rewritten the story of India itself—its civilizations, migrations, and sacred traditions. Studying them through the lens of geology helps us understand where we came from, and where we may be headed. The interplay between climate change, tectonic processes, and river dynamics played a foundational role in shaping the trajectory of one of the world's earliest urban civilizations—the Harappan or Indus Valley Civilization. A complex set of processes, including the gradual decline of the Indian Summer Monsoon (ISM), tectonic uplift along major fault zones and ridges, and the migration or drying of key rivers, fundamentally altered the hydrological fabric of northwestern India and Pakistan during the Mid-to-Late Holocene (c. 2200–1500 BCE).

The Harappan Civilization was deeply intertwined with its riverine environment. Its cities—like Harappa, Mohenjo-Daro, Kalibangan, Dholavira, and Rakhigarhi—depended on perennial river systems for agriculture, transportation, trade, and communication. As rivers, such as the Sutlej and Yamuna migrated or were diverted due to tectonic tilting and basin-wide gradient shifts, and as monsoonal rainfall weakened, the Ghaggar-Hakra system gradually lost its perennial flow. This led to a reduction in agricultural productivity and a decline in the sustainability of urban centres.

Importantly, the transformation was not marked by a sudden societal collapse, rather a protracted, adaptive process of transition. The Harappans responded to these environmental stresses by shifting settlement patterns, modifying agricultural practices, and dispersing into more climatically and hydrologically favourable zones, such as eastern Punjab, Gujarat, and the Ganga-Yamuna plains. This migration and reorganization reflect a civilization that was dynamic and resilient—capable of responding to environmental changes with strategic relocations and cultural adaptations.

The diversion of the Yamuna River, in particular, stands out as a pivotal hydrological event. Once a likely tributary to the Ghaggar-Saraswati system, the Yamuna's deflection eastward into the Ganga Basin—driven by tectonic uplift along the Delhi-Haridwar Ridge—not only weakened the fluvial support for western Harappan sites, but also contributed to the emergence of the Ganga plains as a new civilizational heartland. This shift is closely linked to the rise of post-Harappan cultures, including the Painted Grey Ware culture and Vedic traditions, marking a civilizational continuum rather than a rupture.

By integrating data from satellite remote sensing, palaeochannel mapping, sedimentological and isotopic studies, radiometric dating, and archaeological site distribution, researchers are now able to reconstruct a compelling picture of how environmental change influenced ancient human behaviour. The Indus case study exemplifies a broader global theme: rivers not only sustain civilizations but also transform them. When their courses shift—whether through natural or anthropogenic drivers—societies are forced to adapt, relocate, and sometimes reinvent themselves.

Ultimately, the story of the Harappan civilization's transformation underscores the profound sensitivity of urban societies to environmental dynamics. It serves as a reminder that fluvial systems are not static, and that the health and trajectory of civilizations are deeply dependent on the stability of their water sources. In the context of contemporary climate change and water scarcity, the lessons from the past are not merely of academic interest—they are urgent and instructive for the future of water management, urban planning, and cultural resilience.

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Palaeoscience and Society
How learning from the past benefits us today

Himanshu Mishra

THE DEEP PAST, OUR GUIDING LIGHT

WHAT if we could gaze back into the past -not only decades or centuries, but millions of years ago-to see how the Earth has evolved ? What if we could learn from this and better comprehend our environment, so that we could make better decisions for the future ?

Palaeoscience is the science of Earth's past recorded through clues such as fossils, rocks, ice cores, sediments, amber fossils and tree rings. It teaches us how our planet changed over billions of years-how the continents shifted, how the climate changed, and how life on earth evolved.

We are confronted with giant problems: climate change, melting ice sheets, extinction, pollution, and forest loss. Palaeoscientific information provides a long-term perspective to better comprehend these changes. It makes us more climate-savvy, enables wiser environmental decision-making, and increases public awareness of our relationship with Earth.

Here, we look at how the old earth continues to have something to say to us- and why we need to listen.

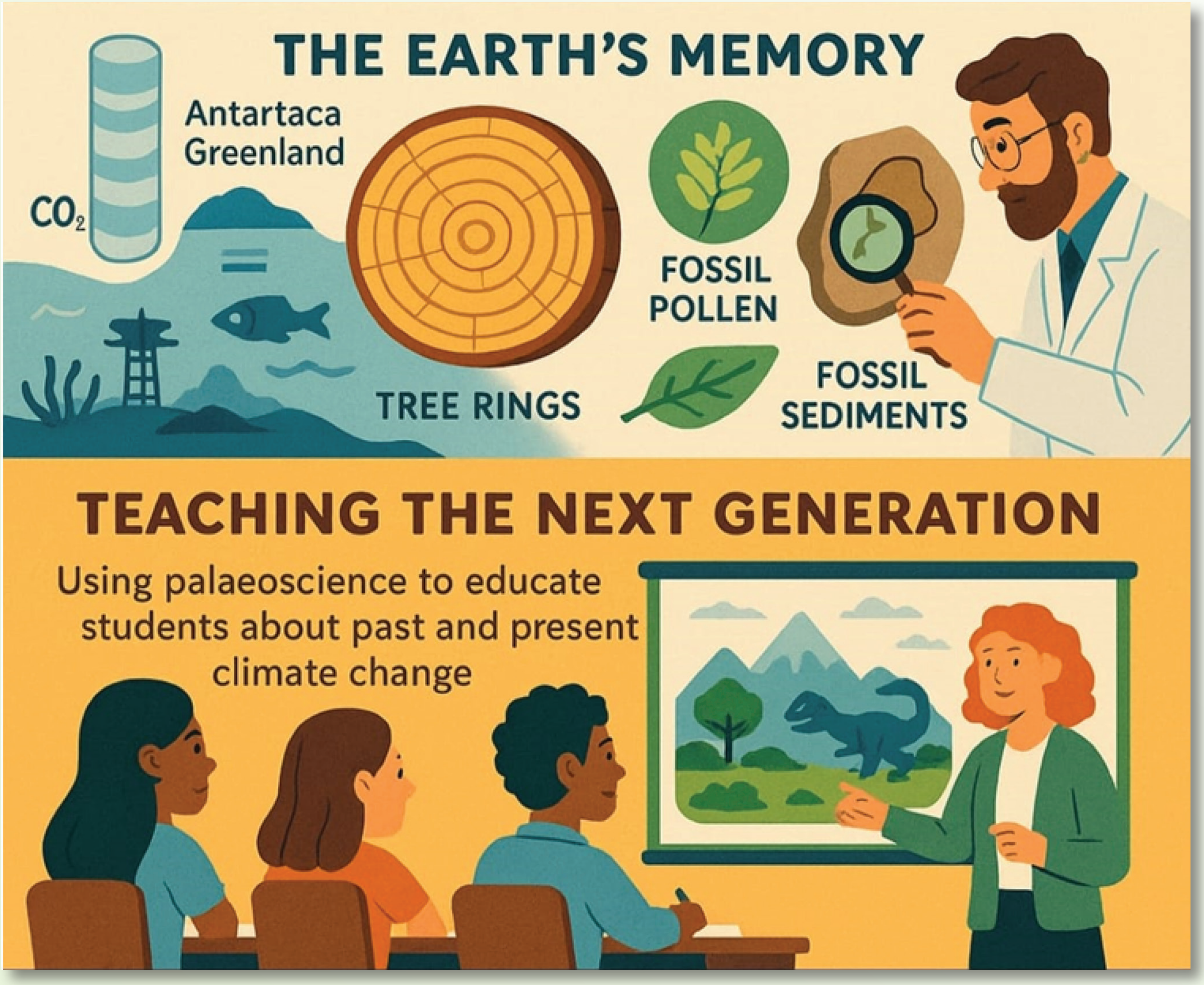
CLIMATE LITERACY? LEARNING TO UNDERSTAND THE PLANET THROUGH DEEP TIME

What is Climate Literacy ?

Climate literacy refers to the ability to comprehend how Earth's climate system operates, how it varies, and how human activities affect it. A climate-literate individual comprehends the science of climate change and can take accountable actions at home, in their workplace, or as a citizen. To be climate-literate, we require more than fleeting weather information or satellite photographs. We require insight into how the climate acted over thousands or millions of years. This is where palaeoscience comes in.

The Earth's Memory

The Earth stores a memory of its past in various forms: Ice cores from Antarctica and Greenland inform us of the amount of carbon dioxide (CO2) present in the atmosphere thousands of years ago. Tree rings indicate annual cycles of droughts and moist seasons. Seas give us ocean temperatures and sea life



from millions of years ago. Fossil pollen provides information on vegetation and climate trends.

By examining these natural records, researchers have learned that Earth's climate has experienced extreme changes. The planet was hotter or colder than it is now at certain times. Volcanic eruptions or increased CO_2 levels led to massive extinctions. Changes occurred slowly or quickly. For example, around 56 million years ago, a sharp rise in carbon levels caused global warming, ocean acidification, and species migration- a scenario eerily similar to what we're witnessing today.

Lighting the Way Forward

Palaeoscience makes climate education come alive. It turns learning into exploration. Students learn how to read the past through clues like rocks and fossils. Teachers can explain today's climate problems by comparing them with ancient ones.

Museums, nature reserves, and computer programs bring ancient Earth with reach and alive. This type of education sparks curiosity. It makes young people realize that Earth isn't merely the backdrop of our lives- it's a living system with a history, and we're a part of it.

ENVIRONMENTAL POLICY: PAST LESSONS FOR FUTURE PLANNING

Nature's Warning Signs

Earth has undergone enormous disruptions in the past-severe climate changes, asteroid strikes, volcanic winters, and global extinctions. Some of these have given us clues on the dangers facing us today. Take these as examples: 252 million years ago, during the Permian mass extinction, over 90% of the species perished as a result of global warming and the alterations in oceans. During the Paleocene-Eocene Thermal Maximum (PETM), a huge rise in CO_2, resulted in severe global warming and extinctions.

After the last Ice Age ended about 12,000 years ago, rapid warming caused glaciers to melt, sea levels to rise, and ecosystems to shift. Palaeosciences shows us that Earth systems are complex, and they can collapse when pushed too far. These lessons are essential when creating modern environmental policies.

Deep Time Clues for Navigating Climate Futures

Governments, planners, and international organizations depend on scientists, information to make environmental choices. Palaeoscience underpins these choices in numerous capacities: It supplies information on past climate-informing scientists on how today's climate change may influence rainfall, crops, or water supply. It assists in the projection of sea level rise based on past ice sheet collapse.It directs conservation actions, by locating ancient ecosystems that are now vulnerable to destruction. It guides risk evaluations for areas that are vulnerable to droughts, floods, or desertification.

For instance, policymakers can develop more effective recovery strategies for today's catastrophes by knowing how past climates affected ecosystems.

A Global Influence

Palaeoscientific knowledge is now being incorporated into worldwide policy-making: The IPCC (Intergovernmental Panel on Climate Change) incorporates palaeoclimate data in its reports to assist governments in comprehending long-term climate risks. UNESCO Geoparks conserve fossil-bearing areas and encourage sustainable use and education. Global agreements like the Paris Agreement consider past carbon trends to set emission targets. When ancient knowledge supports modern planning, our strategies become not only smarter but also more responsible.

PUBLIC ENGAGEMENT: CONNECTING PEOPLE TO THE PLANET'S PAST

Unlocking Earth's Deep History

Fossils are time machines. A petrified leaf, a fish frozen in shale, or an insect trapped in amber. These things have tales to tell from the days before humans. For most individuals, viewing a fossil gives rise to a feeling of awe and sometimes intense curiosity. This is an emotional reaction, it can inspire environmental awareness. When individuals discover that life has been around for millions of years-and that today's species are along for the ride, too-they start taking a greater interest in preserving the natural world.

Science for Everyone

Palaeoscience isn't exclusive to scientists. It is being brought to people in exciting ways worldwide: Natural history museums enable people to trace their way through Earth's past. Science fairs and fossil fairs provide hands-on activities. Digital media, such as podcasts, animations and computer games, engage children with information. Citizen science initiatives encourage individuals to participate in actual research by identifying fossils or observing geological locations.

Even social media is used as a means of communication for palaeoscience, with researchers and teachers uploading fossil images, mini-lessons, and interesting facts. This type of public involvement creates a more robust, better-educated society-one

that values Earth's extensive history and recognizes the value of saving it.

CHALLENGES AND OPPORTUNITIES: TAKING PALAEOSCIENCE FURTHER

Connecting Science & Society

Despite the much that palaeoscience has to contribute to our understanding, it encounters numerous challenges:

Complex language: Most scientific articles are beyond the reach of the public.

Limited funding: In most nations, palaeoscientific research is not prioritized.

Neglected fossil sites: Valuable sites are under threat from construction, pollution, or looting.

Uneven access: Most developing regions do not possess the equipment or training to investigate their palaeontological heritage.

These challenges prevent palaeoscience from having a greater influence on education, policy, and public awareness.

Turning Challenges into Opportunities

To enhance the effectiveness and inclusivity of palaeoscience, we must:

Foster interdisciplinary collaboration: Scientists, teachers, artists, and communicators should unite to tell the ancient Earth's tale.

Defend fossil heritage: Assist local people in the conservation and management of fossil sites.

Invest in training and facilities: Enable researchers and students in disadvantaged areas to join international palaeoscience networks.

With proper support, palaeoscience can be a bridge-between science and society, the past and the future.

CLOSING THOUGHTS: TURNING BACK TO SEE THE WAY FORWARD

Palaeoscience teaches us that Earth is not a fixed entity-it has evolved again, in cycles of growth and decay, evolution and extinction. We are now a part of this narrative. Now the planet is experiencing environmental change, climate patterns are changing, species are vanishing, and ecosystems are strained. But we're not clueless. The ancient Earth has left us hints. Learning about what went on before-during teaches us to act sensibly today. Palaeoscience isn't all about fossils and rocks. It's about foresight. It informs:

Educating the general public and making individuals climate-literate. Assist leaders and planners in making responsible environmental choices. Encourage communities t o engage with nature and safeguard what is important. Let us learn from the past, not to avoid the present, but to build a better future. Because when the past talks, the wise listen.

The Past is the key to the Future

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Palaeoclimate: What BSIP Studies Reveal About India's Palaeoclimate in the Changing Climate Scenario

Krishna G. Misra

EARTH has evolved with time and space since its origin ~4.6 billion years ago. Over this vast timespan, our planet has witnessed the emergence and extinction of countless life forms from invisible microbes to towering sea and land giants. These evolutionary episodes were shaped by powerful natural forces acting both from within the Earth and beyond.

Internally, Earth's shifting tectonic plates, changes in ocean circulation, atmospheric composition, and the feedback effects of ice cover, all have played a role in shaping the climate. Externally, variations in solar energy, slight changes in Earth's orbit, asteroid impacts, and—more recently—human activities have left their imprint on global climate patterns.

These internal and external forces interact over different timescales to drive both gradual shifts, such as ice ages, and abrupt changes, like those caused by massive volcanic eruptions or human-induced global warming. Together, they determine the planet's climate variability, making climate a key regulator of Earth's living and non-living systems.

In the current era of rapid technological advancement and environmental awareness, climate change has become one of the most talked-about global issues. It has moved beyond academic and scientific circles to engage policymakers, conservationists, and the public at large.

Understanding how Earth's climate behaved in the past—known as palaeoclimate—is crucial for decoding present and future climate trends. However, no direct evidence or data is available through which one could look into past climate-vegetation scenarios. So, we rely on indirect evidence called as proxies. These proxies can be the siliceous deposit in plants, i.e. phytoliths, diatoms, charred grains, pollen grains, tree rings, lake sediments, etc., that retain the vital information about the past climate records.

Therefore, proxy data along with the available instrumental data fetch essential information and knowledge of past climate, which, in turn, aids in refining models that predict future climate changes. Hence, understanding the Earth's climate is not just about observing weather patterns; it's about deciphering the intricate history recorded in the geological and biological remains.

Birbal Sahni Institute of Palaeosciences (BSIP) plays a pivotal role in this quest. Through its extensive research in geosciences and fossil records, BSIP helps uncover how India's climate has changed over millennia, providing vital insights into natural and human-driven changes. Here, scientists work in varying geographical parts, ranging from the high-altitude Himalayas to the coastal marine settings, the vast stretch of the Ganga Plains to the dry areas of Gujarat and Rajasthan, and the moist north-eastern part of the country. On a temporal scale, the ongoing research at the BSIP varies from the Precambrian to the Holocene (present day).

Some of the research highlights based on proxy records at the BSIP are as follows:

1. **Pollen Analysis (Palynology)**: We often encounter the yellowish dusty particles that stick to our hands while touching flowers, especially Hibiscus and roses. They are the reproductive units of flowering plants or conifers. The scientific study of pollen grains is

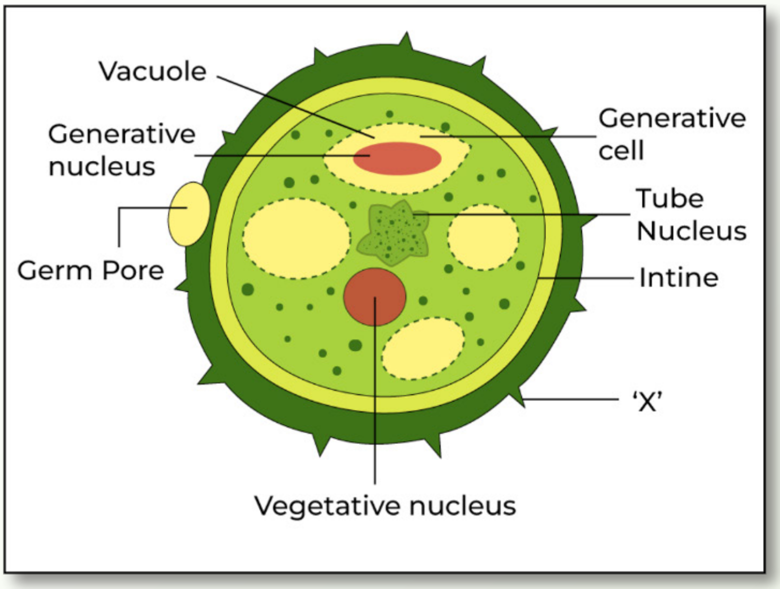


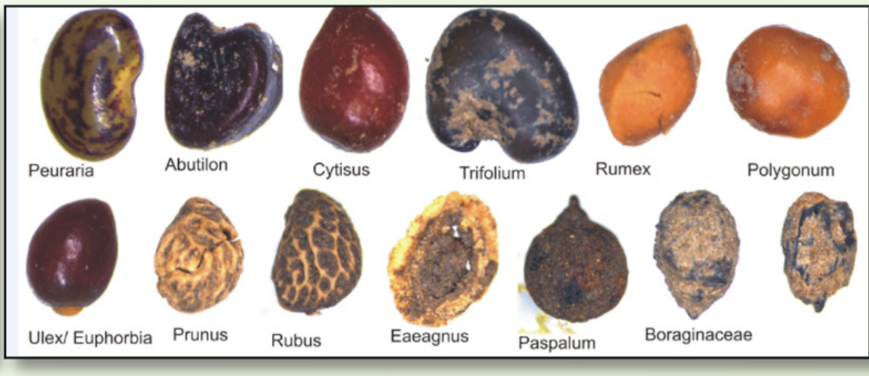
Diagram of a pollen grain

Pollen grain of *Melia azedarach* (Indian lilac)

called palynology. Through wind, water, animals and humans, they disperse in the environment and get transferred to soil. They stay in soil for extended period and does not undergo degradation due to a protective layer called sporopollenin (long-chain fatty acids, phenylpropanoids, phenolics, and traces of carotenoids, all arranged in a random co-polymer structure) Thus, studying fossil pollen grains preserved in sediments (lake beds, peat, soil) to know about vegetation changes, monsoon variability, and human impact over several thousands of years.

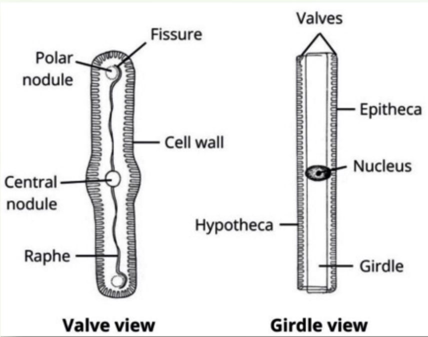
2. **Plant Macrofossils:** Plant macrofossils are the preserved remains (through carbonisation, water logging, desiccation and mineralisation) of plants large enough to be seen with the naked eye, typically measuring over 1 mm in size. These fossils, including leaves, seeds, fruits, stems, cones, and roots, are crucial for reconstructing past flora, environments and climate.

3. **Diatoms:** Diatoms are single-celled **s**iliceous fossil algae belonging to the class *Bacillariophyceae. They* are found in various environments, ranging from freshwater lakes to coastal to deep marine environments. Diatoms recovered from oceans, freshwater bodies, and moist terrestrial environments worldwide reflect past temperature, sea ice, and water conditions, such as pH, salinity, and nutrient levels. They are used to reconstruct lake and marine environments and help to understand the past monsoonal activity.

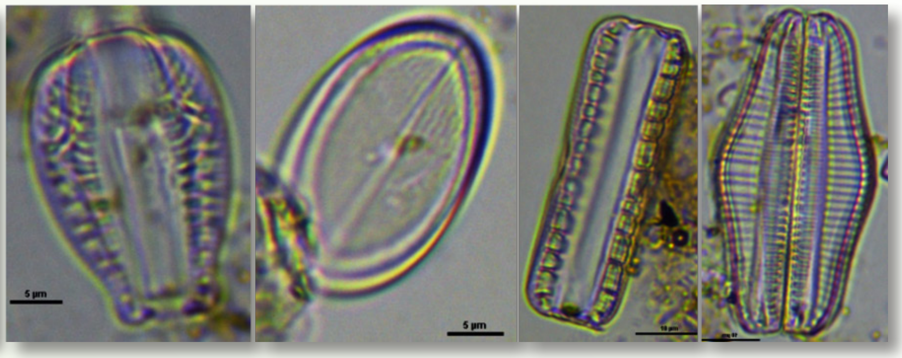


Charred Rice grain

Charred grain



Views of a Diatom



Diatoms under the Light Microscope

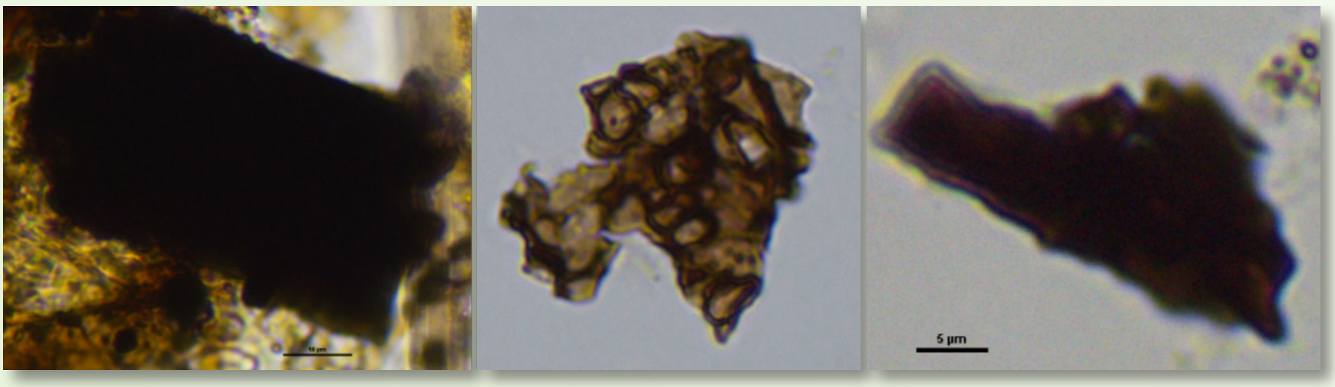
4. **Stable Isotope Analysis and Geochemistry:** Everything on Earth has a chemical composition, and many elements occur in multiple forms called isotopes that differ in mass due to varying neutron numbers. These isotopic variants can reflect environmental conditions, such as temperature and precipitation. Carbon and oxygen are the most abundant elements in living and preserved matter. Their stable isotopic ratios-$\delta^{13}C$ ($^{13}C/^{12}C$) and $\delta^{18}O$ ($^{18}O/^{16}O$) record isotopic fractionation patterns in carbonates, organic material, and fossils. These values are used as proxies to reconstruct past temperatures, hydrological cycles, and carbon cycle variations, helping scientists trace historical climate change. Geochemical analysis of a soil's elemental and textural composition can reveal detailed information about past precipitation patterns and environmental conditions.

5. **Charcoal Analysis:** Micro-charcoal particles in sediments infer past fire events and human activity. A thin section of micro charcoal recovered from geological and archaeological sites aids in understanding the past distribution of woodland taxa at spatial and temporal extent, as well as their economic use.

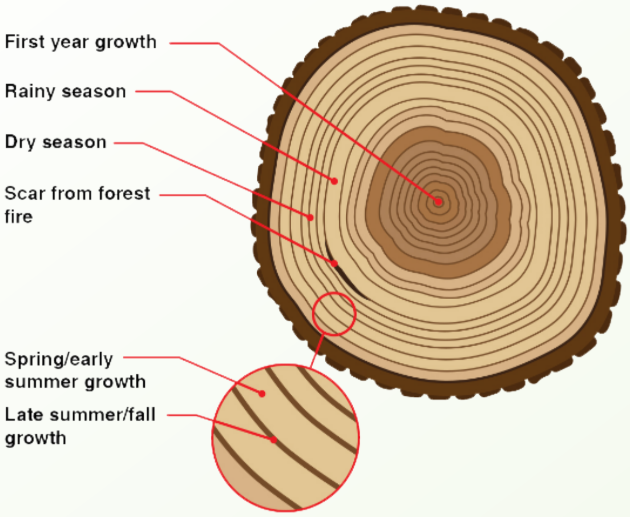
6. **Dendrochronology:** The scientific method of dating tree rings to the exact year they were formed in a tree. This method is used to determine the age of trees and to study past environmental conditions and events, as climatic factors influence tree growth. Using high-resolution tree rings, precipitation, temperature, river discharge, droughts, floods, snowfall variation, treeline migration and crop production, etc., could be reconstructed/analysed.

7. **Palynofacies Analysis:** It examines the full suite of particulate organic matter, including palynomorphs and amorphous material in sedimentary slides. Quantifying their types, preservation, and relative abundances allows interpretation of the depositional environment.

8. **Radiocarbon (^{14}C) Dating:** Radiocarbon dating measures the remaining amount of radioactive carbon in organic material, such as plant, pollen, peat,



Microcharcoal under Light Microscope



A diagrammatic view of a wood stem to show the details of growth rings

charcoal or wood up to about 50,000–60,000 years old, converting that decay into calibrated calendar years to establish time brackets for depositional events during the Quaternary Period.

BSIP significantly contribute to our understanding of India's palaeoclimate and the evidence of climate change over time. Here's a concise key contribution of BSIP to palaeoclimate studies in India.

1. **Monsoon Evolution:** Using pollen analysis, sediment cores, and isotopic data, researchers have shown that:

- The Indian monsoon system has undergone significant shifts over geological timescales.
- During the Holocene (~last 11,700 years), there was an initial wet phase followed by progressive aridification, especially in northwest India.
- Monsoon variability is linked to orbital changes, solar activity, and ENSO-like phenomena.

2. **Himalayan Uplift and Climate:** Palynological and sedimentological studies from the Siwalik Hills and other Himalayan foreland basins indicate that the height of the Himalayas increased with time. The presence of the Himalayas increased the intensity of rainfall. These studies also show a shift in the ecosystem from sub-tropical to temperate.

3. **Aridification of central and western India:** Studies from this part show that during the geological past, savanna/forest ecosystems turned to present-day arid desert conditions during the Late Holocene (~last 4,000 years).

4. **Sea-Level and Climate Change along Coasts:** Studies using microfossils (like foraminifera) and sediment cores indicate that during the last 2.6 million years, there have been repeated episodes of sea level rise and fall, which directly impacted human settlement. They also postulated a link between the cold and warm phases of Earth and the rise and fall in the sea level in the geological records

5. **Past Reconstructions and Human Adaptation:** Studies from the western Himalayas demarcated the Little Ice Age (LIA) duration, and the highest treeline migration responds to climate change. Regional and local climate have always influenced human settlements. Human migration and cultural transitions are directly influenced by climate at the regional and global scales.

6. **Implications for Modern Climate Change:** By reconstructing past climates, BSIP helps to differentiate between natural and human-induced climate change. Also, BSIP researches on palaeoclimate provide insights into resilience and tipping points in monsoon systems and ecosystems. Past climate data serve as a benchmark for testing climate models, helping scientists predict how current and future greenhouse gas emissions might influence global temperatures and weather patterns. Thus, palaeoclimate data help validate the current climate models. Knowledge of past climatic events can guide us in formulating current environmental policies and strategies for mitigating climate change.

About author

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Rains That Shape a Nation: Unraveling the Science of the Indian Monsoon

Mohammad Firoze Quamar

MONSOON means a seasonal reversal in wind direction, poleward westerly flow in summers and equatorward easterly flow in winters. The summers are generally associated with the wet season, whereas the winters are relatively dry. The term 'monsoon' is derived from the Arabic word 'mausam', which means season, and refers to the seasonal prevailing winds experienced by the sailors in the Arabian Sea. However, 'monsoon' is popularly used to denote the rains without any reference to the winds. Monsoon, more specifically, is an i nter-hemispheric, land-atmosphere-ocean-coupled mechanism in

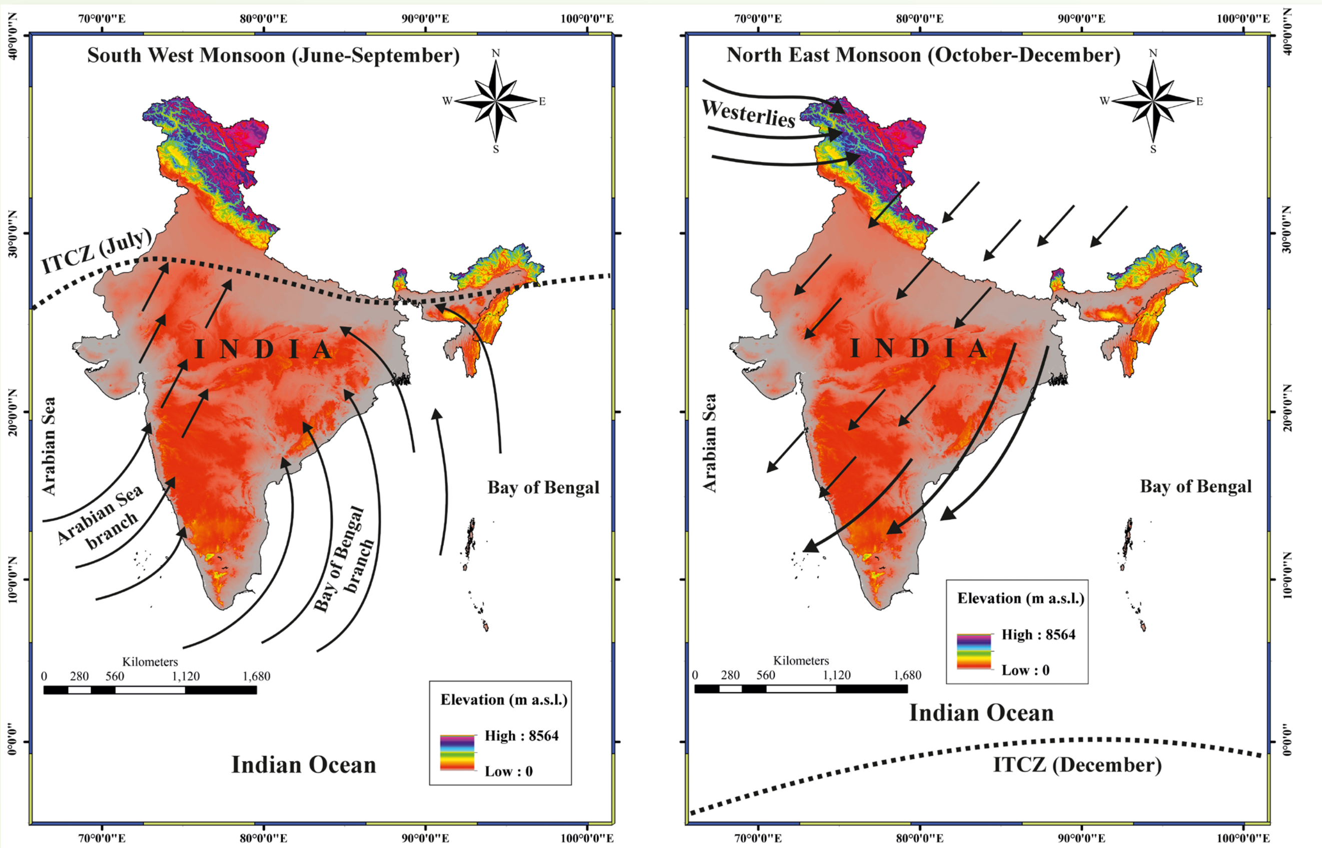

Figure 1. Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) of India showing Southwest Summer Monsoon (SWSM/SWM; June-September), and Northeast Monsoon (NEM; October-December). Also, showing the migration of the Inter Tropical Convergence Zone (ITCZ) (represented by dashed lines) during SWM and NEM. Western Disturbances (WDs) or Westerlies are also seen.

the tropics. The tropical monsoon system plays an important role in the heat and energy distribution on the Earth. The primary cause of monsoon is the difference between annual temperature trends over land and sea (due to the seasonal march of the sun). There are five major individual monsoon systems, occurring across the globe, such as the North American Monsoon, the South American Monsoon, the African Monsoon, the Australian Monsoon and the Asian Monsoon. The Asian Monsoon System has two major components: the South Asian Monsoon and the East Asian Monsoon.

The scientific study of the Indian monsoon was initiated by Sir Edmund Halley (1686), who described it (the Indian monsoon) as a 'giant land sea breeze', which arises due to the thermal contrast between the land and the Sea. It can be defined in various ways, such as

i) Monsoon is a circulation system driven by the energy of the sun,

ii) Major wind systems that change direction seasonally,

iii) Almost all the phenomena associated with the annual weather cycle within the tropical and sub-tropical continents of Asia, Australia, Africa and adjoining Seas and Oceans,

iv) Seasonal winds blowing from the Indian Ocean and Arabian Sea in the southern, bringing heavy rainfall in the region,

v) Monsoon is an atmospheric phenomenon in which the mean surface wind reverses its direction from summer to winter, etc.

Owing to the critical importance of the ISM in the Indian context, its variability in the past and its influence on the early civilizations have been studied extensively. The monsoon initiated across the Oligocene-Miocene boundary (~22 Ma); however, the timing of the beginning of the modern-day Indian monsoon is in the late Miocene (~10 Ma).

During boreal summers, cross-equatorial southeasterlies flow from the Indian Ocean, entering the Indian sub-continent from the southwest, known as the Southwest Monsoon (SWM). In general, the geometry of the Indian landmass facilitates bifurcation of the ISM winds into two branches, the Arabian Sea (AS) and the Bay of Bengal (BoB) branches. Between these two, the AS branch is more dominant, first strikes the Western Ghats (Kerala, SW India) and proceeds towards the low-pressure areas of the Indian Peninsula and Ganga Plain. The BoB branch initially strikes NE India and moves westward following the Himalaya along the Ganga Plain.

In fact, after entering the Kerala coast, typically by the beginning of June, the monsoon gets divided into the two parts: the Arabian Sea branch and the Bay of Bengal branch. The monsoon normally reaches Mangalore on the west coast and Vishakhapatnam on the east coast within four days of hitting the mainland. Both the branches move swiftly to reach Mumbai and Kolkata (on average between June 10 and 13). The monsoon crosses Varanasi, Ahmadabad and Bhopal by June 15, Agra by June 20 and Delhi by June 29. The two branches merge over Punjab and Himachal Pradesh, and by mid-July, the SWM engulfs the entire sub-continent.

During boreal winters, winds blow from the Indian sub-continent towards the Indian Ocean from a northeast direction and are called the northeast Monsoon (NEM) or winter monsoon or post-monsoon (Figure 1).

Monsoon rainfall is characterized by a declining trend as the distance the winds travel over the land increases. For example, Kolkata receives on average 1190 mm rainfall, whereas Ahmedabad receives 760 mm and Delhi 560 mm. The SWM provides ~80% of the annual precipitation throughout the Indian sub-continent, except in a few regions of southern and western India, during the months of June to September (JJAS).

The NEM winds are relatively dry, but acquire some moisture while crossing the BoB and bring precipitation to parts of southern India (Coromandal Coast) and Sri Lanka. The NEM contributes ~50% of the annual precipitation in the east coast during the months of October to December (OND). On the other hand, the Western Disturbances (WDs) or Westerlies produce short, but extreme precipitation over northern India (Fig. 1).

The WDs are more intense over the Himalayas, due to orographic land-atmosphere interactions.

During December, January and February, snowfall due to the WDs is the dominant precipitation in the Higher Himalaya that sustains the regional snowpack and replenishes the regional water resources. The ISM is influenced by El-Niño, La-Niña, the El Niño–Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Atlantic Multidecadal Oscillation (AMO), Atlantic Zonal Mode (AZM), and Pacific Decadal Oscillation (PDO). The monsoons are, however, caused by the movement of the Intertropical Convergence Zone (ITCZ) over the equatorial region. More specifically, the summer rains associated with the SWM are initiated by the seasonal northward movement of the ITCZ, due to warming of the Asian continents during summers.

The Indian Summer Monsoon (ISM) or South Asian Monsoon (South Asian Summer Monsoon, Southwest Monsoon, Southwest Summer Monsoon, Indian Monsoon or *simply* Monsoon) is an inherent part of the global climate and hydrological systems, exhibiting a complex ocean-atmospheric-coupled mechanism of the tropics, and is indispensable in inter-hemispheric heat transfer on the Earth.

The ISM causes ~80% of the total rainfall over India and nearby regions, thereby influencing the agricultural productivity and Gross Domestic Product (GDP) of the country, as well as the socio-economic growth of one of the most densely populated regions of the globe. The intensity of the ISM precipitation varies over the Indian landmass owing to the variations in latitude, altitude and distance from the sea. A slight deviation of ~10% from the normal ISM rainfall affects the agricultural production and water availability across the region.

A variation of ~20% can be disastrous in the form of extreme floods and widespread droughts associated with famines, directly affecting agricultural output, economic development and societal well-being of this densely populated region. The ISM, which occurs from June to September (JJAS), is the primary source of rainfall for the growth of Kharif crops (Summer-grown crops) in India.

Conversely, the NEM, which occurs from October to December (OND), is responsible for the growth of Rabi crops (Winter-grown crops). Knowledge and understanding of the climate change influenced by the ISM rainfall variability during the late Quaternary could be of immense interest in order to strengthen our understanding of the present ISM-influenced climatic conditions, as well as for understanding possible future climatic trends and projections, and also for a scientifically sound policy planning with a key aspect of societal relevance.

About author

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Hidden Villain in the Air
How Black Carbon Fuels Global Warming

Madhav Prasad Mishra

In the layers of our atmosphere, a small but powerful villain is active — Black Carbon, commonly known as soot. This microscopic particle is so tiny that it is invisible to the naked eye, yet its impact on the Earth's climate system and delicate natural processes is profound. This dangerous particle is formed when fuels like wood, cow dung, crop residues, diesel, and coal are incompletely burned. It spreads into the atmosphere along with smoke and intensely absorbs sunlight. Black Carbon is one of the strongest absorbers of visible light. In terms of warming the climate, it is the second most potent agent after carbon dioxide, with a direct radiative forcing effect up to 0.9 $W{\cdot}m^{-2}$. Its impact is not limited to the air - it's visible on the ground as well. When it settles on glaciers and snow surfaces, it forms a black layer that absorbs more sunlight, causing the ice to melt faster. This leads to reduced ocean salinity and disrupts the thermohaline circulation, which is the global ocean current system driven by temperature and salinity. These changes affect climate patterns and threaten marine life. Black Carbon is also a serious health hazard for humans. When food is cooked indoors on traditional stoves, it pollutes indoor air and increases respiratory diseases.Yet, despite its dangers, black carbon is not invincible; with the right scientific understanding and policy measures, its threat can be mitigated.

Recommended Measures to Reduce Black Carbon

1. Adopt Clean Energy
   - Replace traditional stoves with improved cookstoves.
   - Use LPG, biogas, and electricity as fuel.
   - Avoid burning crop residues; adopt better agricultural practices.
   - Implement early warning systems and control measures to prevent forest fires.
2. Reduce Emissions from Vehicles
   - Install Diesel Particulate Filters (DPF) in diesel engines.
   - Promote electric vehicles.
   - Use low-sulfur fuels.
3. Control Emissions in Industries
   - Install electrostatic precipitators, bag filters, or wet scrubbers.
   - Adopt clean and energy-efficient production technologies.
4. Improve Urban Waste Management
   - Ban open waste burning.
   - Ensure waste segregation, recycling, and conversion to energy.
5. Adopt National and Global Efforts
   - Include Black Carbon control in National Climate Policies like Nationally Determined Contributions (NDCs).
   - Participate in global initiatives such as Climate and Clean Air Coalition (CCAC) and UNEP.

By implementing all these measures, air pollution is reduced, public health improves, and global temperature rise can be limited by up to 0.5°C by 2050, especially in vulnerable regions like the Arctic.

Remember: Black Carbon may be a tiny particle, but its impact is massive — take the right steps now to secure the future.

About author

Mr Madhav Prasad Mishra is a Birbal Sahni Research Scholar (BSRS) at the BSIP, Lucknow. His research focuses on black carbon (recognized as the second most significant contributor to global warming after carbon dioxide)

Simple to Complex: Tracing Evolution of Life from the Krol-Tal belt of the Lesser Himalaya, India

Veeru Kant Singh, Yogesh Kumar and Vimochani Tripathi

A very, very long time ago, billions of years before dinosaurs, before forests, even before jellyfish, Earth was home to life. But it wasn't the kind of life we're used to. Picture a world of quiet oceans, life sparked in the oceans, where tiny, single-celled organisms floated in the dark like invisible dust motes in water that lived and died unseen for billions of years. This was the Precambrian Era, the time of quite innovations, and for most of it, life was small, soft, and simple. For nearly 4 billion years, nothing much changed, at least not in ways we could easily see with the naked eye; microorganisms were Earth's only inhabitants. Life is thought to have first emerged around 3.8 billion years ago. In the Precambrian world, these early organisms were simple, single-celled prokaryotes: bacteria and archaea that lacked nuclei and internal compartments. For the next 2 billion years, life remained this way: invisible to the naked eye, metabolizing chemicals or sunlight, and existing in a world devoid of predators, movement, or even colour as we know it. The oceans were full of microscopic life, mostly bacteria and algae (Fig. 1). Some of them, called cyanobacteria, began releasing oxygen into the atmosphere. This slow process eventually changed everything. Oxygen made it possible for more complex organisms to evolve. During the later Precambrian time, some major biological revolutions took place viz.: Oxygenation: Photosynthetic cyanobacteria released oxygen, slowly transforming Earth's atmosphere in what's known as the Great Oxidation Event (GOE); eukaryotes emerged: Complex cells with nuclei appeared; Multicellularity evolved: Simple multicellular life, like algae and soft-bodied organisms, such as the Ediacaran biota, began to appear; But life was still relatively quiet; no hard shells, no predators, no complex food chains.

Figure 1. Microbial mat layers and their primary constituents recorded from the Kaudiyala Formation, Krol Group, Mussoorie Syncline. Scale bar is of 20 µm.

The Precambrian time, lasting for ~3500 Ma (from c. 4200 to 538.8 million years ago), is one of the most important time intervals in the entire Earth's history, which passed through changes in atmosphere, hydrosphere, lithosphere, as well as in biosphere. Over the past few decades, investigations to understand these global changes have played a significant role in understanding the Earth's atmospheric and biological evolution patterns in deep time. Laminated carbonate structures formed by microbial mats indicate widespread shallow marine environments, suggesting that early microbial ecosystems thrived in carbonate platforms. These changes are mostly documented worldwide in marine sedimentary successions.

By the end of the Precambrian, some larger, soft-bodied creatures had appeared. These strange beings, known as the Ediacaran biota, looked like flattened sea pancakes or frilly leaves. They didn't have eyes, mouths, or bones and didn't leave much of a trace

Figure 2. Field Photographs showing exposures of black silicified chert bands of the Kaudiyala Formation.

behind. It was as if nature was still sketching out ideas in pencil. But then, something incredible happened.

The Krol Belt (Fig. 2) of the Lesser Himalaya is a persistent lithostratigraphic unit spread over approximately 390 km from east to west in eight synclines (Nainital, Garhwal, Mussoorie, Korgai, Nigalidhar, Kamildhar, Krol, and Pachmumda), extensively exposed in the states of Uttarakhand and Himachal Pradesh (Fig. 3).

The Krol hill is present in the Solan District of Himachal Pradesh (Fig. 4). The Krol Belt in the Lesser Himalaya has been divided into Outer and Inner Krol

Figure 3. (A) Outcrop of Krol Group of rock in Rishikesh, Uttarakhand. (B) Mountain ranges of Krol-Tal Belt around the Mussoorie area, Uttarakhand. (C) Outcrop of Krol D carbonate successions in the vicinity of the river Ganga in Rishikesh, Uttarakhand.

Figure 4. Photograph of Krol Hill, Solan, Lesser Himalaya, Himachal Pradesh, India.

Belts, based on different basements of deposition. The Outer Krol Belt, deposited unconformably on the Simla Group, consists of the Blaini and Krol groups. The Krol Group is divided into Infrakrol, Krol Sandstone, Krol 'A', Krol' B', Krol 'C', Krol 'D', and Krol' E' formations. The Inner Krol Belt is deposited unconformably on the Jaunsar Group and includes the Blaini, Krol and Tal groups.

In the Precambrian, the Ediacaran Period (~635 to 538.8 million years ago) was a time of the most profound biological and geological changes that records transitions from a planet significantly

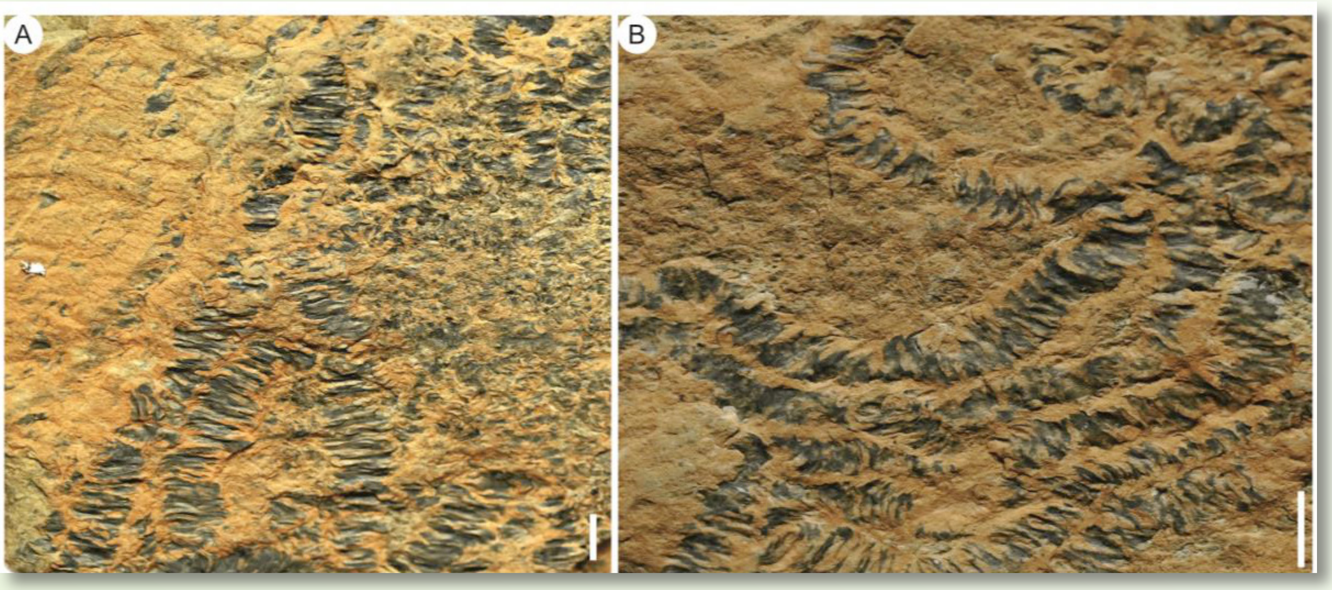

Figure 5. Different taphonomic preservations of *Shaanxilithes ningqiangensis* from the upper part of the Krol-E formation of the Nigalidhar Syncline, Lesser Himalaya. Scale bar is of 1 cm.

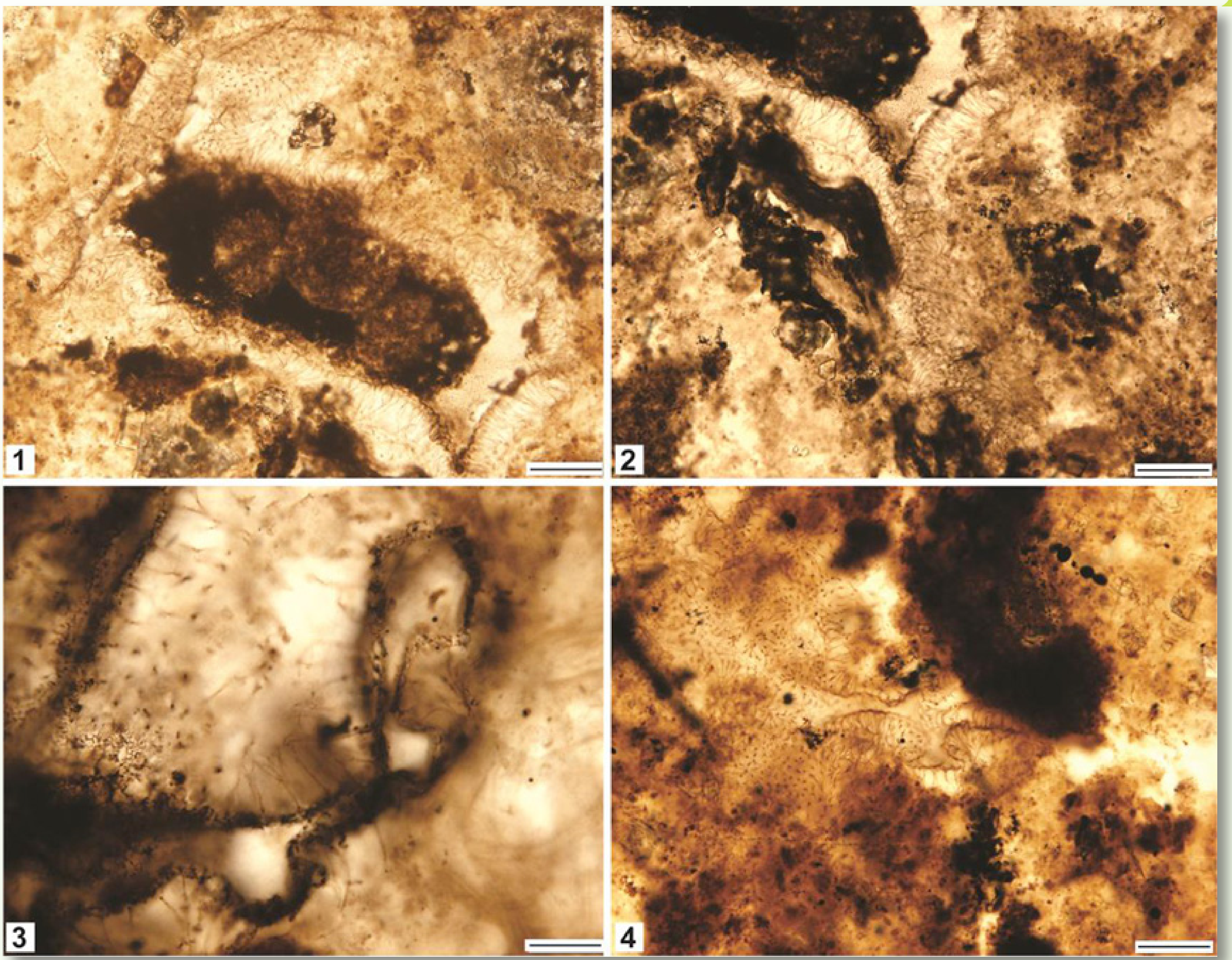

Figure 6. Early Ediacaran Acanthomorphic acritarchs from the Krol A (Mahi Formation) Formation of the Krol Group, Pachmunda Syncline, Himachal Pradesh. 1, 2. *Appendisphaera hemispherica*; 3. *Appendisphaera grandis*; 4, *Appendisphaera longispina*. Scale bar is of 20 μm.

dominated by simple microscopic organisms to the Cambrian world swarming with animals in Earth's history. Therefore, it is one of the most fascinating and unique periods in the history of life on Earth. Understanding how and why the earliest animals evolved and diversified is important. Evidence so far recorded from this period can be categorized into organic-walled microfossils (acritarchs), carbonaceous compressions (Fig. 5), permineralized microbiota, complex metaphytes (impressions), and complex soft-bodied metazoans (animals). Until recently, the characteristic Large Acanthomorphic Acritarchs (LAAs) radiated and diversified in the lower and middle parts of the Ediacaran Period (i.e., between ~635 and ~551 Ma) worldwide, known from Australia, the Eastern European Platform, India, Siberia, South China, and Svalbard, termed as Ediacaran Complex Acanthomorph Palynoflora (ECAP) assemblages (Fig. 6).

The Krol belt holds the Neoproterozoic to the Cambrian succession represented by the Baliana, Krol, and Tal Groups, revealing several palaeobiological entities, including small shelly fossils, trace fossils, acritarchs, cyanobacteria, and algae. These studies

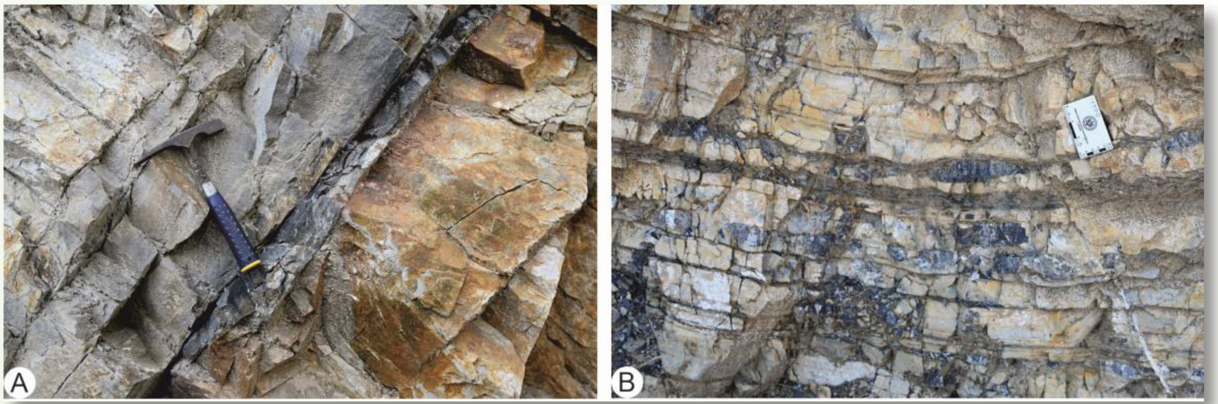

Figure 7. (A) Field Photographs showing exposures of black shale bands between quartzite of the Korgai Syncline, Himachal Pradesh; (B) Chert bands in Korgai Syncline.

report fossil and sequence stratigraphic details of the Krol Belt and show the presence of a distinct Ediacaran succession. Well-preserved microfossils, including large-sized acanthomorphic acritarchs, are documented from the different formations of the lower part of the Krol Belt.

An assemblage of large acanthomorphic acritarchs (Figure 6) was documented from chert nodules and chert bands (Fig. 7) of the Mahi Formation /Krol A Formation of the Khanog and Rajgarh synclines in the northwestern part of the Krol belt and from chert nodules of the Infrakrol Formation exposed in the Nainital Syncline.

These studies suggested that the Ediacaran age for the Infrakrol Formation is equivalent to the Doushantuo Formation of China, i.e., 635.2 ± 0.6 Ma to 551.1 ± 0.7 Ma. Taxonomically diverse microfossils, especially ECAP flora, are essential for evaluating the complexity of the early Ediacaran ecosystem, providing insights into a complex microbial world that evolved after the termination of Cryogenian global glaciation. The transition from the Ediacaran to the Cambrian Period is more than a biological milestone; it is a profound metaphor for emergence, consciousness, and the unfolding complexity of being. In the stillness of the Ediacaran seas, life existed in quiet forms, passive and patient, as though the world were meditating in soft-bodied dreams.

Then came a turning point: the Cambrian Period. About 538.8 million years ago, life went from

Figure 8. Field photographs of trace fossils collected from the Mussoorie Syncline, Uttarakhand. (a). long tubular burrow having a circular disc-like structure at the base. (b). A circular structure represents the transverse section of *Skolithos* burrows.

whispering to shouting. In a relatively short window, a few tens of millions of years, fast in Earth's history, life exploded into a dazzling variety of forms. This event is called the Cambrian Explosion. Suddenly, the oceans were alive with creatures that had eyes, legs, shells, spines, and teeth. Animals began swimming, crawling, burrowing, and even hunting for the first time.

Small Shelly Fossils (SSFs) and Trace Fossils (Tal Formation) (Fig. 8) (Cambrian Series 1 (~541–520 Ma): Marks the Precambrian–Cambrian boundary; definitive signs of complex animal behaviour and skeletonization. The food chain was born. This explosion of life gave rise to nearly all the major animal groups we know today. Among them, trilobites (scuttled across seafloors), arthropods (early ancestors of insects and crustaceans, developed armour-like exoskeletons), sponges, brachiopods, and early molluscs flourished. The first eyes, mouths, and muscles evolved. What began as a quiet world of microbes had become a planet bursting with colour, movement, and noise; it suddenly became a living laboratory of evolutionary experimentation. The Cambrian marked the dawn of animals as we know them. It was the start of something big, a chain reaction that would, over hundreds of millions of years, lead to fish, dinosaurs, birds, mammals and eventually, us. The Cambrian wasn't just an explosion. It was life turning on the lights. The Earth had changed. Life had found new ways to grow, survive, and compete.

The rise of complex life wasn't the end but the beginning. From the Cambrian seas emerged the first vertebrates. Some of these moved onto land, eventually giving rise to amphibians, reptiles, birds, and mammals. Intelligence and consciousness evolved in one lineage of primates, leading to humans.

This incredible journey from the shadows of microbial mats to the spark of complex ecosystems tells us about evolution, resilience, creativity, and the power of transformation. Life on Earth today, with its coral reefs, forests, animal migrations, and human civilizations, is the legacy of that great explosion of complexity. The Cambrian Explosion didn't come from nowhere; it was the culmination of billions of years of slow, hidden innovation. It reminds us that even in long periods of apparent stasis, change is brewing beneath the surface. The story of life is not just about survival but about possibility. From the shadows of simple cells emerged the spark of something extraordinary.

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Tiny Grains, Big Stories: Reconstructing Ancient Climates with Pollen

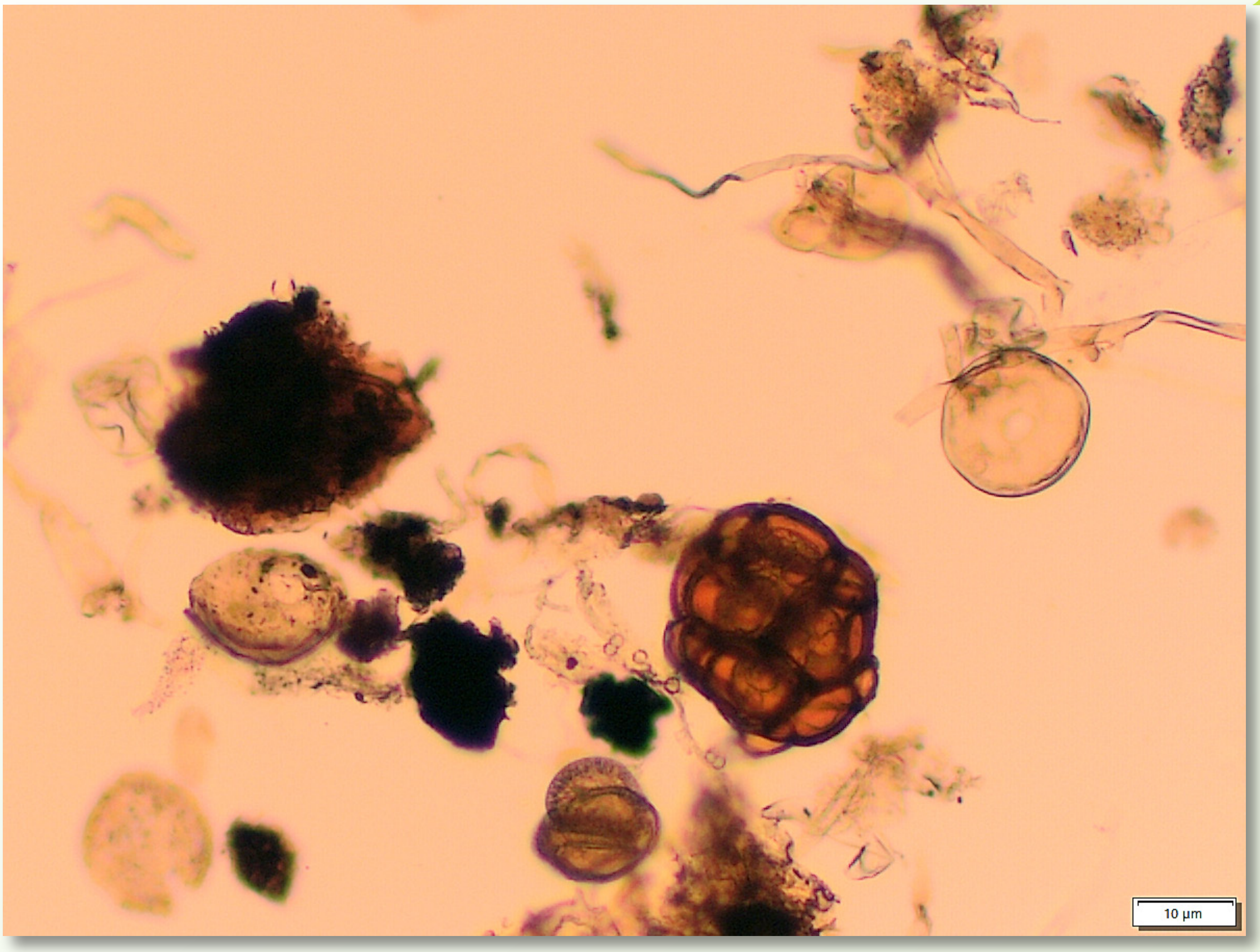
Swati Tripathi

PALAEOCLIMATE refers to the climate conditions of Earth's distant past, reconstructed using natural records, rather than direct measurements. Scientists study palaeoclimate to understand how Earth's climate has evolved over time scales ranging from decades to millions of years, and to identify the natural drivers behind these changes. Nevertheless, a fundamental question arises: How do scientists uncover climate information from thousands—or even millions—of years ago, long before weather instruments or satellites existed? Since no thermometers were available in ancient times, researchers rely on indirect evidence known as climate proxies. These proxies include ice cores, tree rings, ocean sediments, and one of the most informative land-based proxies: pollen and spores. Pollen grains are produced in vast quantities by plants and have remarkably durable outer walls made of sporopollenin, a substance highly resistant to decay. This durability allows pollen to be preserved for thousands of years in sediment layers of lakes, peat bogs, and floodplains. By analyzing the types and abundance of pollen in different layers, scientists can reconstruct past vegetation patterns—and, by extension, the climate conditions that supported them.

Palynological Research in India: History, Methods, and Climatic Significance

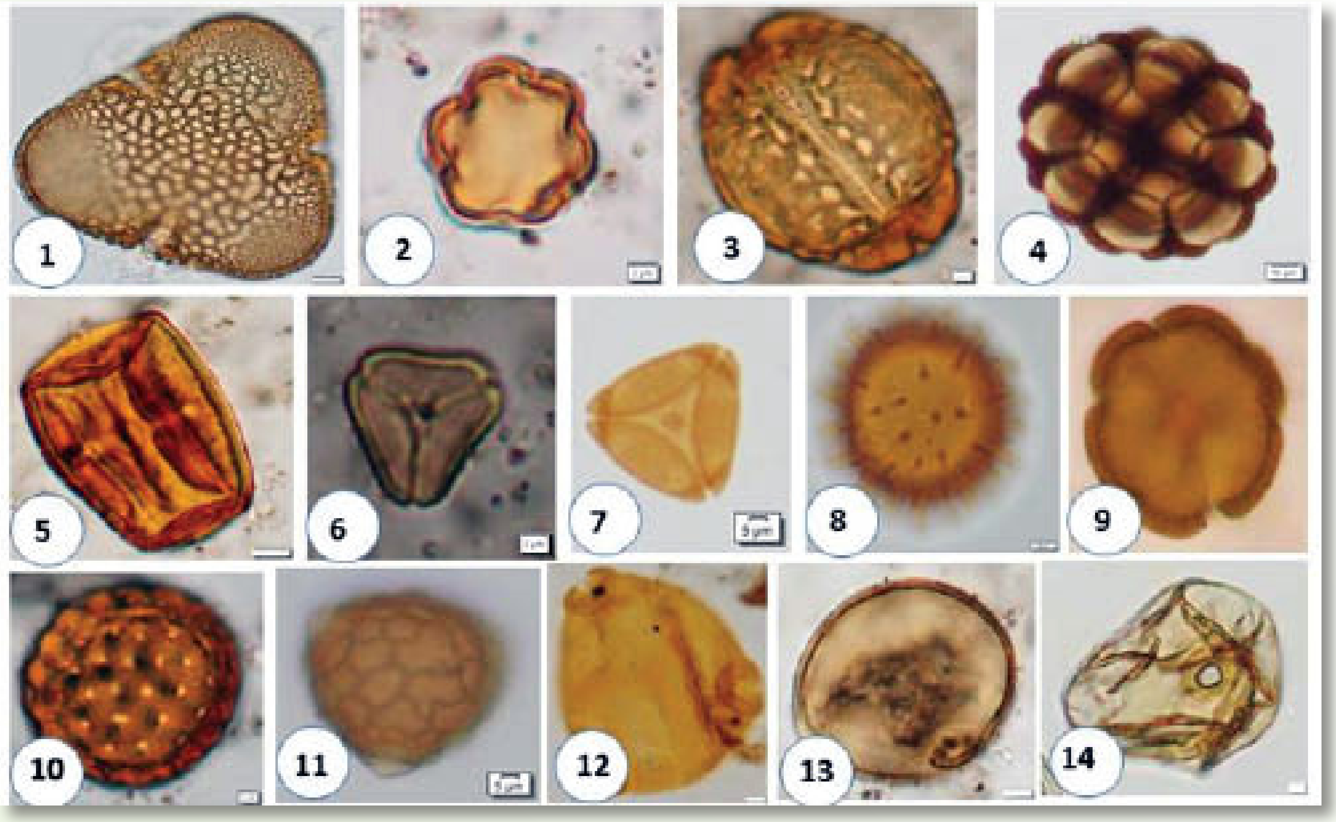
Palynological research in India began to take serious shape during the 1940s and 1950s, primarily through the efforts of Professor Birbal Sahni, widely regarded as the father of Indian Palaeobotany. His pioneering vision led to the establishment of the Birbal Sahni Institute of Palaeosciences (BSIP) in Lucknow, which became the foundation of palaeobotanical and palynological studies in the country. In the 1950s and 1960s, Dr R.N. Lakhanpal and his colleagues

A view of prehistoric life and vegetation



Pollen types under Light Microscope

conducted some of the earliest and most influential studies in Indian palaeopalynology. Their work focused on analyzing Quaternary pollen records from various sedimentary basins, peat deposits, and lacustrine environments across India, laying the groundwork for understanding past vegetational and climatic changes. The methodology typically involves extracting sediment cores from lakes, bogs, and other depositional environments. These cores preserve stratified layers of sediments that have accumulated over time, much like the pages of Earth's diary. To determine the age of each layer, scientists commonly use radiocarbon dating (C-14), which provides a reliable chronological framework. The preserved pollen within these layers serves as a biological archive, allowing researchers to reconstruct the sequence of climatic and environmental shifts over thousands of years. By examining pollen in each sediment layer, researchers can identify which plants were growing when that layer was formed. Since different plants thrive in different climates, the pollen record reveals past climate conditions. For example, a layer rich in spruce (*Picea*) and silver fir (*Abies*) pollen suggests a cool climate, while an abundance of grass pollen might indicates a warm, dry period. By comparing patterns over time, scientists can decode climate changes across thousands of years. By examining the types and abundance of pollen preserved in each sediment layer, researchers can determine which plant species were dominant at the time that layer was deposited. Since different plants flourish under specific climatic conditions—some preferring warm



Angiospermic pollen types recovered from Kukrail Reserve Forest

and humid environments, others thriving in cooler or drier ones—the pollen record provides valuable insight into the climate that prevailed during various periods of Earth's history. Beyond reconstructing past climates, pollen analysis contributes significantly to refining climate models, which are essential for predicting future climate change. It also aids in distinguishing natural climatic variability from anthropogenic (human-induced) influences, offering a long-term perspective on current environmental trends.

Some of the most significant past global climate periods identified through such proxies include:

Last Glacial Maximum (~18,000–21,000 years ago): A time when ice sheets were at their greatest extent and global temperatures were significantly lower; Holocene Climate Optimum (~9,000–5,000 years ago): A warm phase with enhanced monsoonal activity and flourishing vegetation; Medieval Climatic Anomaly (~950–1250 CE): A period of relatively warmer temperatures in parts of the Northern Hemisphere; and Little Ice Age (~1300–1850 CE): A cooler interval marked by glacier advances and significant socio-economic impacts in Europe and parts of Asia. These periods serve as benchmarks for understanding climatic fluctuations and their impacts on ecosystems and human societies across time.

Decoding Past & Future Environments through Modern Pollen Analogue

The Kukrail Reserve Forest, located in Lucknow, Uttar Pradesh, is a vital green lung for the city and an important ecological zone known for its biodiversity, including a gharial rehabilitation center. However, rapid urbanization in and around Lucknow poses serious threats to Kukrail's ecosystem. Here's a brief overview of the situation: 1. Encroachment and Land Use Change; 2. Habitat Fragmentation; 3. Pollution and Waste which include Increased construction,

A view of Kukrail Reserve Forest

vehicular traffic, and population density in nearby areas contribute to air, noise, and water pollution, which can degrade the quality of the forest ecosystem; 4. Water Table Depletion-Urban development often involves groundwater extraction and paving over recharge zones, affecting the hydrological balance critical for forest sustainability.

The Kukrail Conservation Forest in Lucknow, Uttar Pradesh, has recently been the focus of significant palynological research aimed at understanding the region's modern vegetation and its implications for reconstructing past climates and environments. Each plant species has unique pollen morphology and the modern pollen taxa helps in getting proxy data of the climatic condition of the past, which along with present data, can be an indicator for the future climatic condition. Pollen studies from the Kukrail Conservation Forest in Lucknow indicate a warm and humid climate characterized by high monsoonal activity. Pollen grains of *Artemisia* (wormwood) and Chenopodiaceae (bathua) suggest a signal of winter dryness, indicating seasonal variations in precipitation and temperature, with drier conditions during the winter months. The regular presence of pollen grains from conifers and other broad-leaved taxa, including *Alnus, Betula, Quercus* (broad-leave taxa) along with the Pine (winged pollen) suggests high wind activity possibly indicating climatic influences from surrounding high altitude regions. The higher frequencies of cereal (grass) and *Brassica* (sarso) pollen reflect ongoing anthropogenic activity, including agriculture and pastoral practices, influencing the local vegetation and climate.

Vegetation Shifts and Biodiversity Threats in Reserve Forests: A Pollen-Based Perspective

Climate change is increasingly driving periodic shifts in vegetation, particularly within ecologically sensitive regions such as reserve forests, which serve as vital sanctuaries for biodiversity conservation. The rising incidence of extreme and unpredictable weather events, along with the growing frequency and severity of natural disasters, has significantly affected these ecosystems, contributing to biodiversity loss and ecological degradation.

Pollen analysis in the reserve forest near Lucknow reveals a concerning trend: the pollen of several native tree species—such as Indian Plum (*Ziziphus mauritiana*), Indian Coral Tree (*Erythrina variegata*), False White Teak (*Lannea coromandelica*), Amla (*Phyllanthus emblica*), Mahua (*Madhuca longifolia*), and Indian Beech Tree (*Pongamia pinnata*)—was found in significantly low concentrations. This decline suggests a reduction in forest cover and hints at the potential emergence of treeless zones in the future, posing a serious threat to forest biodiversity. Conversely, an increased abundance of pollen from cultivated plants—such as mustard (Brassica spp.), rice, wheat, and coriander (*Coriandrum sativum*)—indicates that agricultural expansion has intensified in areas surrounding the forest. This pattern reflects the encroachment of human activity and a shift in land use, likely driven by urbanization and the shrinking of the Kukrail River, further exacerbating ecological stress.

The findings, based on pollen study, underscore an urgent need for preserving and restoring forest ecosystems. To mitigate these challenges and ensure the ecological stability of the region, the following measures are crucial: Sustainable urban planning supported by thorough ecological impact assessments; Community engagement and awareness programs to foster local stewardship; Development of green infrastructure around protected forest zones; Implementation of restoration projects for degraded habitats. Such integrated approaches are essential to breaking the "breathing barrier" of the City of Nawabs, ensuring that natural ecosystems and urban development can coexist in a balanced, resilient manner.

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Whispers in the mud:
How pollen solves the past mangrove dynamics in Sundarbans

Sangram Sahoo

IMAGINE standing where land and water blur into one. A vast, green labyrinth of tangled roots breathes with the rhythm of the tides. This is the Sundarbans, a sprawling mangrove forest cradled by the Ganges and Brahmaputra rivers, shared between India and Bangladesh. Famous for its tigers and UNESCO status, it's also something more profound: a vast, muddy archive holding secrets of a time long before humans walked its shores.

How can we glimpse this ancient world, understand how seas rose, storms raged, and forests transformed? The answer lies in nature's most unlikely timekeepers: tiny grains of pollen. Pollen, often just a nuisance for allergy sufferers, is a marvel of endurance. Each grain, uniquely shaped and encased in a remarkably tough shell, is released by plants and drifts on the breeze. Some find their final resting place in the soft mud below. Buried under layers of sediment over centuries or millennia, they become preserved, silent witnesses to the world that was.

Scientists, known as palynologists, carefully extract these fossilized grains from deep mud cores. Like reading a biological fingerprint under a microscope, they use the pollen to reconstruct ancient forests and the environments they thrived in. But to decode the past, scientists first need to understand the present. They must build a reference library: comparing the plants growing today in a specific place with the pollen found in the mud right beside them. How well does the pollen in the mud reflect the actual forest? This is especially crucial in a dynamic place like the Sundarbans, where salty tides, shifting shorelines, and human activity constantly reshape the landscape. Surprisingly, this foundational work was missing for the Indian part of this vast delta.

To fill this gap, researchers turned to two distinct corners of the Indian Sundarbans: the floodplain

village of Pakhiralaya and the wilder Sajnekhali Island within the Tiger Reserve. These became their natural laboratories. At Pakhiralaya, they walked a line stretching nearly 3 kilometers, from dense mangrove forest into open fields shaped by villages and farms. Along this journey, they scooped up soil samples, half from the mangroves, half from the transformed land.

On Sajnekhali Island, amidst its complex waterways, they collected mud from spots rich in both salt loving mangroves and freshwater plants. Back in the lab, the muddy samples underwent a meticulous transformation. They were treated with special chemicals that dissolved away organic matter, removed silica, and stripped down unwanted plant debris to isolate the precious, resilient pollen grains. Mounted on glass slides, hundreds of grains per sample were counted and identified under powerful microscopes, using detailed reference guides. Scientists also noted other tiny clues trapped in the mud: fungal spores, algae, and cysts from marine organisms, all adding layers to the environmental story.

The whispers in the mud began to speak clearly. In Pakhiralaya's mangrove heartland, pollen from true mangrove trees dominated the samples, sometimes making up a staggering 95% of the count. Grains from stilt-rooted *Rhizophora*, knobby-kneed *Bruguiera*, the milky-mangrove *Excoecaria*, and resilient *Avicennia* were abundant. Their close neighbours, like *Thespesia* and the mangrove palm *Phoenix*, were also well represented. Just a short walk away, however, in the open lands, the pollen story changed dramatically. True mangrove pollen became rare or vanished entirely. Instead, the mud told a tale of grasses, hardy weeds, and introduced trees like *Eucalyptus* and *Casuarina*. This was the clear fingerprint of human transformation, the ecological signature of settlements and plantations replacing the wild forest. Sajnekhali Island, though wilder, echoed a similar pattern. Mangrove and associated plant pollen still made up over half the count, featuring familiar names like *Rhizophora*, *Avicennia*, *Sonneratia*, and *Excoecaria*, alongside less common giants like *Heritiera* and the elegant *Nypa* palm. Yet, even here, amidst the tiger reserve, the pollen record revealed subtle human touches: traces of *Casuarina*, neem (*Azadirachta*), and other land-based plants, alongside aquatic types like *Typha* reeds hinting at freshwater flows.

The studies also revealed how the Sundarbans' unique gradients shape the pollen record. At Pakhiralaya, pollen from the mangroves faded quickly just beyond the forest edge. This suggests mangrove pollen doesn't travel far; finding a lot of it in ancient mud likely means those trees grew very nearby. On Sajnekhali, sophisticated analysis mapped the pollen onto environmental gradients. The strongest pattern (explaining over 60% of the variation) aligned with saltiness: salt-tolerant *Rhizophora* and *Avicennia* clustered together, while less tolerant species like *Heritiera* and *Nypa* were found further inland.

Why does this matter? These modern studies provide the essential key to unlocking the past. By confirming that modern pollen in the mud accurately reflects today's nearby plants, scientists gain immense confidence when they find fossil pollen in ancient Sundarbans mud cores. Imagine pulling up a core spanning thousands of years. A sudden spike in

Rhizophora pollen? That strongly suggests these mangroves once flourished right at that spot. A later layer dominated by grass (*Poaceae*) and *Casuarina* pollen? That could mark a time when humans cleared the forest for settlements or plantations. Shifts in pollen types can also whisper of changing sea levels (altering salinity), ancient storms, pulses of freshwater, or even early farming vital clues for understanding how this fragile ecosystem has weathered change and how it might respond to rising seas and a warming climate.

The investigations at Pakhiralaya and Sajnekhali represent a foundational step in uncovering the environmental history of the Sundarbans. These initial studies pave the way for broader research across tropical deltaic systems, with the potential to enhance our understanding of long-term ecological and climatic dynamics. Even at this early stage, the findings are compelling: buried within the Sundarbans' silty substratum lie countless fossil pollen grains microscopic yet resilient archives of the past. These natural time capsules preserve invaluable records of ancient mangrove forests, shoreline migration, and the complex interplay between environmental change and human influence. Through meticulous scientific inquiry, we are beginning to interpret these silent witnesses of millennia, and in doing so, reconstruct the long and dynamic history of this unique coastal ecosystem.

About author

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Decoding 8,000 Years of Grazing History from Palaeolake Sediments

Mohammad Firoze Quamar

The article explores the age-old interaction between grazing animals and mountain landscapes. Herbivory—the act of animals eating plants like grass and leaves—includes both wild herbivores and domesticated livestock such as cows, goats, and sheep. Pastoralism, on the other hand, is the traditional way of life where communities raise and move livestock across natural grasslands, especially in hilly or mountainous regions, to sustain their livelihoods. Set in the picturesque Kumaun region of Uttarakhand—known for its forests, hills, and close-knit rural communities—this research traces the deep-rooted history of grazing and livestock movement in the Central Himalayas. By analyzing palaeolake sediments and coprophilous fungal spores, the study uncovers how these practices have evolved over thousands of years and their long-term impact on the local environment and ecosystems.

HERBIVORY is important and serves as long-term drivers of biodiversity change and ecosystem resilience. An understanding of the interaction between herbivores and ecosystems is particularly important for conservation policies aimed at re-wilding. Moreover, herbivory plays a significant role in regulating many contemporary terrestrial plant ecosystems. However, it remains an imperfectly understood component of past ecosystem dynamics because the diagnostic capability of methods is still being tested and refined. In addition, understanding changes in the abundance of large herbivores over time and assessing the role of animals that play a pivotal role in disturbance regimes, as drivers of biodiversity change and in ecosystem resilience is a key challenge in long-term ecology. Additionally, such study is significant in effective wildlife management, as it needs historical data on herbivore abundance and its interactions with vegetation, climate and disturbance over longer periods that are available through observational and archive data. Spores specific to herbivore dung provide a potential source of information on past herbivore abundances. Coprophilous fungal spores/spores of coprophilous fungi/spores of dung fungi (hereafter the SCF) grow on the dung of herbivores.

Understanding the herbivore grazing (pastoralism) and human pressure around the landscape of an area during the Holocene/Pleistocene, using the SCF, has been one of the main research problems in the science of Quaternary palynology. Since the inception of Bas van Geel's work in The Netherlands, such studies spread throughout the world. However, in India, such study has not been initiated so far. Therefore, to fill this research gap, a 2.75-m-long lacustrine sediment profile from the Rawatsera palaeolake, Kumaun (Central Himalaya), India, was analysed palynologically at the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow, India. This study is first of its kind from India.

Non-Pollen Palynomorphs (NPPs) are all 'extra' microfossils, excluding pollen grains, which survive chemical digestion during the pollen extraction process and appear on palynological microscope slides. Moreover, NPPs are a large and taxonomically heterogeneous group of remains of organisms within the size range of pollen grains (ca. 10–250 µm), living in diverse environments. NPPs include fungal spores, algal spores, testate amoebae, as well as plant

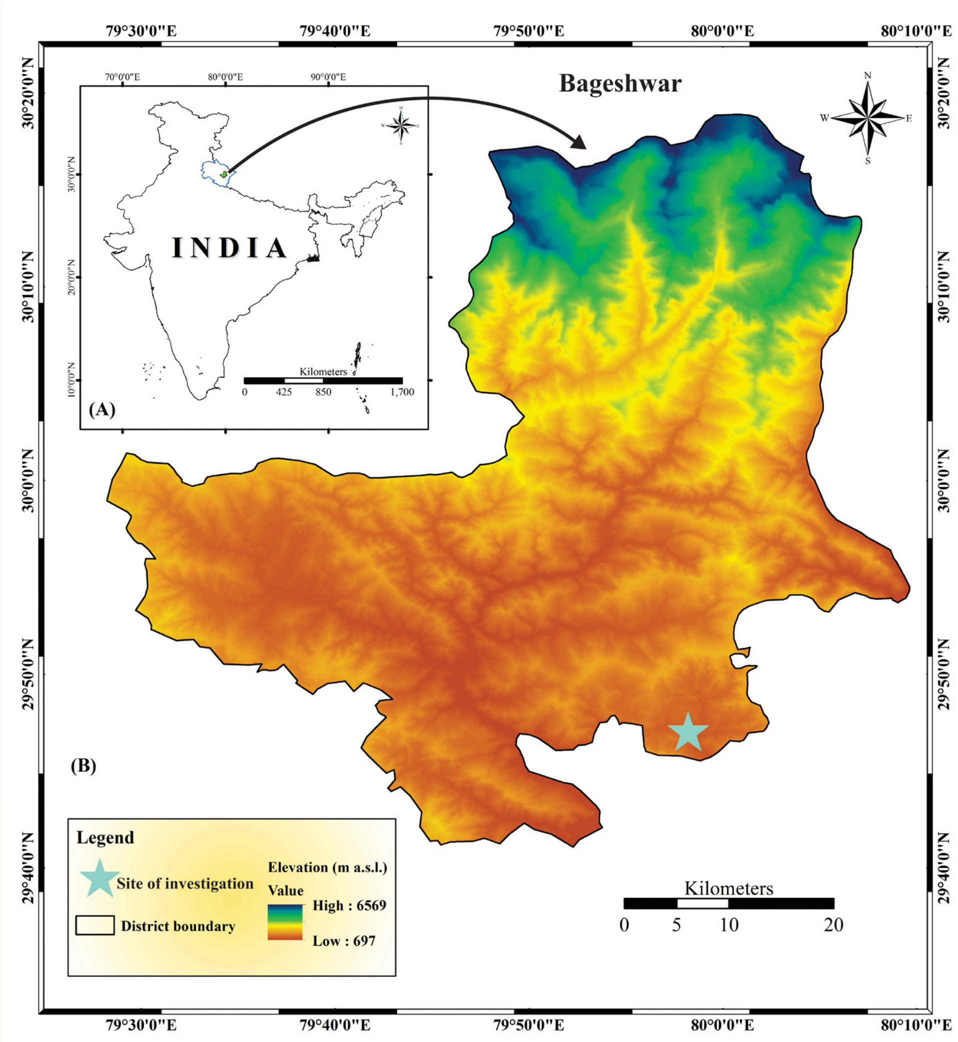
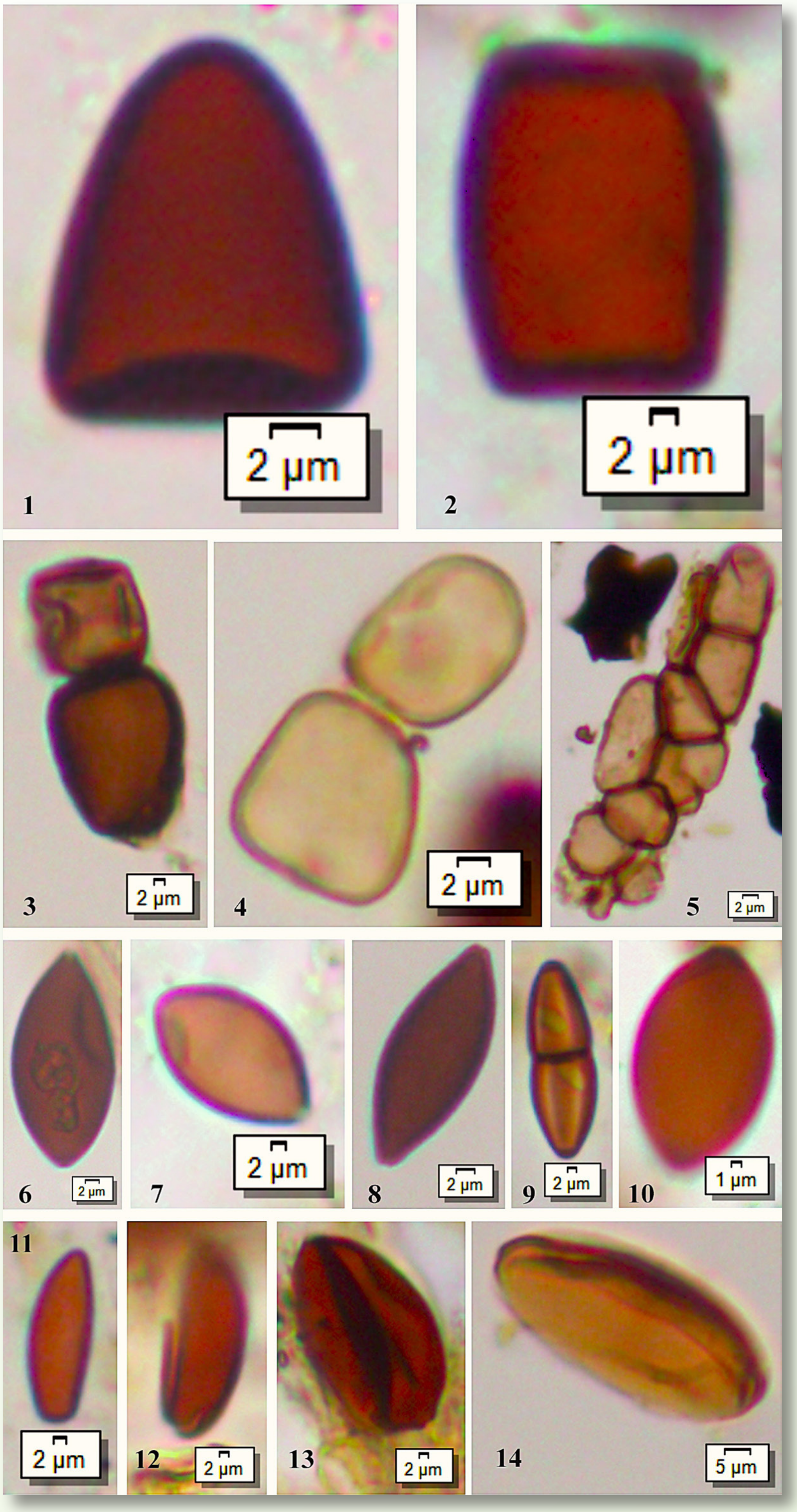


Figure 1. Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) of the study area showing the site of investigation: Rawatsera palaeolake (RSP; "brown star") in Kumaun (Central Himalaya), India (Quamar et al., 2025; https://doi.org/10.1016/j.revpalbo.2025.105288). The Figure has been made using ArcGIS 10.3.

and zoological (animal) micro-remains. Among the fungal spores, the SCF (e.g., *Sporormiella* sp., *Sordaria* sp., *Podospora* sp., *Delitschia* sp., *Cercophora* sp., *Arnium* sp. and *Coniochaeta*) serve as indicators of the local presence of herbivores in relation to the existing vegetation through time across regions. Over the last more than two decades or so, based on the changes in the relative abundance of the SCF, preserved in sedimentary profiles and coprolites, palaeoherbivory (as well as changes in population size) and palaeodietary analyses with respect to possible dietary changes have been made that may have contributed to the extinction of megaherbivores of the Pleistocene (2.58 Ma–11.7 Ka) and Holocene (11,700 cal yr BP) Epochs (Quaternary Period; 2.58 Ma). Moreover, the study of the SCF also provides information on ecology, diversity, niche partitioning, and changes in their relative abundance in a region. The study of the SCF also addressees the questions of pastoral and other human activities. The new research finding is gaining insights into (and an understanding of) the initiation and development of herbivore grazing (pastoralism) since the last ca. 8.3 kyr (Middle Holocene), which is poorly understood, so far, in



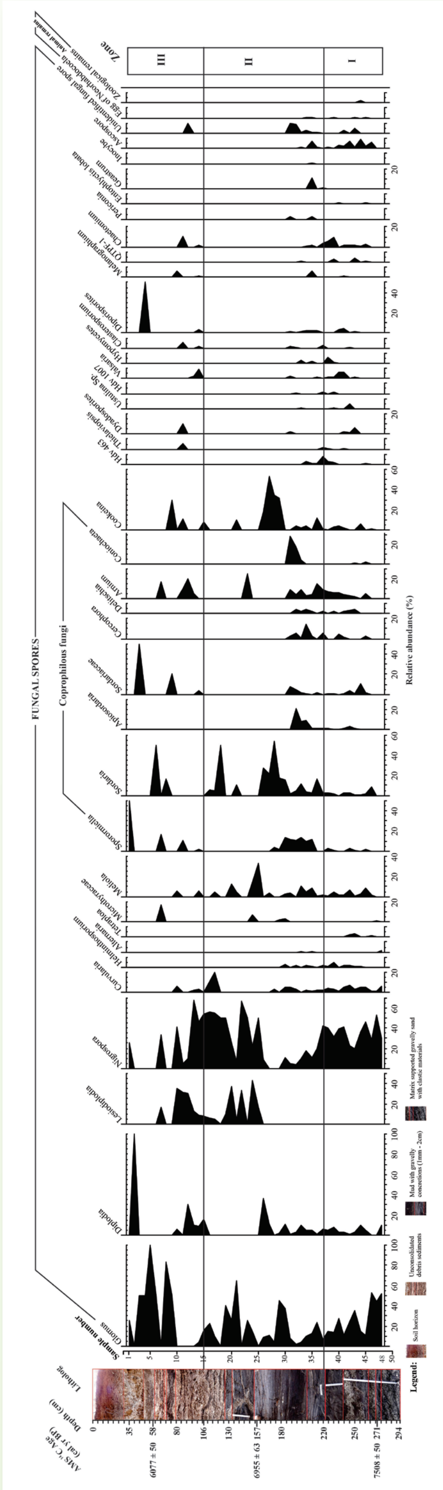


Figure 2. Photomicrographs of *Sporormiella* and other coprophilous fungal spores (SCF). 1. Terminal segment of *Sporormiella*, 2. Medial segment of *Sporormiella*, 3 & 4. *Sporormiella* (cf. HdV-113; terminal and medial segments seem to be attached; also seen the characteristic s-shaped aperture in Medial segment of *Sporormiella* in Figure 3, and in Terminal segment of *Sporormiella* in Figure 4), 5. *Sporormiella*-type, 6 & 7. *Sordaria*, 8. Sordariaceous ascospore (HdV-55), 9. *Delitschia*, 10. *Podospora*, 11. *Cercophora*, 12.*Coniochaeta xylariispora*, 13. *Coniochaeta*-A (cf. TM-016), 14. *Coniochaeta*-B (cf. TM-211). **Figure 3.** Pollen diagram of Rawatsera palaeolake, Kumaun Himalaya.

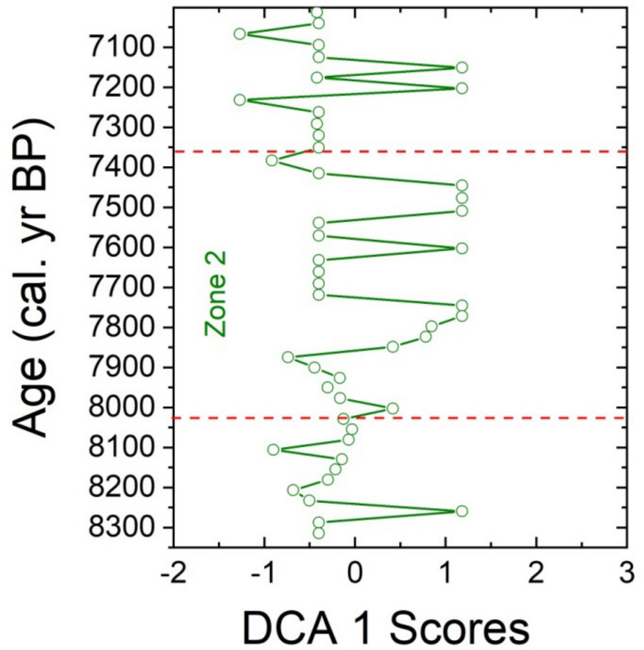


Figure 4. DCA axis 1 site scores were plotted against depositional age. In Zone 2, the DCA axis 1 score was relatively higher than the Zone 1 and Zone 3 which indicates the intensification of grazing activities during this period (Quamar et al., 2025).

India. The study is based on the NPPs, especially the SCF, from the Rawatsera palaeolake sediments profile, Kumaun, India.

The present study demonstrated that during ca. 8327–8041 cal yr BP, local grazing activity and the presence of livestock, particularly bovines, were there around the landscape of the study area in Kumaun (Central Himalaya), India. Subsequently, the local herbivore grazing activity increased during the period between ca. 7406 and 6999 cal yr BP, as was evident with the increase in the number and frequencies of the recovered SCF, but much increase in these spores (the SCF) during ca. 8041–7406 cal yr BP can be linked to the intensification of grazing activities and herbivory (pastoralism) in the area of investigation in Kumaun (Figs. 1–4). The study could be of help in estimating the abundance of herbivores and/or biomass density in a landscape. Additionally, the study may provide insights into the initiation and intensification of herbivore grazing and pastoralism, based on the recovery of the SCF, in an area. The study has significance in representing a broad range of climatic and environmental conditions and, thus, complements the interpretation derived from pollen records. Moreover, the study could contribute to improve the taxonomy of the SCF, particularly by enabling more accurate (high-resolution) identification. This is crucial, as swelling and/or shrinkage-resulting from different processing methods- often led to misidentifications, inconsistencies, and potentially inappropriate ecological or palaeoecological interpretations. Additionally, such study may facilitate the assessment of methane (CH_4) emissions. Overall, this study should be regarded as the starting point to enhance palaeoecological interpretations and to better understand herbivore grazing pressure within the landscape of Central Himalaya, India.

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Tracking the Little Ice Age in the Equator-Tropics: Multiproxy Insights from Coastal Southwest India

Biswajeet Thakur and Pooja Tiwari

THE Holocene epoch, which began around 11,700 years ago and continues today, has seen notable but less intense temperature variations compared to earlier periods like the Pleistocene. These temperature shifts influenced atmospheric circulation and precipitation patterns, which in turn played a key role in glacier dynamics. Understanding these climatic changes helps reconstruct the spatial and temporal distribution of precipitation and glacial behavior during the Holocene. Over the past two millennia, the Earth has experienced several episodes of natural and anthropogenic climate variability, marked by asynchronous and regionally diverse warming and cooling events. Prominent among these are the Medieval Climate Anomaly (MCA), a warm phase occurring between 800 and 1200 CE, and the Little Ice Age (LIA), a cooler period from the 1350 – 1850 CE. The LIA is particularly significant for its widespread glacial expansion, especially across the Northern Hemisphere and regions, such as Greenland, the European Alps, North America, Alaska, New Zealand, and the southern Andes. These global patterns underscore the LIA as a key climatic episode with broad environmental impacts.

While the Little Ice Age (LIA) is traditionally characterized as a globally cold and dry period with weakened monsoons, evidence from the equatorial-tropical regions of South Asia suggests notable regional discrepancies. Recent research challenges the notion of a uniformly cold LIA, highlighting significant spatial variability in climate conditions. For instance, the Kodagu District in southern India experienced a warm and humid phase with enhanced monsoonal rainfall, supporting mixed moist/semi-evergreen and dry deciduous forests during the LIA (1550–1850 CE).

In this context, the study investigates the paleoenvironmental conditions of Ashtamudi Lake, located in southwest Kerala, to assess the region's climatic response during the LIA. Using a multiproxy approach—including diatom analysis, palynofacies study, stable carbon-nitrogen isotopes, and grain size distribution—we aim to evaluate whether the climatic signals of the LIA were synchronous across equatorial-tropical South Asia.

The Ashtamudi Estuary, located in the Kollam District of Kerala, South India, is the state's second-largest estuary after Vembanad and is designated as a Ramsar site. Named for its eight branching arms resembling an octopus, the estuary spans 54 km² and stretches 16 km in length, opening into the Arabian Sea through a 200 m wide mouth. Positioned between 8°57'–9°03'N and 76°31'–76°41'E, it receives freshwater primarily from the Kallada River and its tributaries originating in the Western Ghats. The estuary experiences semidiurnal tides with a mean tidal range of 1 m, transporting silt-laden sediments during flood tides. The estuary lies in a tropical humid climatic zone, with annual rainfall averaging 2,428 mm. The southwest monsoon (June–September) accounts for 55% of the rainfall, while the northeast monsoon (October–December) contributes 24%. Mean annual temperatures range from 26.5°C to

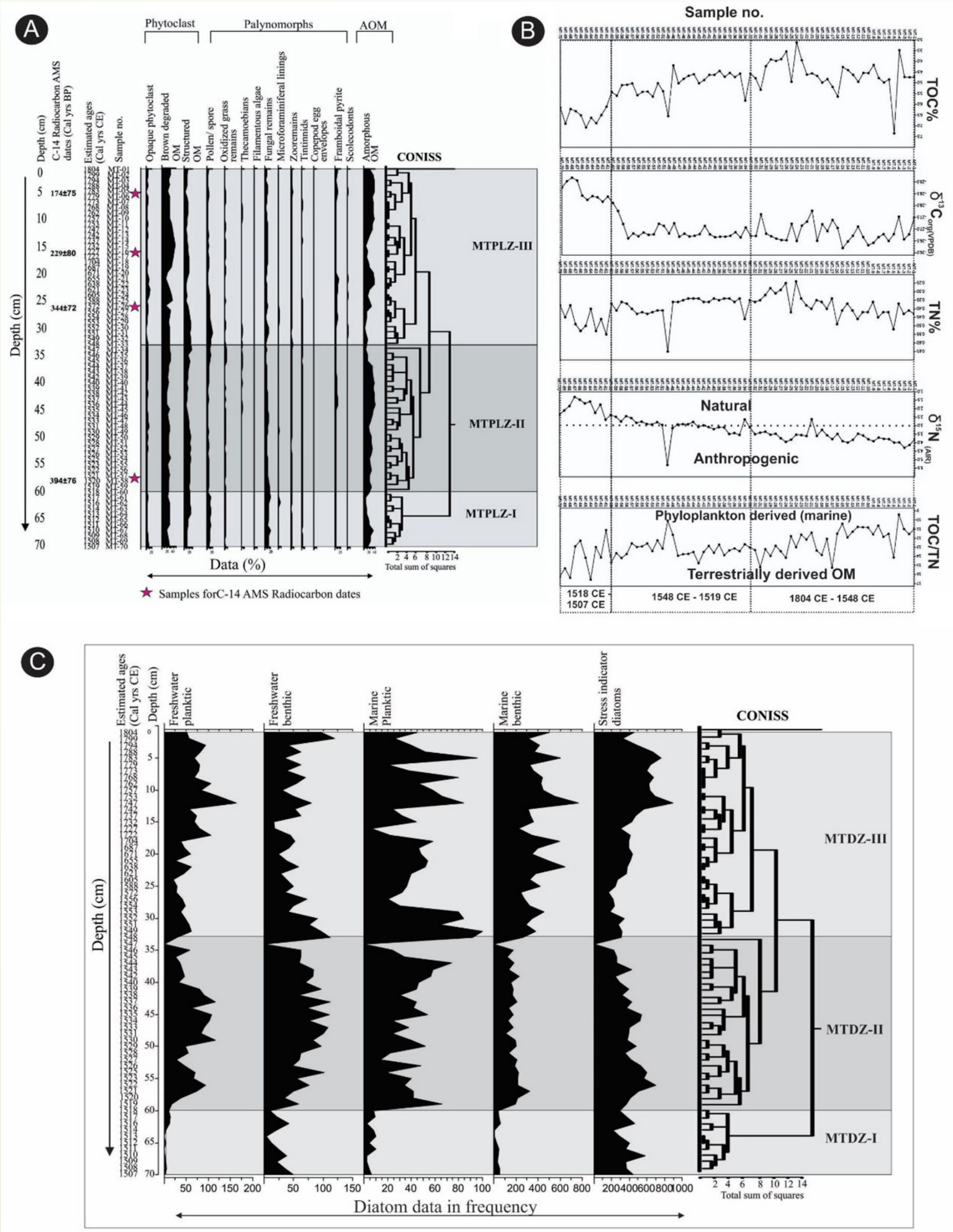

Figure 1. Frequency distribution and CONISS cluster analysis of (A) Palynofacies, (B) TOC%, $\delta^{13}C_{TOC}$, TN%, $\delta^{15}N$, TOC/TN, (C) Diatoms for different phases of LIA.

28.5°C, with high humidity levels and vapor pressures between 27 and 28.5 hPa.

The present study of the MT core from Ashtamudi Lake, southwest India, reveals evidence of the Little Ice Age (LIA), which has been divided into three distinct phases based on multiproxy data, including diatom assemblages, palynofacies, stable carbon and nitrogen isotopes, and sediment texture (Figure 1). The Phase 1 (1507–1518 CE) was marked by a warm and humid climate, characterized by high freshwater and marine planktic-benthic diatoms, abundant stress-indicating epiphytic diatoms, and elevated TOC (6.53%) with $\delta^{13}C$ values around -28.5‰. These data suggest enhanced primary productivity and terrestrial organic input. The high TOC/TN ratio (~14), significant presence of terrestrial palynomorphs, and fungal remains point to dominant terrestrial organic sources. Low marine palynomorphs and occasional dinoflagellate cysts suggest limited marine influence. Despite being synchronous with the LIA globally, especially in Europe and the North Atlantic, this period in South India does not reflect typical cold-dry conditions, aligning instead with a wetter LIA scenario reported from other parts of the Indian subcontinent. The Phase 2 (1519–1548 CE) reflects a climatic transition, with fluctuating organic matter input and an increase in amorphous organic matter (AOM). TOC decreased to 5.03%, with $\delta^{13}C$ at -26.6‰ and TN averaging 0.39%. $\delta^{15}N$ values (~3.04‰) suggest mixed atmospheric and anthropogenic nitrogen sources. The TOC/TN ratio (~13) and presence of coprophilous fungi indicate both terrestrial and human influences. Mixed diatom assemblages and increasing mud content suggest enhanced tidal activity and marine incursions. Reduced pollen productivity between 1519–1537 CE points to monsoonal weakening likely driven by sea intrusion. The final Phase 3 (1548–1804 CE), saw further marine influence, evidenced by dominant

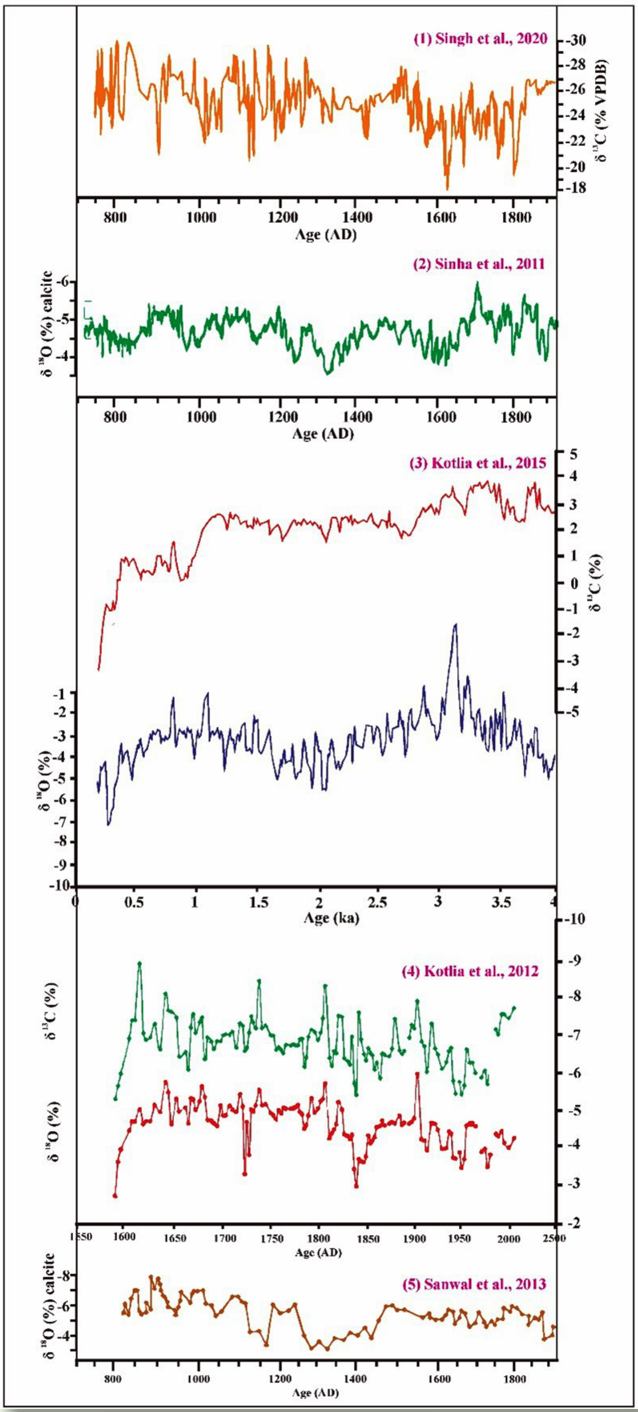

Figure 2. The variations in the Wet (Moist) LIA, recorded 1). from Rewalsar Lake, Mandi District, Himachal Pradesh (NW Himalaya) (Singh et al., 2020), 2). from the Jhumar and Dandak Caves, central Indian Core Monsoon Zone (Sinha et al., 2011), 3). from Indian Central Himalaya (Kotlia et al., 2015), 4). From Kumaun Lesser Himalaya (Kotlia et al., 2012) and 5). From Dharamjali Cave, Pithoragarh District, Central Kumaun Himalaya, Uttarakhand Sanwal et al. (2013).

mud textures, higher marine diatom taxa, stress indicators, dinoflagellate cysts, framboidal pyrite, and elevated marine palynomorph content. TOC averaged 4.6%, $\delta^{13}C$ declined further to -26.8‰, and TN remained at 0.38% with $\delta^{15}N$ reaching 3.67‰, again indicating anthropogenic and atmospheric contributions. These findings suggest increasing marine incursion and a weakened southwest monsoon through this period.

Various studies support the presence of wetter conditions across parts of South and East Asia during this period. Wet phases have been documented in Itanagar, the northwestern and central Himalayas the northern Tibetan Plateau, and southern China. Conversely, evidence of cooler and drier conditions during the LIA also exists. This includes records from Kadapa Cave in peninsular India, the Garhwal Himalaya, and the later phase of the LIA in the northwestern Himalaya (~1640–1800 CE). These findings highlight the LIA as a period of regionally diverse climate expressions rather than a globally homogeneous event (Fig. 2).

These regional climate responses may be associated with broader global phenomena, including reduced solar activity during the Spörer (~1450–1550 CE), Maunder (~1645–1715 CE), and Dalton (~1790–1830 CE) minima. These solar minima likely influenced equatorial and tropical climates by shifting the Intertropical Convergence Zone (ITCZ) southward and slightly reducing atmospheric CO_2, contributing to global cooling of approximately 1°C. In a broader context, the Ashtamudi core data reveal both synchronous and asynchronous climatic patterns with global LIA trends. The early LIA period in southwest India showed strong monsoon activity, while subsequent phases (1519–1804 CE) exhibited weakening monsoons and increasing tidal influence. Declining $\delta^{13}C$ values (by ~2–3‰) are likely linked to land-use changes, such as deforestation and agriculture.

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Looking at the majestic seascapes of Meghalaya through windows of micropaleontology

Suman Sarkar

MEGHALAYA is one of the seven sister states situated in the northeastern India, also popularly known as the "abode of clouds" or "Scotland of the East". These nicknames emerge from a marvelous ensemble of picturesque landscapes unveiling a masterpiece of creation, including lush green valleys, cascading rivers, delightful lakes, fascinating waterfalls, living root bridges, and enigmatic caves, all set against the tranquil backdrop of the Himalayan Mountains. With all its natural charisma and grandeur, Meghalaya is also a geologist's paradise.

The geological timescale age, we are living in currently, has been officially named as 'Meghalayan' ranging about 4200 years to the present, which lies within the Holocene epoch. This term came from the analyses of a stalagmite from the geoheritage site of the Krem Mawmluh cave in the East Khasi Hills of Meghalaya, unravelling a climatic catastrophe in the form of a mega-drought that obliterated most of the Bronze Age civilizations, including the Harappan Civilization nearly 4200 years ago. Apart from this, Meghalaya beholds numerous deep-time secrets still to be resolved by the earth scientists.

The evolution of this region from harboring mangrove forests to assemblages of marine algae and other organisms, ultimately getting transformed into the enormous stretches of hill ranges we observe today presents a magnificent story. Our Earth is nearly 4.5 billion years old and it is widely opined that by 4.3 billion years ago, all the physico-chemical conditions necessary to support life may have developed. The oldest known fossils to date, however, are only 3.7 billion years old. In this regard, it has been postulated that life may have emerged repeatedly during this nearly 600 million year window but failed to sustain owing to the catastrophic collisions of the Earth with asteroids and comets. Talking about the Earth in the 3.7 billion-year old frame, there were no continents as yet, but just a global ocean speckled with several islands. Eventually, a barrage of meteorites resulted in large-scale processes of erosion, sedimentation and volcanic activity which created small proto-continents, developing until they roughly attained their present size approximately 2.5 billion years ago. The continents since then underwent repeated collisions and were physically apart until about 300 million years ago when all landmasses fused together to form the supercontinent Pangaea. During the next 100-150 million years, the continents of Australia, Africa and Antarctica earlier connected to the Indian plate began to pull apart and oceans started invading the empty spaces, where once there was land. This resulted in formation of dense tropical forests along the margins of the seas. It was during this period that the region we know as Meghalaya today, existed as a coral island rising from a tropical ocean swarming with sharks. Ultimately, the Indian subcontinent broke up from African mainland, and moved northwards towards Eurasia. This period was characterized by landmasses getting pushed through tectonic forces, in turn disrupting sea flow and submergence of a large portion of the grown, well developed forests.

In the context of Meghalaya, rivers from inland sources brought sand to the coast, building up sandstones and continued to bury the mangrove forests, which by virtue of a long process of decaying ultimately transformed into coal beds. As the seas flooded the landmass, Meghalaya experienced uplifting and down-thrusting numerous times,

Figure 1. Beautiful landscapes of Meghalaya reflect magnificent contrast from ancient seascapes and marine environments.

accumulating several cycles of marine environment indicating limestones alternating with sandstones, sometimes laterally passing into each other. At several stages, certain parts of Meghalaya witnessed considerable uplifting, forming landscapes like Shillong Plateau. The collision between India and Asia at nearly 56 million years ago potentially created biogeographic barriers and altered the oceanic circulation. The beautiful caves of Meghalaya could be attributed to the factors of limestone accumulation, heavy rains and process of elevation, working together.

The relic marine environments of Meghalaya and many other parts of northeastern India have been analyzed to date by means of several scientific approaches among which micropaleontology is a pivotal study discipline (Fig. 1). Paleontology comprises the scientific study of ancient life, primarily based on the analysis of plant and animal fossils (also trace fossils) to reconstruct their morphology, patterns of evolution, and relationships with their environments. Micropaleontology is a branch of paleontology involving the study of microscopic fossils (microfossils) to understand past environments and climate (paleoclimate), evaluate their relationships with various abiotic and biotic aspects of their environment (paleoecology), determine the age of rocks and sediments (biostratigraphy) and also finds application in various applied fields like oil and gas exploration. Discussion on all aspects of micropaleontology is beyond the scope of this article. Rather, a brief overview of palaeoenvironmental snapshots observed in the limestones of Meghalaya are presented herein.

Meghalaya's paleoenvironment shows robust evidences of marine life from around 75 to 35 million years ago featuring diverse communities of calcareous (calcifying) algae, benthic foraminifera (marine unicellular protists), echinoids and mollusks to name a few biotic groups (Fig. 2). The seascapes were indeed disturbed by multiple cyclical phases of large-scale transgression (rising relative sea level, causing the shoreline to move inward/landward) and regression (shoreline moves seawards/outward) that led to alternate deposition of marine limestones and non-marine sandstones (with other rock types). These organisms are analyzed in the geological context by means of comparative analyses with their recent analogues (same genera or near relatives dwelling in the modern day oceans). The evolutionary journey of calcareous red algae is very fascinating due to the presence of genera like *Corallina*, *Sporolithon* and *Lithothamnion* in the limestones of Meghalaya that

Figure 2. Marine calcareous algal and foraminiferal communities from Meghalaya; (A) app. 58 million years ago; (B) app. 40 million years ago. Scale bars = 1 mm.

can also be observed in the present-day oceans with a pretty wide cosmopolitan distribution. In contrast to the algae, most of the benthic foraminifera have gone extinct at various stages of the geological history thereby gaining impact as index age-marker fossils. Since these organisms are calcifying (secreting calcium carbonate) and exclusive to marine environments with rare exceptions, their presence in the limestones of Meghalaya definitely confirm shallow-marine environments prevalent in the geological past that have gradually evolved into the hilly terrain of the present. The limestones of east Khasi Hills and west Jaintia Hills are known for the shallow-marine communities whereas relatively deeper calcareous nannofossils have also been found from the biotic assemblages deciphered from the Garo Hills, probably indicating greater water depths in this part of Meghalaya. It is noteworthy that several types of marine organisms are found in the limestones of Meghalaya in varying proportions, although calcareous algae and benthic foraminifera are the dominant biota in terms of abundance and frequency. Corals were highly abundant in major parts of the world during the time interval of 65 to 55 million years ago, but their very sparse occurrences to complete absence in the limestones of Meghalaya could be due to very high temperatures or greater invasion potential of calcareous algae and benthic foraminifera in this part of the Earth. Nevertheless, abundant marine microfossils from the limestones of Meghalaya present an excellent opportunity to observe a precious wealth of past biological communities through the microscope lens where a small sample can reveal an entire ecosystem of organisms and convey to us the various facets of the environment in which they lived several million years ago.

About author

Dr Suman Sarkar is Scientist C at the BSIP, Lucknow. His research interests include reconstruction of Cenozoic palaeoenvironments, emphasizing on the impacts of climate change on benthic organisms in deep time.

Tracing geohazards using tree rings: A case study from Kinnaur, Himachal Pradesh

Bency David Chintala, Jussi Grießinger, Parminder Singh Ranhotra, Stuti Jain, Chnadra Prakash Singh and Achim Bräuning

THE global warming trend is resulting into various changes in the environmental conditions, such as increasing frequency of extreme climatic events like droughts and floods, and the related geohazard activities like landslides, snow-avalanches, and flash-floods, etc., which are becoming great challenges for the societal livelihoods. The Himalayan mountain system is highly prone to climate change, and the current warming trend is making the region more vulnerable to hydrological, ecological and land-surface changes, as monitored by the melting of glaciers at high rate, changes in vegetation forms, tree-line advancements, and an increase in the geohazard activities. The extreme climatic conditions results into instability of the ground and slopes that get triggered to geohazards, such as landslides, rockfalls, debris flow, etc. under the intense weather phenomenon of high rainfalls. When geohazards occur in the vicinity of inhabited areas, they destroy the infrastructure and alter the landscapes under human use, thus, hamper the livelihoods and economy. Better knowledge about the climate change processes and triggering factors of the geohazards is important to take proper measures towards climate change and hazard mitigations. The climate (temperature, precipitation, humidity, etc.), extreme weather events, and hazard activities are being continuously recorded instrumentally. These observational or documented records, however, cover the short time phase of last few decades or a century, thus, not allowing to properly understand the role of climate change on the ecology and land stability. Assessment of the characteristics of climatic variations in long-term that is beyond the instrumental records is, therefore, important to identify how the changes in the ecology and land-surface conditions are related to the climate

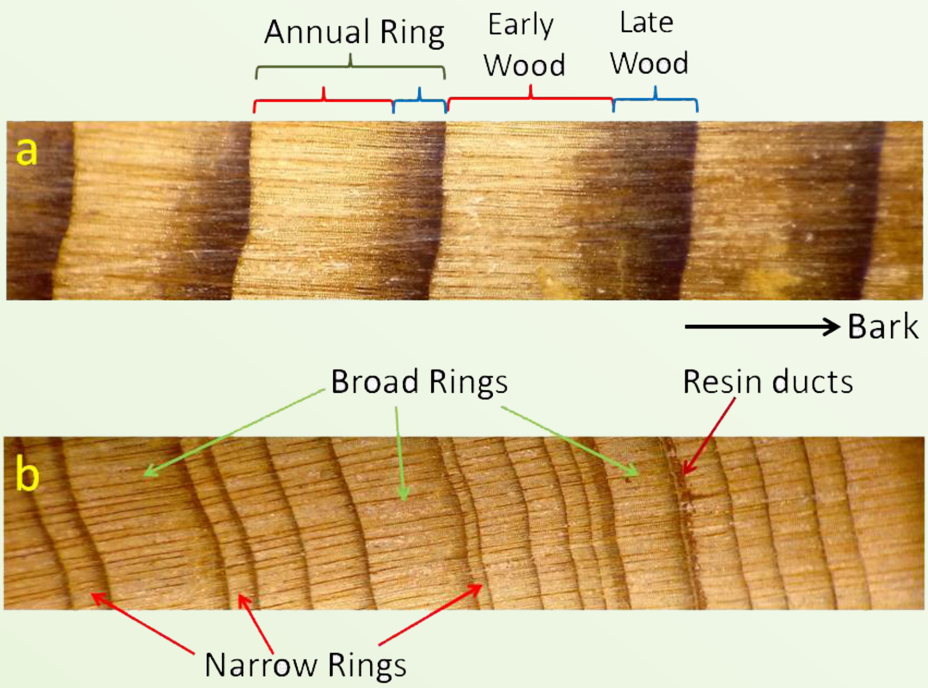

Figure 1. Tree-rings of *Cedrus deodara* (Deodar). (a) Early-wood and Late-wood forming one Annual Growth Ring. (b) Narrow and Broad Rings, and Resin Ducts.

change processes. Tree-rings or the annual growth rings in the trees are the best proxy archives to quantify the climatic and hazard events on inter- and intra-annual time resolution since past. Most tree species can survive for many hundreds of years withstanding normal to extreme climatic conditions and hazard activities. Trees, growing in a region capture the signatures of the climate and the natural events of the region in their growth rings and, hence, provide a scientific base to study the past events. Dendrochronology is the discipline of science that uses the annual growth-rings or tree-rings of the tree-ring forming trees to examine the climatic and non-climatic events embedded in tree-ring structures over time. Trees growing in the temperate regions; mainly conifers (gymnosperms) form distinct annual growth rings, and one annual ring is the combination of 'Early-wood' (or spring-wood) and 'Late-wood' (or autumn wood) (Fig. 1). Each ring can be dated on calendar year by the thumb-rule that the outermost ring adjacent to bark is the youngest ring representing the latest year of formation. Trees show deviation in their ring-width depending on the changes in environmental conditions in each year, such as the years with climatic stress result into reduced growth and the formation of narrower rings, and the years

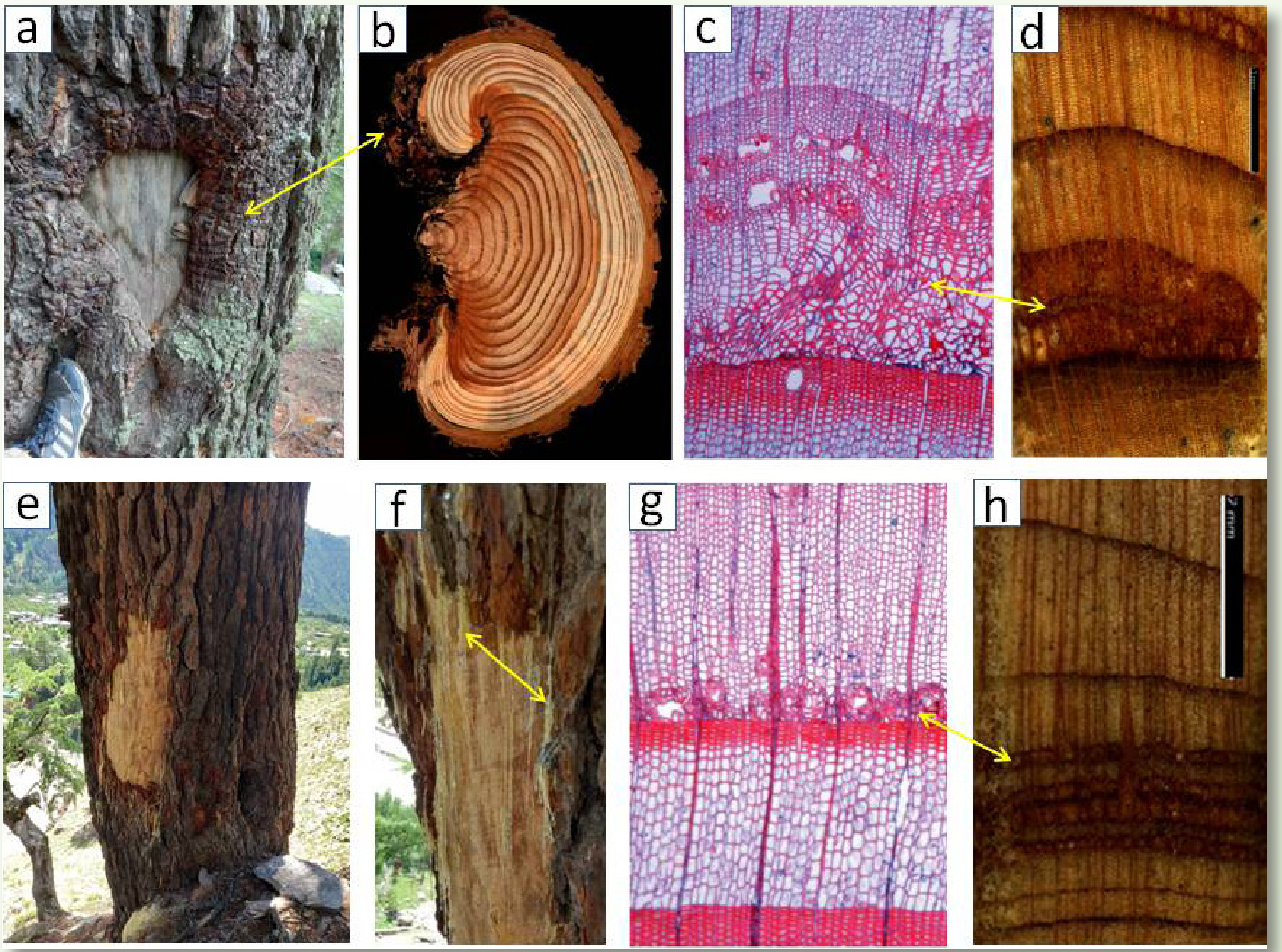

Figure 2. (a) Injured stem, and (b) cross-section showing overgrowth starting from the lateral edges of the injury (yellow arrow). (c,d) Callus tissue in the overgrowing cell layers bordering the injury. (e,f) Release of resin after injury (yellow arrow). (g,h), Tangential rows of traumatic resin ducts formed next to the callus tissue (yellow arrows). Pictures b,c and g are after Stoffel and Bollschweiler, 2009.

with favorable conditions result into wider ring formation (Fig. 1). Dendrogeomorphology is the application of tree-rings that facilitates the study and dating of geohazard processes with the principle of 'process-event-response'. 'Process' of any kind, such as landslides, rockfall, snow avalanche, flashfloods etc. will impact the trees as an 'event', and the tree will 'respond' to such geohazards by producing growth disturbances. Trees affected by a geohazard activity commonly receive scratches and injuries on the outer bark and inner side that disrupt the wood formation in the wounded part of the tree (Fig. 2). To heal the wound, the tree initiates the production of callus tissue layers from the edges of the wound so as to continuously overgrow the injury (Fig. 2). In this healing process the tree produces the Traumatic Resin Ducts (TRDs) that extend both tangentially and axially from the injury. Therefore, the year of geohazard activity can be distinguished by the presence of TRDs in the annual ring of that particular year. Ground moisture is largely responsible for the tree-growth and also

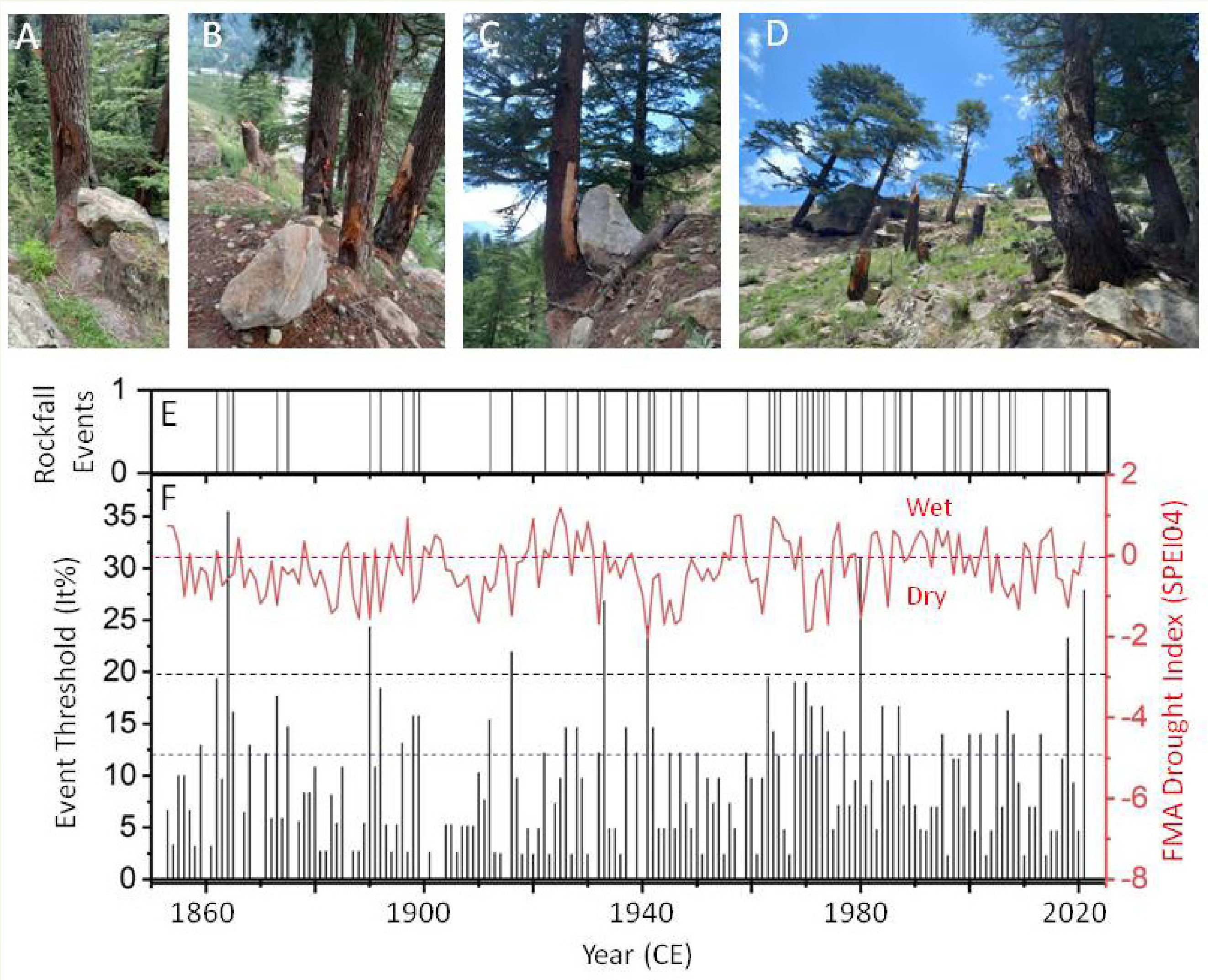

Figure 3. A-D) Boulder impacted and broken trees of Deodar (*Cedrus deodara*) during July 2021 rockfall event at Batseri, Kinnaur (HP). (E) 53 reconstructed Rockfall Events. (F) 8 high intensity above threshold (*It*%) rockfall events (black dashed line) correspond to years with dry spring February-April (FMA) months (SPEI04= standardized precipitation evapotranspiration index).

linked to the geohazard activities. In the Himalayan region, the episodes of landslides and flashfloods increases during the monsoon season as a result of oversaturation of water in soil due to high rain falls, thus, leading to slope failures. Dendroclimatology and dendrogeomorphology techniques can be used to effectively quantify the climate variability and geohazard episodes to understand the climate-induced geohazard mechanisms since long-past.

In a pioneer attempt, dendroclimatology and dendrogeomorphology techniques were integrated to reconstruct the moisture variability and geohazard episodes for the past few centuries from the Kinnaur region in Himachal Pradesh, western Himalayas. The Kinnaur region is highly prone to landslides, rockfalls and other geohazard activities due to its tectonically- and climatically-driven landform setups. We carefully examined the tree-rings of older trees of Deodar (*Cedrus deodara*) growing in and around Batseri Village in the Baspa Valley in Kinnaur and recreated a 378-year (1558-2021 CE) long history of moisture changes in the Kinnaur region. To recreate the moisture history, we used a Standardized Precipitation Evapotranspiration Index (SPEI) which is a parameter to analyze the drought conditions in time and space. The positive values of SPEI (0 to +5) indicate the high moisture conditions and negative values (0 to -5) indicate low moisture and drought conditions. In our study, it was found that the growth of Deodar trees is sensitive to the moisture of spring season months [February-March-April (FMA)]. The Kinnaur region receives more than 50% of annual precipitation during winter and spring months that is from November to March in the form of snowfall by a weather phenomenon known as Western Disturbances (WD). The melting of snow supplies water to soil which is used by the trees for growth and early-wood formation during spring and pre-monsoon summer months. Therefore, the years with less winter precipitation could lead to dry conditions during spring and pre-summer monsoon months, hampering the growth of trees. In the drought reconstruction, it was found that between the years 1725 and 1757 CE, the Kinnaur region experienced a wettest phase of spring months (FMA), due to strong influence of WD. This period falls within the time frame of Little Ice Age (LIA) which is a globally known phase of cooler climatic conditions recorded from most parts of the Northern Hemisphere. After 1757 CE, the region started experiencing dry conditions during spring months and an overall decline in moisture. This shift toward dry spring conditions continued through the 19th and 20th century when the trees also showed declining trend in their growth patterns.

Using dendrogeomorphological approach, the 168 years (1853-2021 CE) long history of rockfall activities were reconstructed from Batseri locality. Geohazard reconstruction highlighted 53 episodes of rockfall since 1853 till 2021 CE, of which 8 episodes were of extreme intensity, including the recent documented rockfall activity happened on 26th July 2021 (Fig. 3A-D). The reconstructed moisture variability and the rockfall episodes were compared and it was found that majority of the rockfall years within the period 1853 to 2021 CE coincided with the years having dry spring months with negative SPEI values (Fig. 3F). The warming temperature trend aggravates spring season drought conditions. The studied hazard prone slope is south facing, which is also the Sun-facing slope and has thin soil cover. The temperature rise is possibly creating the drier ground conditions on the slope resulting into poor vegetation cover and making the slopes more prone to failure when saturated by summer rainfall. This study also found that the rockfall episodes became more frequent after 1960 CE, probably as a result of an enhanced winter and spring warming coupled to higher moisture variability. The continued spring warming and the reduced winter and spring precipitation might increase the number of dry spring days, enhancing the risk of geohazards. The tree-ring analysis also showed how the events like El-Niño and La-Niña, as well as changes in ocean surface temperatures in the Atlantic and Pacific regions, played a vital role in driving the wetter or drier periods in the Kinnaur region.

The implications of this study are very important for local communities and decision-makers. Forests in the Himalayas are not only home to valuable biodiversity, but they also help to stabilize the land and support agriculture and tourism, which are the main sources of income in the region. The continued climate warming with more number of dry years leads to more such disasters in near future, thus, underscoring proper management of forests and water resources. Moreover, monitoring of tree growth and slope stability measures should become part of regular planning in vulnerable areas like Kinnaur. Early warning systems for landslides and better land-use planning can help reduce future risks. The study also shows how older trees can help to understand the changing climate to better predict the future. As climate change continues to reshape our world, such research becomes essential for the protection of human and nature. There is a need for more such studies from other parts of the Himalayas where climate conditions and risk levels may be different, but equally important.

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Fossil whispers: Unearthing a Bamboo tale from South India

Harshita Bhatia and Gaurav Srivastava

IN the quiet depths of Tamil Nadu's Neyveli lignite mines, a remarkable discovery lay waiting—not a relic of human history, but a silent witness to Earth's deep botanical past. Preserved in ancient sediments for nearly 20 million years, a fossilized bamboo stem, Ventriculmus neyveliensis, has emerged as a rare and revealing clue to the plants that once flourished in southern India. The genus name derives from Latin—ventriculus ("swollen stem"), referencing its bulbous nodes, and neyveliensis, denoting the site of its discovery.

Although bamboos are ecologically and economically vital today, their fossil record is surprisingly sparse and often fragmentary. Most known fossils lack the diagnostic features needed to trace their evolutionary lineage. That's what makes the Neyveli (Fig. 1) find so extraordinary. It is not only the first well-preserved bamboo fossil from southern India, but also the only known fossil globally to preserve both swollen nodes and nodal buds (Fig. 2)—delicate structures rarely seen in the fossil record. These traits firmly place it within the bamboo subfamily Bambusoideae, offering a rare glimpse into the early stages of bamboo evolution, long before modern lineages fully diverged.

Dating to the Early Miocene (~20 million years ago), the fossil captures a time of dynamic geological change. After breaking away from the ancient supercontinent Gondwana, the Indian plate drifted northward and eventually collided with the Eurasian plate. This monumental tectonic event not only gave rise to the Himalayas, but also forged land bridges, enabling the exchange of flora and fauna between India and mainland Asia. It is

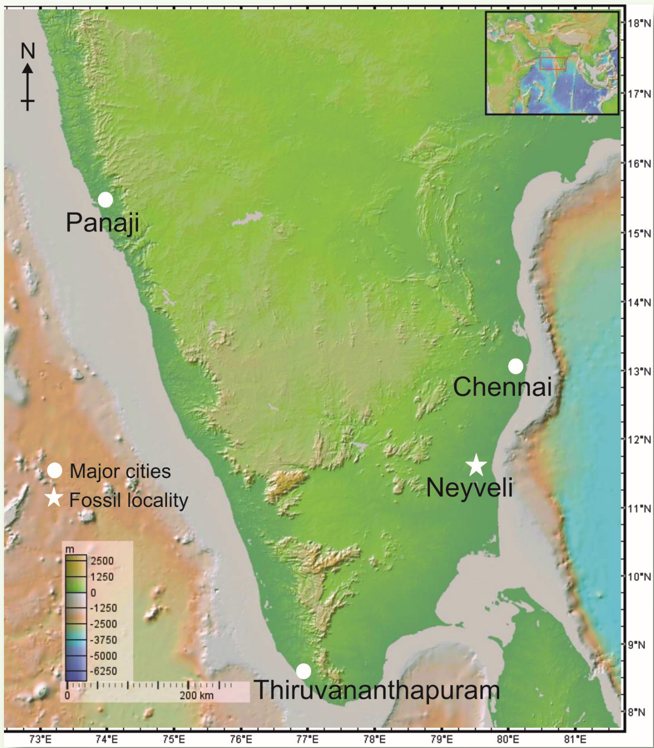

Figure 1. Figure showing the locality from where the fossil was excavated.

believed that the ancestors of modern Asian bamboos had a Gondwanan origin, likely evolving in India while it was still drifting through the Southern Hemisphere. As the Indian plate moved northward and sutured with Asia during the Neogene, these ancestral bamboos may have migrated into China and Southeast Asia, seeding the rich diversity seen today. The fossil from Neyveli provide evidence in support of this hypothesis. Morphologically, the fossil bamboo from Neyveli closely resembles modern temperate woody bamboos found in China, Southeast Asia, and the Himalayas—particularly species in the genera

Neyveli Lignite Mine

Section of the Neyveli lignite mine from where the bamboo was excavated

Field photograph of the bamboo excavated from the lignite mine

Figure 2. Fossil bamboo recovered from the Neyveli lignite mine, Tamil Nadu, showing the preserved morphological features like swollen nodes and nodal buds (after Bhatia et al., 2025).

Chimonobambusa and *Sinobambusa*, many of which thrive in warm temperate climates. Its presence in South India during the Miocene suggests that such bamboos once had a much broader distribution across the subcontinent. However, as the climate changed over time, these temperate lineages likely retreated to favorable regions or became locally extinct in southern India.

More than just a glimpse into one ancient plant, *Ventriculmus neyveliensis* reshapes our understanding of bamboo evolution. It suggests that India was not merely a corridor, but possibly a cradle of Asian bamboo diversity, where early lineages emerged before spreading across Asia. Extending the known range of woody bamboo fossils, this discovery hints at more botanical treasures still buried in India's ancient sediments. In an age of accelerating climate change, such fossils are more than scientific finds—they are enduring records of how life responds to shifting environments, offering vital clues for preserving biodiversity in the future.

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Echoes of a hotter earth: What palaeotropical Indian forests tell us about climate chnage

Poonam Verma

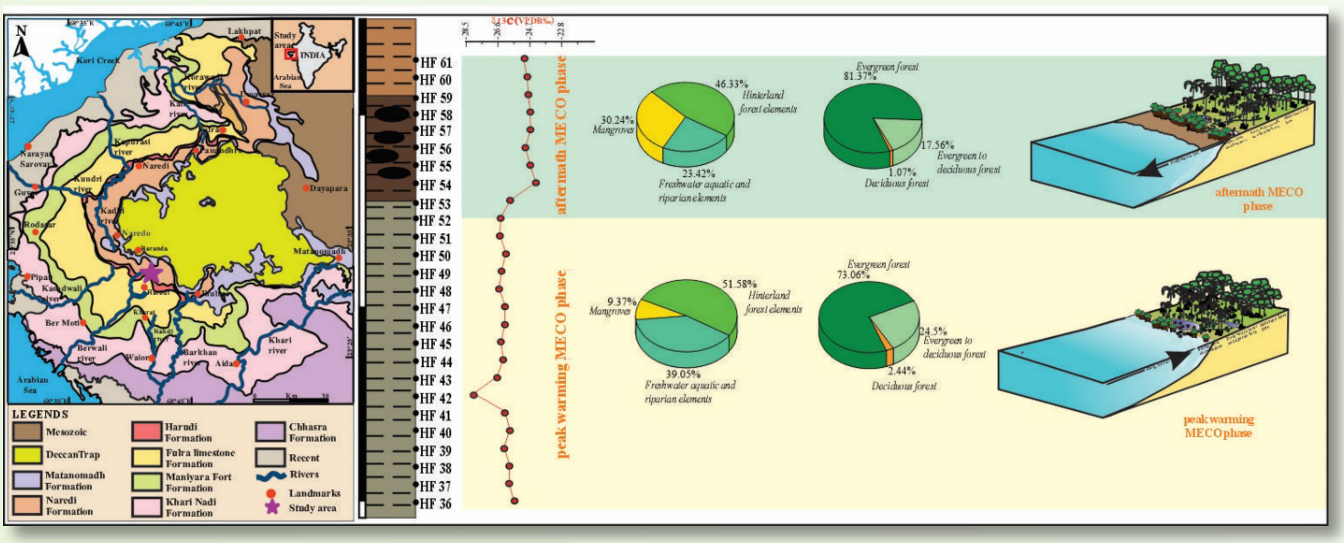
THE Middle Eocene Climatic Optimum (MECO) was a brief yet significant warm period 40 million years ago. Recent research from India's Kutch Basin offers a rare glimpse into how tropical rainforests responded—and what that means for us today.

The Eocene Epoch, spanning roughly 56 to 33.9 million years ago, was a time of extraordinary transformation on the Earth. It opened with intense greenhouse conditions—rainforests thrived even in polar regions—and closed with the first hints of permanent ice at the poles. In this time of planetary flux, two climate events have dominated the spotlight: the Paleocene-Eocene Thermal Maximum (PETM), a dramatic spike in global temperatures and carbon levels 56 million years ago, and Eocene Thermal Maximum 2 (ETM-2), which followed a few million years later.

Nevertheless, besides these extremes, a relatively lesser-known climatic event—the Middle Eocene Climatic Optimum (MECO) occurred about 40 million years ago, signalling a brief, transitory and sudden increase in global temperatures that temporarily interrupted the Earth's gradual cooling trend. Lasting for approximately half a million years, it marked an era that some scientists refer to as the "doubt-house world", possibly due to unclear forcings behind the event. While marine records—particularly isotopes from ocean sediments—have long recorded MECO's signature, terrestrial environments have told a much quieter story, until now.

A tropical time capsule in India

A recent study from the Harudi Formation in India's Kutch Basin is shedding new light on what happened on land during MECO—and the results are eye-opening. By analysing fossil pollen grains and carbon isotope signatures preserved in sedimentary deposits, scientists have reconstructed how tropical ecosystems responded to this unexpected warming. The findings also point to a pronounced Carbon



Isotope Excursion (CIE) of about 2.5‰, signalling a significant disruption in the global carbon cycle. This coincides with MECO's peak and aligns with elevated atmospheric CO_2 levels and rising temperatures globally.

At the time, the Kutch region was home to dense, evergreen tropical rainforests nourished by warm, wet conditions. But as MECO took hold, change swept through the ecosystem. Deciduous plant species appeared in the fossil pollen record—an indication that rainfall patterns were becoming more seasonal, perhaps due to shifting monsoon dynamics. Mangrove communities, sensitive to changes in coastal salinity, also began to falter, likely impacted by increased freshwater runoff.

Recovery with a cost

As MECO's peak phase faded and the climate began to stabilise, evergreen species and mangroves gradually returned. But something had changed. The fossil pollen record suggests an overall decline in biodiversity, implying that not all species were able to bounce back. Some may have been pushed out by shifting environmental pressures.

This long-lost episode of warming, once obscure, now offers a stark reminder of the fragility of Earth's tropical ecosystems— even in climates that seem favourable on the surface.

Lessons for a warming world

Although MECO was driven by natural forces, the environmental themes it addressed—rising CO_2, temperature spikes, shifting rainfall, coastal stress—are strikingly familiar today. The parallels to our modern, human-driven climate crisis are unmistakable.

MECO demonstrates that even resilient systems, such as tropical rainforests and mangroves can be disrupted by relatively short-lived climatic changes. It also raises urgent questions about the speed at which ecosystems can adapt and whether complete recovery is always achievable.

In the layers of ancient Indian rock, we find more than just fossil pollen—we find a warning. As we navigate our own uncertain climate future, the story of MECO may help us understand not only where we're headed, but what we might lose along the way.

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Reconstructing Permian Palaeofires: Insights from Charred Microstructures

Neha Aggarwal, Shivalee Srivastava, Divya Kumari Mishra and Runcie Paul Mathews

FIRE, an inherently rapid oxidative process, has played a pivotal role in shaping terrestrial ecosystems from the Late Silurian (~ 419.2 to 443.8 mya– million years ago) to the Quaternary Period (2.58 mya). Its imprints, whether through vegetation alteration or sedimentary transformations, are integral to understand the evolutionary past of the Earth. One of the most tangible proxies for ancient fire activity is charcoal—particularly macrocharcoal—formed through vegetation combustion. However, microscopic fossil charcoal embedded in clastic deposits offers a far more consistent, though historically underexplored, archive of palaeofire events.

In past palaeobotanical studies focusing on the Late Paleozoic (~ 419-252 mya), these microscopic charcoal remains were often overlooked, despite their frequent appearance in palynological preparations. The distinction between various origins of such material—whether derived from oxidation, low-temperature exposure, or full-scale palaeowildfires—has largely remained ambiguous. Moreover, prior interpretations, based on macrocharcoal and SEM

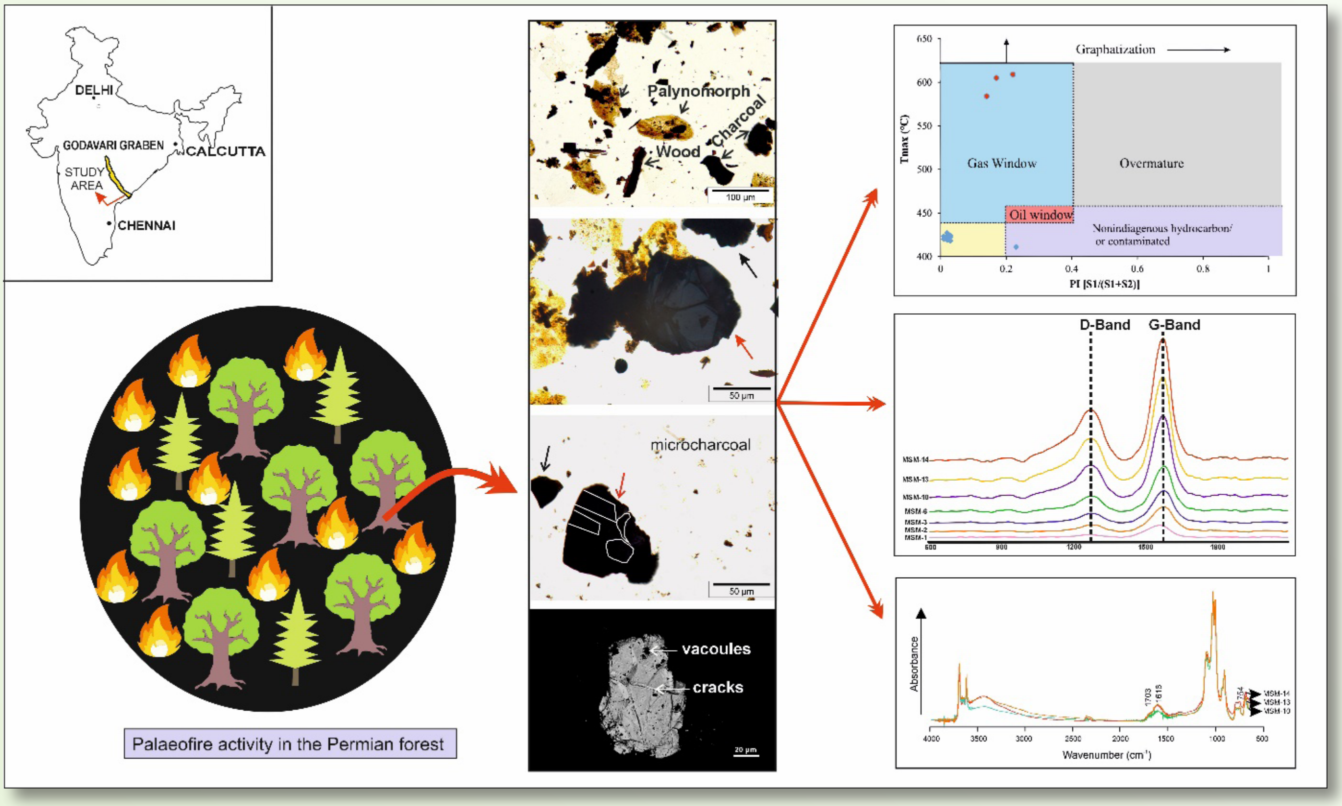

Figure 1. Graphical representation of the integrated approach to resolve palaeofire activity during the Permian in Godavari Basin.

analysis, lacked conclusive evidence to confirm whether the charred remnants were in-situ (preserved in place) or ex-situ (transported from somewhere else). These gaps have been addressed in a study (Fig. 1) (Aggarwal et al., 2025) by distinguishing two types of microcharcoal in the Artinskian-aged (~ 290.1 to 279.3 mya) Barakar Formation of the Godavari Valley Coalfield, South India: (i) charcoal produced by palaeofire events (PAL-CH), and (ii) oxidized charcoal (OX-CH). Through a combination of palynofacies, geochemical (Rock Eval Pyrolysis), and spectroscopic methods (Raman spectroscopy and Fourier Transform Infrared Spectroscopy (FTIR)), the research investigates their structural and thermal characteristics to better understand the conditions under which they formed.

Palynofacies analysis of coal and associated samples revealed three main organic components: Translucent Organic Matter (TrOM), including palynomorphs and phytoclasts; and two distinct opaque phytoclasts—PAL-CH and OX-CH. The palynofacies classification is based on their visual morphology under the microscope and their association with other sedimentary components. To complement these observations, high-resolution techniques (e.g. Raman spectroscopy, Rock-Eval pyrolysis, and FTIR) were applied.

Raman spectra proved useful, especially in identifying thermally altered carbon. The intensity ratio of the disorder (D) and graphitic (G) bands (ID/IG), ranging from 0.20 to 0.47, pointed to variable levels of thermal maturity. Samples with higher ID/IG values corresponded with increased evidence of palaeofire activity. Broader D bandwidths (D-FWHM) and the D-FWHM/G-FWHM ratio exceeding one further highlighted significant structural shifts toward disordered carbon—attributes consistent with high-temperature combustion.

Rock-Eval pyrolysis supported these interpretations, revealing low hydrogen index (HI) values and high T_{max} readings between 411°C and 609 °C. These metrics are characteristic of charred or inert organic matter, likely formed due to intense heat. The FTIR spectra added another dimension to the interpretation, revealing aromatic and aliphatic transformations consistent with thermal alteration. Notably, the absence of aliphatic C-H stretching bands in the 2800–3000 cm^{-1} region and out-of-plane aromatic C-H bending confirmed coalification and molecular alteration due to intense heat exposure.

The combined data distinguish PAL-CH as a product of in-situ palaeofires, whereas OX-CH is interpreted as resulting from post-depositional oxidation. Notably, the narrowing of the G band, absence of aliphatic C-H bonds, and high RBS values (Raman Band Separation) are all indicative of over-mature organic matter, pointing towards localized burning events in the depositional setting. Further, the AD/AG (area ratio of D and G bands) values provided a quantitative perspective on the extent of graphitization and disorder within the organic matter. This ratio showed a consistent correlation with T_{max}, supporting previous interpretations and validating palaeofire influence across multiple samples.

The depositional framework also appears to have played a key role in charcoal preservation. Sequences rich in PAL-CH align with regressive

depositional phases, where in-situ burning and limited water transport preserved the charcoal in place. In contrast, mixed occurrences of OX-CH and PAL-CH suggest transgressive settings where reworking of sediments and longer transport pathways led to oxidation or partial combustion before final burial. Importantly, these findings hold broader implications beyond palaeoecological reconstruction, aiding in palaeogeographic interpretations. Understanding these distributions offers a strategic advantage in exploring palaeoenvironmental transitions and source rock potential.

Beyond basin analysis, this study also highlights the importance of integrating microscopic, spectral, and chemical data to decipher the origins and transformation pathways of ancient charcoal. The differentiation between in-situ burning and post-depositional oxidation helps reconstruct local fire regimes and their climatic drivers. The findings link charcoal occurrence with fire dynamics and vegetation shifts, underlining palaeofires as indicators of ecological transitions during the Permian.

In conclusion, the study offers a comprehensive framework to identify and interpret palaeofire signals. These insights not only help reconstruct Permian fire regimes, but also open new pathways in understanding

sedimentary carbon cycling, hydrocarbon potential, and even modern climate analogs through the lens of deep-time fire activity.

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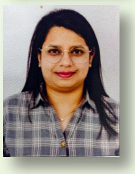

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Can fossil records help us forecast future biodiversity shifts?

Harshita Bhatia and Gaurav Srivastava

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

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

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

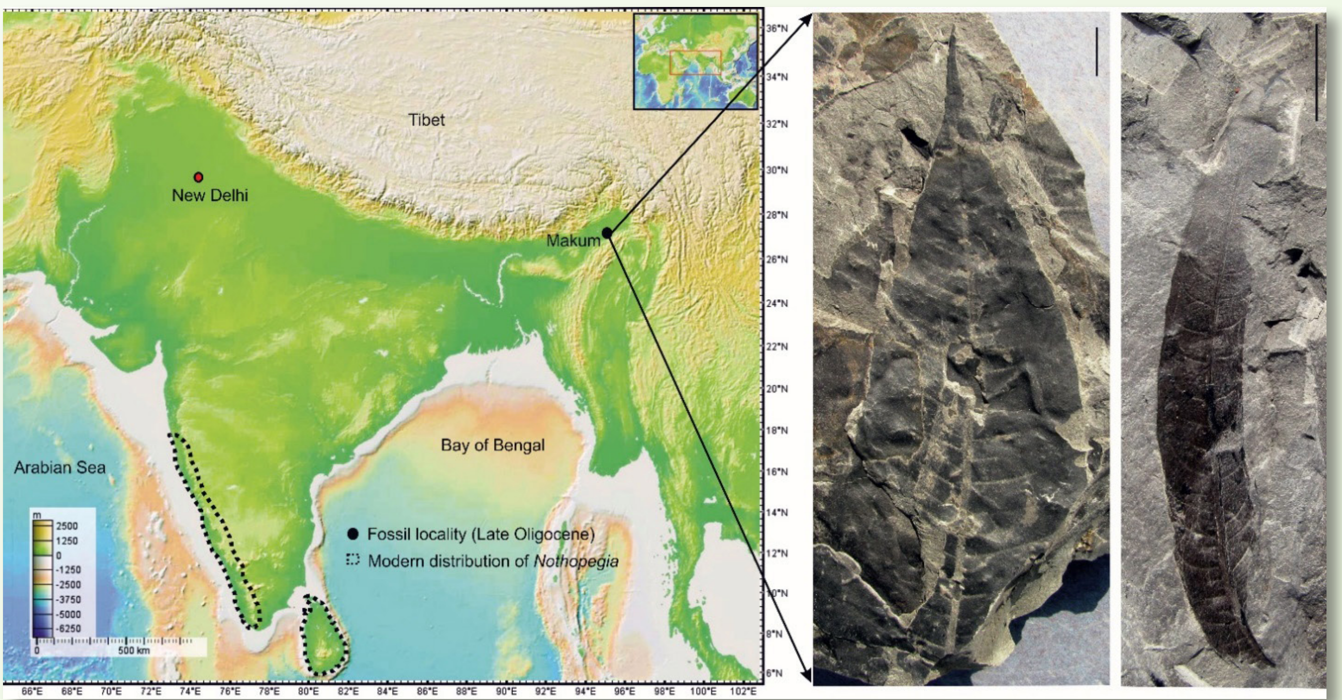

Figure 1. The diagram shows how climate change over millions of years caused the disappearance of *Nothopegia* from northeast India, while the species survived and became endemic to the Western Ghats (after Bhatia and Srivastava, 2025).

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

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

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

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

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

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About authors

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

Dr Gaurav Srivastava is a Senior Scientist (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.

Fossils of India: What They Tell Us–

Highlights from BSIP collections, discoveries, and their significance

Ranveer Singh Negi

INDIA, a land of vibrant culture and diverse landscapes, is also a treasure trove of ancient history preserved in its rocks. Fossils, remnants of life from millions to billions of years ago, offer a window into Earth's distant past, revealing stories of long-lost ecosystems, climates, and creatures. From the roof of the world, the Himalayas to the arid deserts of Rajasthan, India's fossils' legacy, tell us about the evolution of life, the movement of continents, and the environmental changes that shaped our planet. At the heart of this scientific journey to the past, is the Birbal Sahni Institute of Palaeosciences (BSIP) in Lucknow, a pioneering institution dedicated to unravelling these mysteries. This article explores what Indian fossils reveal about our planet's history, spotlighting three remarkable examples, studied extensively by the BSIP, and their significance for both science and curious minds.

Fossils: Windows to the Past

Fossils are the preserved remains or traces of ancient life forms; be it organism or plant, from bones, shells, footprints, leaf impressions to even faecal matter of animals. They form when organic material is buried in sediment, slowly replaced by

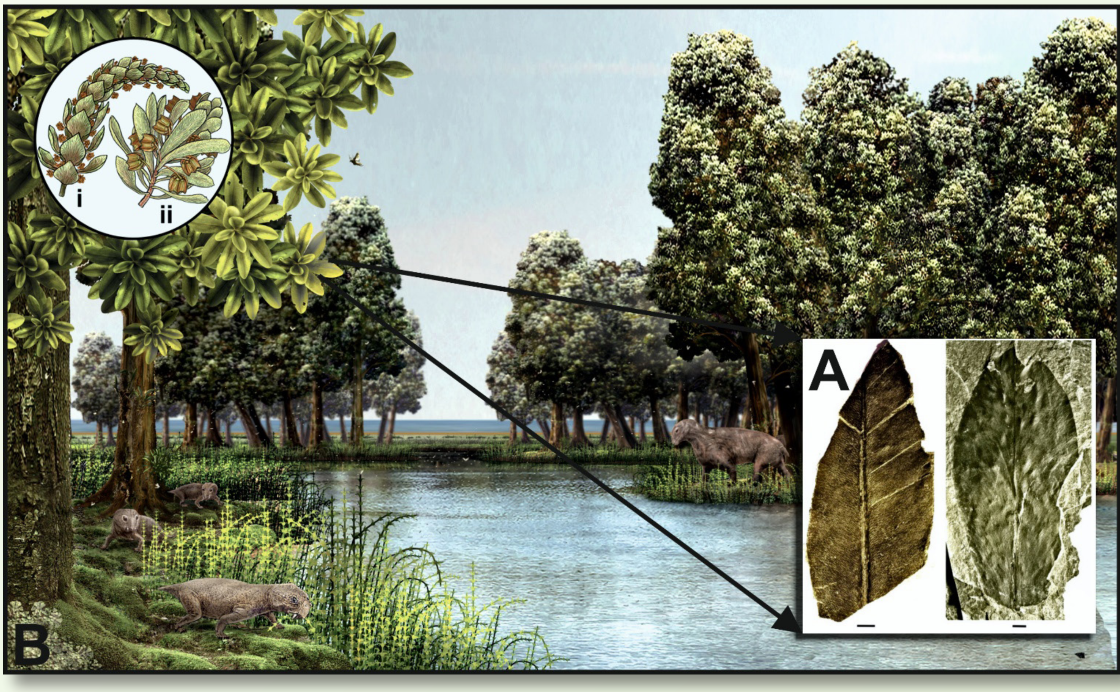

Figure 1. **A.** Fossil leaf of *Glossopteris* with a scale bar of 1 cm (Courtesy: Tewari et al., 2015); **B.** Reconstruction of a Middle Permian lakeshore palaeoenvironment featuring *Glossopteris* trees (Courtesy: Prevec et al., 2022).

minerals, or preserved in exceptional conditions like amber or tar. In India, fossils range from microscopic algae to massive dinosaurs, offering clues about life across geological eras—from the Precambrian (over 538 million years ago) to the Cenozoic (the last 66 million years).

India's unique geological history makes it a fossil hotspot. Once part of the ancient southern supercontinent Gondwana, India began to break away around 130–120 million years ago, fully separating from Madagascar by about 90 million years ago. It then embarked on the fastest continental voyage ever recorded, drifting northward at speeds up to 20 centimeters per year. After nearly 40 million years, this journey culminated in a monumental collision with the Eurasian landmass around 50 million years ago, an earth-shaping event that gave rise to the mighty Himalayas, the youngest and highest mountain range on the planet, often referred to as the "Roof of the World." This dynamic tectonic journey of nearly 40 million years has resulted in a geologically diverse landscape, and, thus, left behind a rich and varied fossil record, now preserved across multiple terrains of the Indian subcontinent. The Birbal Sahni Institute of Palaeosciences (BSIP), established in 1946, has been instrumental in studying these fossils. Through a blend of rigorous fieldwork, advanced laboratory analysis, and cutting-edge techniques, BSIP has helped decode India's prehistoric past. Its contributions—from the discovery of ancient plant life to the reconstruction of past climates—have made the institute a cornerstone of Indian palaeontology.

Glossopteris: A Fossil Leaf that Powered a Continent

One of the BSIP's landmark contributions to palaeoscience is its research on *Glossopteris*, a seed fern that thrived across the southern continents during the Permian period (299–252 million years ago) (Fig. 1). These tongue-shaped leaves are widely found in India's Gondwana coalfields, especially in the Damodar Valley, and were once part of vast, swampy forests that later formed the coal seams that power parts of India today.

BSIP's studies of *Glossopteris* helped establish a key piece of the continental drift puzzle—its identical fossils are found in India, Australia, South America, Africa, and Antarctica, offering strong evidence of the ancient Gondwana supercontinent. These fossil forests not only fueled a continent, but also connected Earth's climatic and tectonic past. To celebrate this legacy, the rooftop of BSIP's upcoming building will be shaped like a Glossopteris leaf, fitted with solar panels—symbolising both its photosynthetic past and a sustainable scientific future, where fossil heritage inspires innovation.

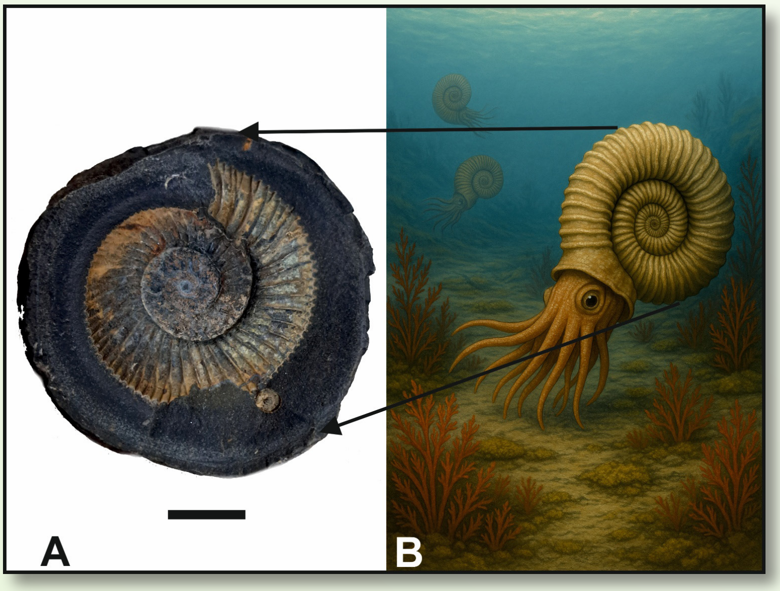

Figure 2. A. Fossilized ammonite with a scale bar of 1 cm (Courtesy: Dr Hukam Singh & Dr Ranveer Singh Negi, BSIP); **B.** Artistic reconstruction of the Tethys Sea depicting an ammonite-rich marine ecosystem (AI-generated).

Ammonites: Spinning Stone Spirals of Time

Beautifully coiled and intricately patterned, ammonites are extinct marine creatures that once thrived in the Jurassic seas over 150 million years ago (Fig. 2). Recovered from the dark shale beds of the Spiti Shale Formation in Garhwal

Himalayas, Uttarakhand, they are silent witnesses to an ancient ocean that once covered the Himalayas. Their intricate, ribbed spirals not only captivate the eye but also serve as time markers for geologists, helping decode the age and environment of the rocks they're found in. Ammonites like these reveal how India's mountains were once ocean floors, connecting our highlands today to deep-sea life of the past. Through the lens of palaeontology, they bridge time, science, and wonder.

Kakar Bhirvav: Sacred Stones from the Age of Dinosaurs

In the villages of Dhar District, Madhya Pradesh, locals have long worshipped round stone-like objects known as *Kakar Bhirvav*, revered as Kuldevta (ancestral totems) believed to protect their land and cattle. Remarkably, these sacred "ball stones" are actually fossilized dinosaur eggs, dating back over 70 million years to the Late Cretaceous Period (Fig. 3). Laid by giant herbivorous sauropods like Titanosaurs, these eggs tell us that central India was once a lush, river-fed landscape teeming with prehistoric life. Preserved in the Lameta Formation, this region holds one of Asia's richest dinosaur nesting grounds. Today, these fossils not only excite scientists, but also beautifully bridge ancient natural history with enduring local traditions. BSIP's ongoing research, including studies on associated plant fossils, continues to shed light on the ecosystems these dinosaurs once called home.

What Fossils Tell Us About India's Past

These fossils, studied by BSIP and other institutions, reveal three key stories about India's ancient history:

Continental Drift and Gondwana: The *Glossopteris* flora, among other fossil groups, confirms India's place within the ancient Gondwana

Figure 3. A. BSIP Director Prof. M.G. Thakkar with a local resident holding a fossilized dinosaur egg (stone ball) at Padlya village, Dhar District, Madhya Pradesh (Courtesy: *Times of India*); **B.** Reconstruction of long-necked herbivorous dinosaurs (sauropods) laying eggs in a natural setting (Courtesy: Getty Images).

supercontinent. Their distribution across multiple continents traces India's tectonic journey over millions of years—a process that BSIP continues to study in detail through fossil correlations and palaeogeographic mapping.

Ancient Environments: Fossils like the Jabalpur dinosaur eggs and *Glossopteris* plants paint a picture of India's past landscapes—swampy Permian forests, Cretaceous river valleys, and Cambrian seas. BSIP's research on plant microfossils and pollen has further clarified these environments, showing how climate changed as India moved north.

Evolution of Life: From trilobites to dinosaurs, India's fossils trace the evolution of life. The Cambrian trilobites mark the rise of complex animals, while dinosaur eggs show the dominance of reptiles before mammals. BSIP's work on plant and microfossils complements this, revealing how ecosystems supported such life.

Role of BSIP in Unlocking These Stories

The Birbal Sahni Institute of Palaeosciences stands at the forefront of India's fossil research. Named after its founder, Professor (Dr) Birbal Sahni, FRS, a pioneer in palaeobotany in India, BSIP combines fieldwork in regions like the Himalayas and Gondwana basins with advanced laboratory techniques, such as palynology (study of pollen and spores) and isotope analysis. Its studies on *Glossopteris* and other fossils have global impact, contributing to UNESCO's International Geoscience Programme and collaborations with institutions worldwide. BSIP offers inspiration, showing how Indian scientists lead in understanding Earth's history. India's fossils are not just rocks, but stories of a dynamic planet, preserved through dedicated research.

Challenges and Future of Fossil Research

Fossil exploration in India is no easy feat—scientists often work in extreme environments, from the high-altitude Himalayas to the scorching basins of central India. Access is further limited in remote or border areas due to security and conservation concerns. Despite these challenges, BSIP continues to make strides, using advanced tools, such as electron microscopes, Raman spectroscopy, 3D CT scanning, imaging techniques, and artificial intelligence to study fossils with greater precision. These technologies are not only enhancing research, but also making fossils accessible to the public through virtual museums and interactive platforms. The future of fossil science in India is set to be more innovative, inclusive, and engaging for all.

Why Fossils Matter to Us

Fossils are far more than remnants of the past—they are storytellers of Earth's incredible journey. From imagining dinosaurs once roaming the heart of Madhya Pradesh to envisioning ancient seas that once covered the Himalayas, these preserved traces spark awe and curiosity. They also open doors to exciting careers in palaeontology, geology, and climate science, with institutions like BSIP leading the way. Through BSIP's research, India's fossil heritage reveals how continents shifted, climates changed, and life evolved over millions of years. These ancient clues remind us that the very ground we walk on holds secrets of worlds long gone—waiting to be uncovered, understood, and shared.

About author

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Teeth vs. Bones: Tracing Ancient Lives Through Geochemical Clues

Prashant Mohan Trivedi

Introduction: Listening to Ancient Voices

DEEP beneath the layers of earth, in ancient graves and forgotten settlements, human remains silently wait to be discovered. For archaeologist studying the distant past, these remains—especially bones and teeth—are like time machines. They hold clues about how ancient people lived, what they ate, where they travelled, and even how the climate around them changed. But when both bones and teeth survive the test of time, which of the two gives us the clearest and most accurate picture of the past? This article, based on detailed scientific review, explores that very question—whether bones or teeth offer more reliable clues for reconstructing ancient diets and environmental conditions. While both have distinct advantages, the findings suggest that teeth, particularly the enamel, are better preserved and carry more precise chemical signals compared to bones.

Why Bones and Teeth Are Crucial in Palaeoscience

Palaeoscience relies on many kinds of evidence—from sediment layers and fossil pollen to invertebrate remains—to reconstruct past climates and environments. But human remains provide something more personal: biological signatures from real individuals. Both bones and teeth contain elements and isotopes absorbed during life, which can reflect a person's diet, climate exposure, and even geographical movement. Isotopes like carbon, nitrogen, oxygen, and strontium, and trace elements, such as barium and zinc, become locked into bone and tooth and can be measured to reveal these ancient life histories.

Bones: Long-Term Records, But Easily Altered

Bones are dynamic tissues. Throughout life, they constantly remodel themselves, breaking down and

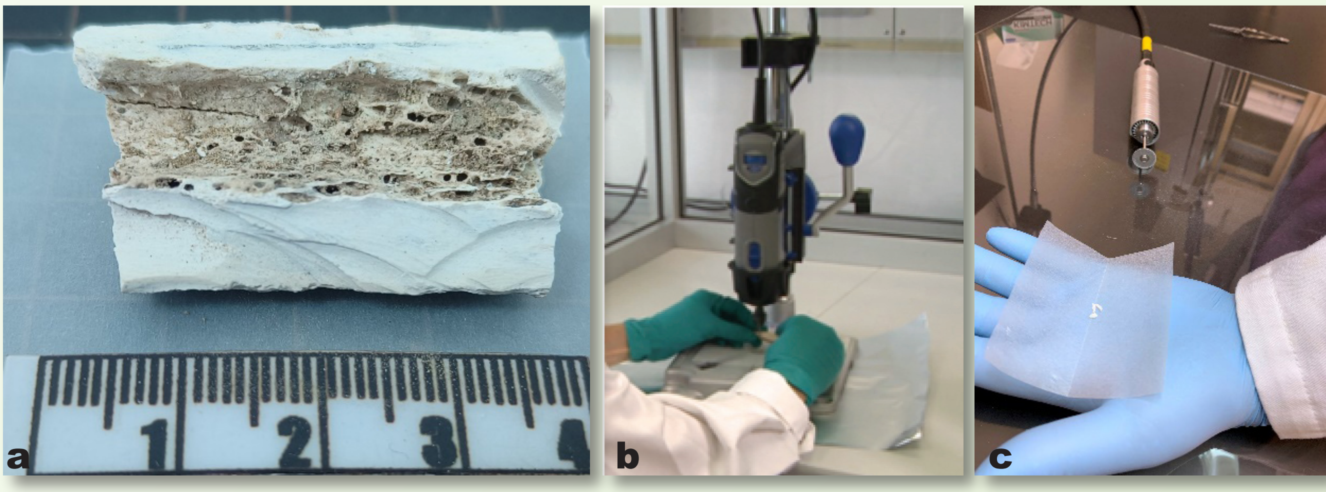


Figure 1. a. A section of human femur bone excavated from the Rakhigarhi archaeological site in Haryana, India, b. The interior of the sample was drilled to minimize surface contamination, c. Powder obtained after drilling, prepared for subsequent analysis.

rebuilding in response to stress and nutrition. Because of this, bones can provide a broader picture of an individual's lifestyle over the last 10–20 years of life. Their mineral and organic composition allows for the retention of dietary and environmental information through isotopes and trace elements. However, bones are also porous and biologically active, making them vulnerable to post-mortem changes once buried (Figs. 1, 3, 4).

After death, bones lose their natural repair mechanisms. Their porous structure allows groundwater, microbes, and soil chemistry to seep in. This causes diagenesis—a process where the original chemical structure gets altered. For example, bones in acidic soils tend to dissolve more quickly. Similarly, bones in environments with strong water flow or seasonal wetting and drying show more cracking, mineral loss, and staining. Microbial activity, particularly from fungi and bacteria, can enter through natural openings and destroy collagen and minerals from the inside out.

How Archaeologist Handle Bones for Analysis

To counteract diagenetic damage, bones must undergo careful pre-treatment before chemical analysis. These procedures include physical cleaning with scalpels or brushes, ultrasonic baths, and chemical washes using acetic acid, hydrogen peroxide, or EDTA (Ethylenediaminetetraacetic acid). These steps help remove external contaminants and preserve what remains of the original isotopic or elemental composition.

Despite these efforts, the bone's diagenetic history must always be considered when interpreting results. Collagen from bones is still widely used in isotope studies of carbon and nitrogen to infer diet, while the mineral fraction can provide oxygen and strontium signals related to climate and mobility. However, because bones remodel and are susceptible to contamination, their chemical record often represents an average of life, not a snapshot of a specific time.

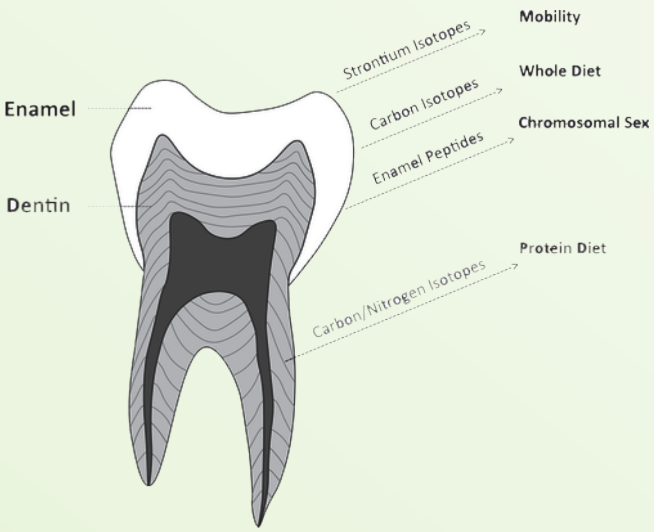


Figure 2. Types of information about a person that can be assessed using isotopic and enamel peptide analyses of the teeth (Sudron et al., 2023).

Teeth: Tiny Time Capsules of Childhood

In contrast to bone, teeth—especially the enamel—do not remodel after formation. Enamel is formed in early childhood and remains unchanged throughout life, acting as a hard, mineral-rich record of that specific developmental period. Enamel's dense crystalline structure (about 96% mineral) makes it extremely resistant to physical and chemical alterations. This gives teeth a significant advantage in preserving original biogeochemical signals, especially in burial conditions where bones may degrade or lose information. (Fig. 2)

After literature review, I found that enamel not only survives better but also maintains the original isotopic and elemental data more reliably than bone. Since enamel doesn't absorb water or allow microbial intrusion easily, it avoids many of the diagenetic problems that affect bones. Even when buried in acidic or waterlogged soils, enamel retains its chemical integrity far more often than other tissues.

Methods for Tooth Analysis

Like bones, teeth undergo pre-treatment before scientific analysis. However, due to their better preservation, tooth cleaning is often more straightforward. The outer enamel layer is gently abraded or powdered using micro-drills or milling

Figure 3. Long bone samples collected from Roopkund archaeological site (Awanish Tirkey / Shutterstock)

tools. Teeth may be sonicated and rinsed with mild acids or ethanol to remove external contamination. The resulting enamel powder is then analyzed for stable isotopes and trace elements.

Because each tooth forms at a known stage of childhood or adolescence, scientists can choose which tooth to sample based on the age window they wish to study. For example, first molars reflect early childhood, while third molars (wisdom teeth) reflect adolescence. This gives teeth a unique advantage in offering high temporal resolution, helping researchers explore early-life conditions with remarkable accuracy. Also, oxygen and strontium isotopes in enamel can reflect local climate and water sources, revealing where a person grew up. Carbon and nitrogen isotopes show what they ate as children.

The Power of Chemical Signals

Both bones and teeth offer different kinds of information through their isotopic records. Carbon isotopes differentiate between C_3 and C_4 plants, helping us identify whether people consumed crops, such as wheat and rice or millet and maize. Nitrogen isotopes reveal the trophic level of the diet—whether someone ate more plant-based food or animal protein. Oxygen isotopes help reconstruct temperature and rainfall patterns, while strontium isotopes, influenced by local geology, can tell us where a person spent their early years.

Trace elements, such as zinc and barium also play a role. Zinc levels tend to be higher in meat-eaters, while barium concentrations reflect plant-based diets. These elements integrate into bones and teeth through food and water, and their presence offers insight into health, status, and even exposure to environmental pollution. However, teeth—especially enamel—retain these chemical fingerprints with far more reliability than bones.

Comparative Insights: Who Tells the Story Better?

This article systematically compared bones and teeth in three key areas: chemical preservation, temporal resolution, and contextual reliability. In every category, teeth—particularly enamel—came out ahead. In terms of preservation, enamel's dense mineral structure makes it less affected by burial environment, pH, and microbial activity. Bones, by contrast, are vulnerable to leaching, microbial attack, and mineral replacement.

Figure 4. A skeleton found in Rakhigarhi archaeological site (Shinde et al., 2018).

When it comes to time resolution, teeth provide a clear advantage. Since they do not remodel, they preserve chemical records from the exact time they were formed. This allows researchers to pinpoint childhood diets and environmental exposures. Bones, meanwhile, are constantly being rebuilt, so their chemical signature reflects long-term averages rather than specific time periods.

Lastly, in contextual integrity, enamel offers more reliable data. Once formed, enamel does not change. Bones can absorb external elements from their burial environment, making it harder to separate original biological signals from contamination.

Conclusion: Teeth Take the Lead

In the race between bones and teeth as tools for reconstructing past environments and diets, teeth clearly take the lead. While bones are still useful—especially for understanding adult life—they are more prone to post-mortem alterations and require more careful handling. Teeth, on the other hand, act as stable, high-resolution archives of early life. Their superior preservation makes them ideal for studying childhood diet, geographic origin, and environmental adaptation.

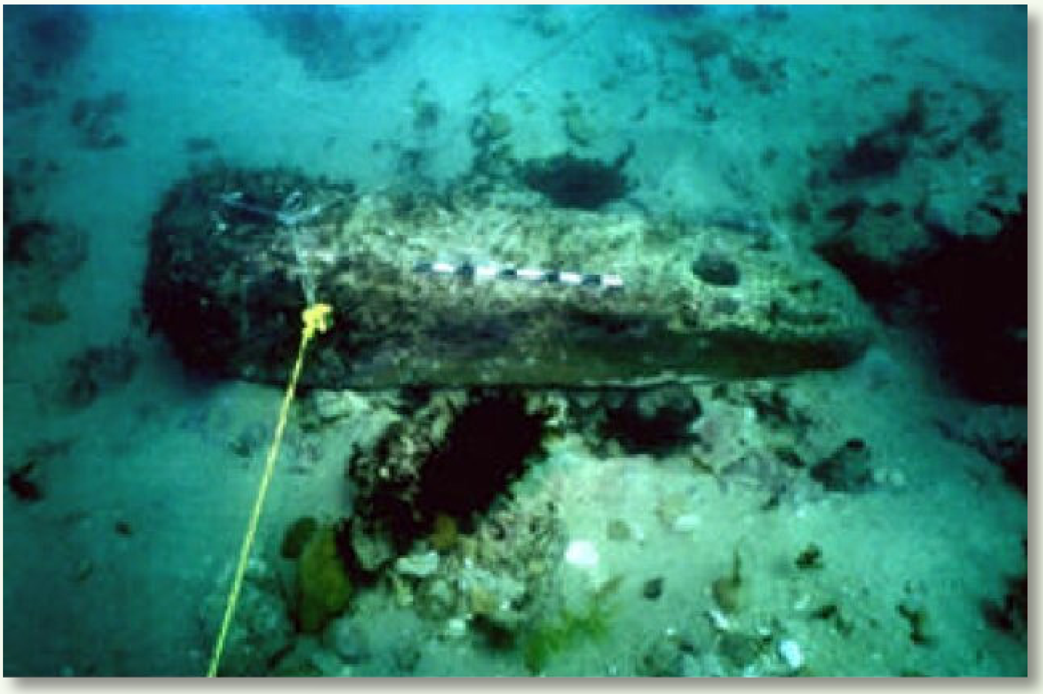
This article supports a growing consensus in the scientific community: for the most accurate and reliable data in palaeoscience, archaeological teeth—and especially enamel—are the better choice. As research continues to advance, these tiny, mineralized storytellers will remain one of our most powerful windows into the human past.

About author

Mr Prashant Mohan Trivedi is pursuing his Ph.D. at the BSIP, Lucknow. He is a geochemist whose work unravels the stories hidden within archaeological human bones through isotopic and elemental analysis.

The lost city of Lord Krishna's Dwarka exists underneath the Indian Ocean?

Prem Raj Uddandam



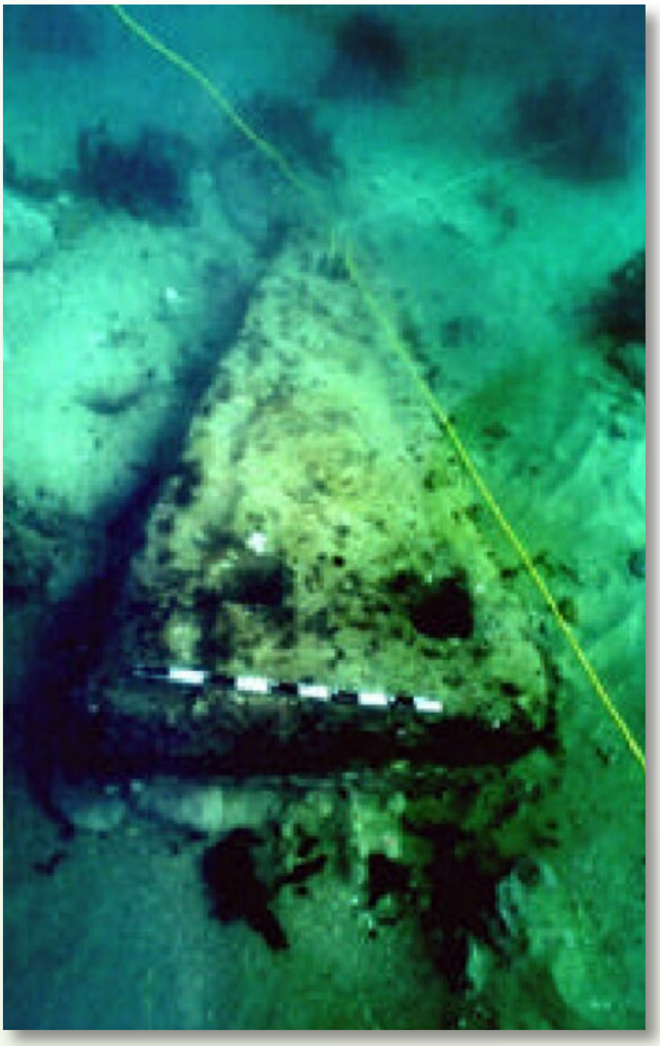
Grapnel or Indo-Arab type anchor

IN the late 1990s, archaeological excavations brought to light remains of an ancient city beneath the Indian Ocean, near Dwarka, raising the question of whether the civilizations mentioned in Hindu epics, such as the Mahabharata existed in reality. If so, were they much older than we had previously thought about the origin of civilizations in the Indian subcontinent? This also questions whether what we know about ancient civilization in the Indian subcontinent is adequate, or if we lost greater information as ancient civilizations in the coastal regions were lost due to catastrophes, such as tsunamis or rising sea levels that submerged them.

Ringstone anchors

We all know the lost Harappan Civilization was one of the oldest civilizations in India, flourishing between 3300 and 1300 BCE. Several archaeological pieces of evidence helped to unravel the history of these civilizations. Several other lost civilizations were found outside the Indian subcontinent, such as Mesopotamia, known as the "cradle of civilization," which existed between the Tigris and Euphrates rivers and saw the rise of the first cities and writing systems. Similarly, Ancient Egyptian civilization thrived along the Nile River and is famous for its pyramids, hieroglyphics, and sophisticated governance. The migration of human beings from Africa to different parts of the world and the eventual evolution of human life from nomads to early complex societies, characterized by agriculture, settled communities, and sophisticated development, led to the formation of several civilizations across the world. These societies, often centered in river valleys, developed systems of government, writing, and social structures. In the Indian subcontinent, the Indus Valley Civilization has been thought to be the oldest civilization with well-developed architecture and the discovery of evidence of a lost city underneath the Indian Ocean near Dwarka.

Dwarka, one of the most important religious and pilgrim centres for Hindus, has also attracted tourists from all over the world, primarily due to its fabulous architectural planning of the temple. The history of Dwarka is closely tied to Hindu mythology. Those who are aware of Hindu mythology could easily recollect Dwarka as the capital of Lord Krishna's kingdom. According to mythology, after fleeing from Mathura due to constant attacks by Jarasandha, Krishna migrated to Dwarka and reclaimed 12 Yojanas from the sea and ordered God Vishwakarma to build a city (Vishnu Puran). As per the Mahabharata, one of the two major Sanskrit epics of ancient India, Dwarka is described as a prosperous city with a strong fort and a large population. The city was evacuated before Krishna's descending from the world at the beginning of the Kali Yuga and submerged by the sea due to natural hazard or tsunami. Though uniform agreement is not present on whether the Dwarka of the present day and the Dwarka of the Mahabharata are the same or not. Scholars like Anant Sadashiv Altekar and D.D. Koshambi suggested that Gujarat's Dwarka had no link to the famed kingdom of Krishna. Historian D.D. Koshambi has gone to the length of suggesting that Dwarka might have been in Afghanistan, for there are places like Daravaz in Afghanistan, which means something similar to Dwarka, i.e., "many gated." In their book "Excavations at Dwarka (1969)," Z.D. Ansari and M.S. Mate say that the antiquity of Daravaz is unclear and which could not be older than the 12th century, whereas in Saurashtra itself we have several references to Dvārakā going back to the 5th-6th century AD (CE). However, books by Pulaskar and Sankalia strongly argue in favour of present-day Dwarka as Krishna's Dwarka from the Mahabharata. The earliest epigraphical reference about Dwarka came from a Palitana copper plate datable to the 6th century AD (CE).



One of the biggest composite stone anchors

Stone blocks with L-shape cut

The Archaeological Survey of India and the Marine Archaeological Division of the National Institute of Oceanography, Goa, worked extensively for more than two decades in the offshore Dwarka. SCUBA diving system has been a major source of primary data collection beneath the Arabian Sea. Extensive diving operations have been undertaken in depths ranging from the inter-tidal zone to 25 m waters in about 1 km^2 off Dwarka between 1997 and 2001. At one excavation site present between 3-4 m water depth opposite the mouth of Gomati creek, about 200 m offshore, and another site on the southern side of the transit line of Dwarkadhish and Samudranarayan temples, several structures were detected. The findings off Dwarka include structures lying underwater and stone anchors of varying sizes and types, such as triangular, prismatic, and ring stone. It was found that all the anchors are made-up of limestone. One of the grapnel anchors, which is the heaviest among the stone anchors so far found in the Dwarka area, has two rectangular holes on the lower side and an upper circular hole. In an excavation, several semicircular structures were found, and a few of them are fully scattered. The blocks of semicircular structures are L-shaped and have provision for dowels, and a few of them have cementing material, which has bound them till date. These structures have 2-3 courses with a 60-80 cm height. The average size of one block of semicircular structure is 95 X 55 X 25 cms (Gaur et al., 2005). Along with the semicircular blocks, large rectangular blocks were scattered in the same area, which are probably part of the same structure. The important findings may include a rectangular stone block bearing Gujarati script, which may not be very old.

In an expedition took in the year 2000-2001, an important finding took place: at a site in the transit line of Dwarkadhish and Samudranarayan temples, 34 stone anchors lying randomly were recorded. They are of various types and sizes. A few anchors are partially buried in sediment; however, the majority of them are lying exposed over the rocky seabed. In this location, one of the biggest triangular stone anchors has been reported from this area (estimated weight is 496 kgs), and so far, this size of anchor has not been found anywhere in India. Similarly, two grapnel anchors of 2.3 m in length have been reported from this zone, which are perhaps the heaviest anchors found in Dwarka waters. All the triangular and 13 grapnel types of anchors are made of limestone, while 2 grapnel anchors are made-up of basalt. All these structures, such as square and rectangular blocks, semicircular structures, various anchor kinds, and single-holed stone objects suggest that these could be bastions of some fortified structure of a habitational site. All these stone objects and stone anchors suggest that perhaps during the earlier period, this place was a busy port, and boats were anchored here to these anchors. It is interesting to recollect the meaning of the word Dwarka as 'entrance'. It could be possible that this place was named Dwarka as it might be a busy port, and also an entrance to India for ships coming from other countries.

A circular stone structure exposed during low tide off Dwarka

A.S. Gaur and team, based on their research and the data available from the extensive and systematic underwater search, and the absence of any pottery or artifacts, suggested that the found traces do not belong to some habitation site; they rather appear to be the remains of a jetty. The probable dating of the stone anchors is complex due to the absence of any archaeological association. In the absence of direct evidence, the age of the stone anchors has to be determined by comparing them with similar structures from elsewhere. However, the stone anchors found in Dwarka have no similarity with the earliest anchors reported from Lothal and Kuntasi, which were dated to the Harappan phase, revealing that the anchors at Dwarka are not to be associated with the Harappan or the Late Harappan Phase. A.S. Gaur and team, based on several comparisons with anchors worldwide, opined that stone anchors from the Okhamandal area may not be earlier than the historical period, but not later than the 14^{th} Century AD (CE). To achieve a firm dating, anchors will need to be found associated with other archaeological material; for instance, shipwrecks or a dated context on land.

Despite the arguments about its age, the large number of stone anchors reveals that Dwarka was a busy port and it has drawn inhabitants and sailors from the dawn of Indian civilization and has done so to this day. This may be because of the area's safe harbor, rich variety of fish and shells, and favorable climate.

About author

Dr Prem Raj Uddandam is Scientist C at the BSIP, Lucknow. His work focuses on reconstructing past climates and sea level changes by using microfossil recovered from the ocean sediments.

Coal Petrological Studies at Advanced Organic Petro-Geochemical Laboratory of the BSIP, Lucknow, and its significance

Runcie Paul Mathews, Neha Aggarwal and Divya Mishra

What is Coal?

COAL is a special type of sedimentary rock formed from ancient plants that were buried under the Earth over millions of years (Fig. 1). It has many different types, each with its own look and chemical make-up. Scientists have been studying coal for a long time to understand how it forms and where it can be found. This topic helps you learn about the different kinds of coal, how they were formed in different periods of Earth's history (like the Carboniferous, Permian, Cretaceous, and Tertiary Periods), and where major coal deposits are found around the world.

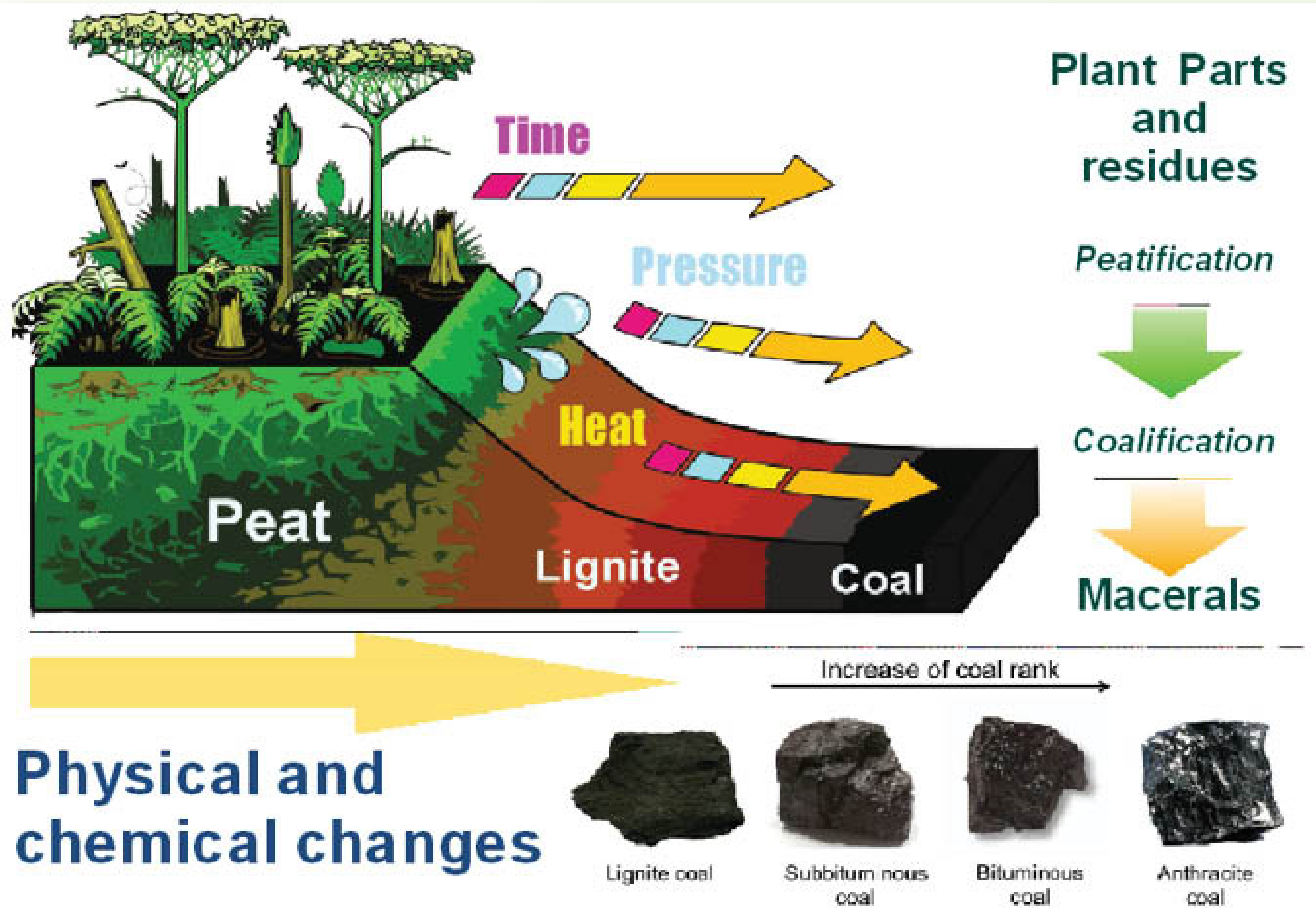


Figure 1. Diagrammatic representation of formation of coal from plant materials.

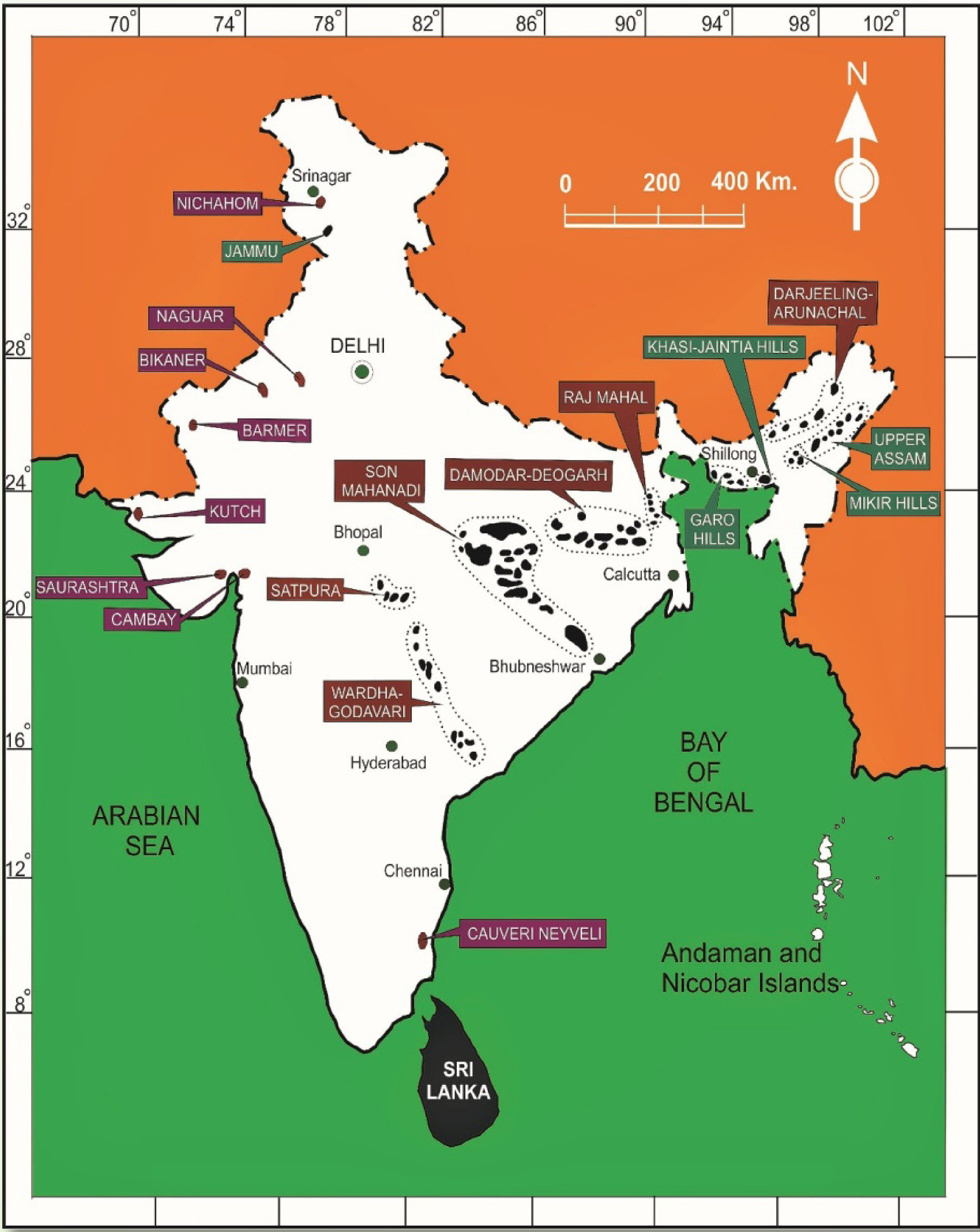


Figure 2. Distribution and coal and lignite deposits in India.

Figure 3. Photographs showing various analytical facilities at the Advanced Coal Petro-Geochemical Laboratory of the BSIP.

Classification of coal

The whole range of coal spans over a continuous quality scale often divided into two main categories, namely hard coal and brown coal. These are further divided into two sub-categories according to the physico-chemical properties as:

- Anthracite
- Bituminous coal
- Sub-bituminous coal
- Lignite
- Peat

Coal Resources and Exploration

Coal is searched in India through two main steps-regional exploration and detailed exploration. In the first step, government agencies look at large areas to find out where coal might be present. Once they find promising areas, coal companies then do more detailed studies to figure out exactly how much coal is there and where to mine. As of April 1, 2025, the Geological Survey of India (GSI), in collaboration with organizations, such as the Central Mine Planning and Design Institute (CMPDI), Singareni Collieries Company Limited (SCCL), and Mineral Exploration Corporation Limited (MECL), has estimated India's total geological coal resources at approximately 389.42 billion tonnes. This includes both coal and lignite resources, with lignite resources estimated at 47.29 billion tonnes. These lignite deposits are primarily located in states, such as Tamil Nadu, Rajasthan, and Gujarat.

Coal deposits in India

Globally, Asia is currently the main coal producing region, with China being the largest producer, followed by India, the United States, Australia, Indonesia, Russia, South Africa, Germany, and Poland. The Indian coal deposits are primarily concentrated in the Gondwana sediments (Upper Paleozoic to Mesozoic systems) located in the Eastern and Central parts of Peninsular India and also in parts of North Eastern Regions, such as Sikkim, Assam and Arunachal Pradesh. The coal is of bituminous to sub-bituminous rank and is restricted to the sediments of Permian age. Lignite deposits in India are primarily

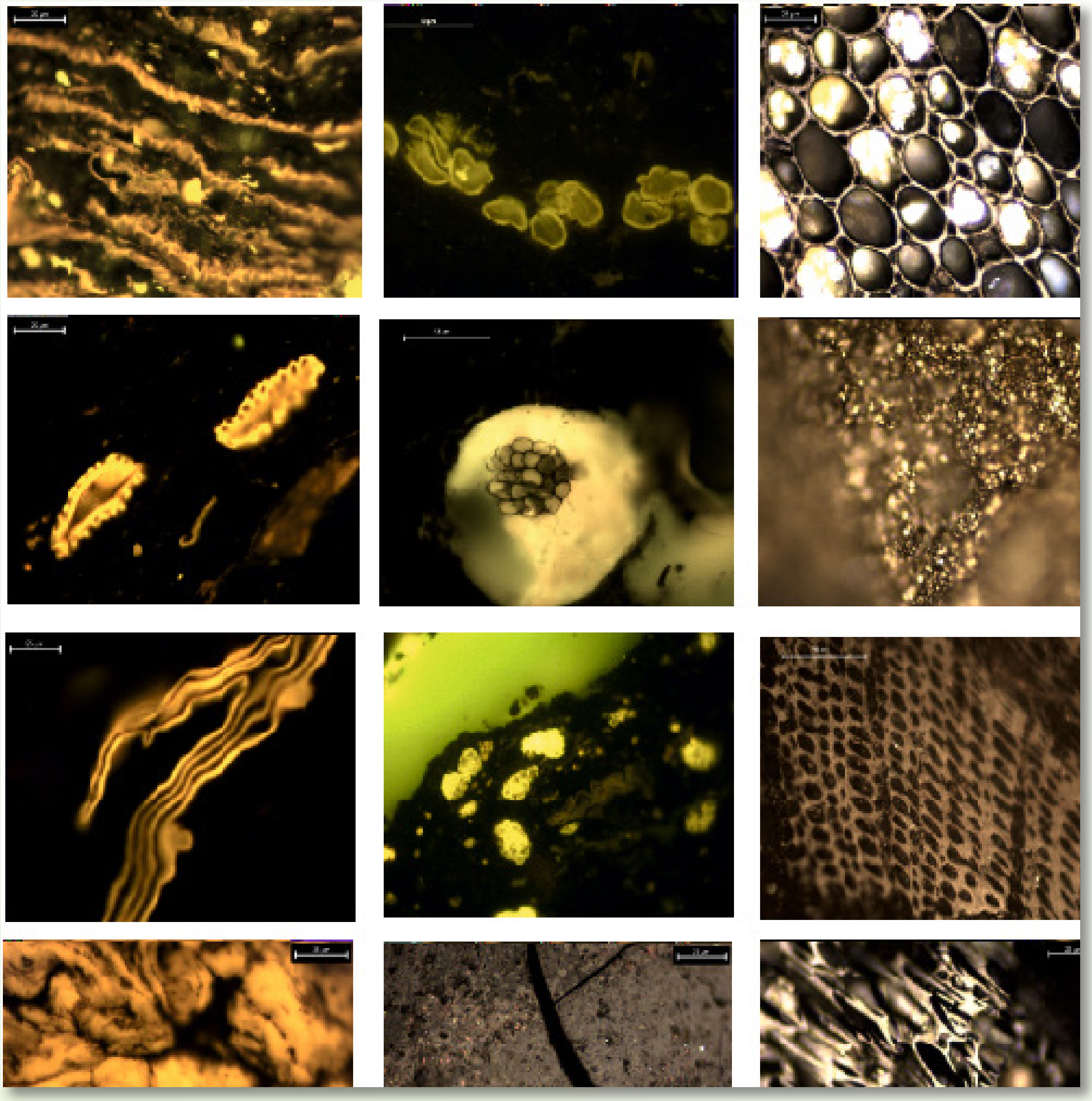


Figure 4. Photomicrographs of various macerals in a lignite sample from Rajasthan.

located in the Tertiary sediments in the Southern and Western parts of the peninsular shield, particularly in Tamil Nadu, Pondicherry, Gujarat, Rajasthan and Jammu & Kashmir. Lignite is also available in minor quantities in Odisha, Kerala and West Bengal (Fig. 2).

Advanced Organic Petro-Geochemical Laboratory at the BSIP

The Advanced Organic Petro-Geochemical Laboratory is a modern research laboratory at the Birbal Sahni institute of Palaeosciences (BSIP), where scientists study geological sculptures and its impression on the rocks that contain fossilized flora and fauna. Likewise coal, lignite, and carbon-rich shales act as fossilized fuels. These rocks are important because they can tell us how and where they were formed millions of years ago. In this lab, scientists examine what these rocks are made of, how much energy they generate on burning, and the kind of environment from where they came. This lab is helpful not only for understanding Earth's past climate and environment (palaeoenvironmental studies), but also for industries that search hydrocarbon exploration (oil and gas). The major analytical facilities include Coal Petrological Microscope with spectrophotometer, FTIR with microscope, Elemental Analyzer (CHNS-O), Thermogravimetric Analyzer (TGA), Bomb Calorimeter and allied instruments for sample preparation (Fig. 3). Researchers of the BSIP and many other institutes and universities in India use this facility for their scientific work.

Organic Petrographical study of Coal

Organic petrography includes the study of coal and its constituents under the microscope. The basic constituent of coal is called as a maceral (like mineral in rock) (Fig. 4). These macerals mainly belong to three group, such as huminite/vitrinite, liptinite and inertinite. These groups vary in microscopic characteristics, physico-chemical composition and its origin. Hence, the composition of these macerals is important in understanding the formation of coal, depositional environment and the utilization properties. Along with these macerals, coal also consists of a small amount of mineral matter which was either deposited along with the plant material or added into the coal later on by various reactions.

Recent advancement in Coal usages

The conventional practice to mine coal has become a big problem for the sustainable development of the society, therefore, in recent years, scientists have discovered new ways to use coal as a source of energy without digging it out and burning on the surface earth. These unconventional methods give birth to Coal Bed Methane (CBM), Liquefaction (UCL) Underground Coal Gasification (UCG), etc. These methods applied to remove methane gas from coal and coal mines while it is still underground, which can then be used as fuel. Another method is to convert coal into a liquid form that can be used like petrol or diesel. There is also a technique where coal is burned underground to produce gas, which can be collected and used for energy. These modern technologies are especially useful in places where traditional coal mining has stopped where coal is buried too deep to mine easily, or where mining harms the environment. These new techniques make it possible to use coal more safely and efficiently and also for the sustainable development of the country.

About authors

Dr Runcie Paul Mathews is Scientist-D at the BSIP, Lucknow. He is specialized in Organic Geochemistry and Coal Petrography. His study areas are on floristic characteristics, depositional environments, hydrocarbon source characteristics, and palaeowildfires.

Dr Neha Aggarwal is Scientist-E at the BSIP, Lucknow. She is specialized in Gondwana Palynology and palynofacies. Her study areas are on floristic characteristics, depositional environments, palaeowildfires etc.

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FIELD NOTE

Quantitative Reconstruction of Historical Vegetation Using Pollen Analysis

Understanding Paleoecology and Environmental Change

Jyoti Srivastava and Sourav Hazra

POLLEN-BASED quantitative reconstruction of past vegetation is a method used in paleoecology to determine historical landscapes and ecosystems. This technique involves examining preserved pollen grains from sediment cores to understand vegetation dynamics over extended periods. The information obtained from these studies offers insights into climate variability, ecological changes, and human influences on the environment.

Pollen grains are microscopic entities generated by seed-bearing plants for the purpose of reproduction. These grains transport the male genetic material of plants and are frequently disseminated via wind, water, or animals. Owing to their resilient outer covering, known as the exine, pollen grains exhibit significant resistance to decomposition and can remain preserved within sediment layers for extended durations. Pollen grains are species-specific, meaning they can be identified under a microscope to determine the plants present in a given area during a specific period. By analyzing the proportions of different pollen types in a sediment sample, researchers can infer the composition of past vegetation and its changes over time.

Phyla nodiflora and *Cynodon dactylon*

Observation through the quadrat method

The process involves extracting sediment cores from locations, such as lakes, peat bogs, or ocean beds. These cores serve as natural records, preserving pollen grains within distinct layers corresponding to specific time periods. Using microscopy and chemical processing, researchers identify and quantify the pollen grains found in the samples. This requires expertise in palynology, the study of pollen and spores, as well as reference collections for comparison.

Monitoring vegetation is a crucial step for the quantitative reconstruction of past landscapes, as it establishes a baseline for interpreting pollen data accurately. Precise vegetation monitoring allows researchers to improve their understanding of species distribution and ecological dynamics, which are vital for identifying the complex relationships between vegetation types and environmental factors. By comparing contemporary vegetation patterns with pollen assemblages in sediment cores, scientists can enhance model accuracy and ensure that reconstructions reflect the complexity of historical ecosystems. This integration of current vegetation studies and paleoecological data expands the scope for addressing ongoing environmental challenges and informs conservation strategies by linking past trends with future possibilities.

To translate pollen data into accurate vegetation reconstructions, researchers utilize sophisticated mathematical models including:

- Modern Analogue Technique (MAT): This method aligns pollen data with contemporary vegetation compositions.
- Weighted Averaging Partial Least Squares (WA-PLS): This model forecasts environmental variables, such as temperature and precipitation.
- REVEALS (Regional Estimates of VEgetation Abundance from Large Sites) Model: This

Community mapping

Vegetation data collection

Aerial photographs for vegetation monitoring

approach adjusts for biases in pollen representation and infers regional vegetation patterns.

Advancements in technology, including DNA analysis of ancient pollen and machine learning applications, are enhancing the precision

Post-field group photograph

of quantitative reconstructions. These innovations hold promise for dissecting even finer details of past vegetation and climate interactions.

Pollen-based quantitative reconstruction is a cornerstone of paleoecology, offering invaluable insights into the history of Earth's ecosystems. By studying the microscopic remnants of ancient vegetation, researchers are piecing together the intricate tapestry of ecological and climatic evolution, guiding our understanding of environmental resilience and change.

About authors

Dr Jyoti Srivastava is Scientist-E at Quaternary Paleoclimate Division at the BSIP, Lucknow. She works on vegetation dynamics in response to climate change over a range of timescales with a concern for human-environment interactions in past, present, and future.

Mr Sourav Hazra is a Ph.D. student working under the supervision of Dr Jyoti Srivastava at the BSIP. His work currently focuses on the reconstruction of past landcover using proxy records from Southwest India.

The Cobble Archive: Exploring Ancient Megafloods in the Upper Alaknanda Catchment

Prakash R. Jena, Rabiul H. Biswas, S. Nawaz Ali and Arbaz N. Pathan

Introduction to Quaternary floods and climate change

The Himalayas have witnessed a range of flood events during the Quaternary period, some of which were extremely destructive. Scientific studies show that large, rare floods, known as megafloods, occur roughly once every hundred years. However, the World Health Organization (WHO) reports a rise in both the frequency and intensity of floods in recent decades, a trend expected to worsen due to climate change. Shifts in atmospheric circulation, often influenced by Earth's position in its orbit, and anthropological activities are altering weather patterns. According to the 2023 IPCC report, Earth's surface temperature has risen by 1.1°C since the mid-1800s, primarily due to human activities. This warming has led to dramatic changes in global weather, including intense rainfall, floods, and heat waves.

The Himalayas are already experiencing the effects of this changing climate. The 2013 Kedarnath flood is a clear example, triggered by a cloudburst and intense rainfall in the central Himalayas. It caused massive flooding across major rivers, with water levels rising tens of meters in some areas and impacts felt as far downstream as Haridwar. Historical events like the Birehi Ganga outburst in 1871, the Chamoli flood in 1970, and the more recent Rishiganga flood in 2021, which destroyed the Raini village and Tapovan dam, show that the region is highly vulnerable to such disasters.

Motivation for the Research

What truly captures attention is how high above the river some of the cobbles and boulders are found, well beyond the reach of modern floods. How did such large clasts get deposited so far up the valley sides? How powerful were the floods that carried

them? And what can they tell us about future flood risks? To answer these questions, we aim to study the timing and intensity of past megafloods using these cobbles as geological markers. This investigation forms part of a broader palaeoflood study, where scientists reconstruct ancient floods based on the physical evidence left behind.

Team and journey overview

Our team consists of four members: Arbaz, I (Prakash), Dr Rabiul from the Indian Institute of Technology Kanpur (left to write in photograph), and Dr Nawaz (man with a hat in photograph) from the Birbal Sahni Institute of Palaeosciences, Lucknow. Along the way, we crossed Devprayag, the sacred confluence of the Bhagirathi and Alaknanda rivers. We began our journey at Srinagar (Uttarakhand), and headed northwards along the Alaknanda River till Balwan, upstream of Mana village. Srinagar, located at about 550 meters above sea level, lies in the Lesser Himalayas and marks a key spot where the Alaknanda forms its widest valley and flows in an S-shaped meander.

River Terraces at Srinagar

At Srinagar, the Alaknanda River slows down and deposits large volumes of sediment, creating wide floodplains and staircase-like landforms called river terraces. These terraces are formed by the river during intense floods, when it carries more sediment and water, followed by periods when it cuts down into the deposited material. The lowest terrace, known as T-0, is closest to the active river channel. As you move uphill, the terraces increase in number (T-1, T-2, and so on), representing older surfaces. Near Chauras, we identified four such terraces built directly over low-grade metamorphic bedrock. In places, this bedrock is well exposed, suggesting that the river hasn't changed its course significantly over time.

The fluvial section and cobble stratigraphy

We found an excellent road-cut section across terrace T-3, about 40 meters above the current riverbed, along the main highway opposite Chauras (Fig.1). This 20-meter-thick sediment profile begins with a lithified sand layer about 2 meters above road level. Above that lies a thick layer of rounded cobbles, supported by both matrix and clasts, interspersed with thin sand lenses. The cobbles are arranged horizontally and aligned in a uniform direction, evidence of high-energy river flow during deposition. In contrast, debris flow deposits are usually chaotic, with angular clasts and no specific orientation. The characteristics of this layer strongly suggest it was formed during a powerful megaflood.

Field documentation and sample collection

We documented the entire section by drawing a detailed lithology in our field notebook, this included sediment types, grain sizes, cobble shapes, layer thickness, and elevation from the riverbed. A lithology is a graphic log showing the vertical arrangement of sediment layers. We photographed the section with scale markers. To collect cobble samples, we climbed a steep 5–7-meter slope above the road. For sampling, we had to cut small footholds and create a shaded, light-free environment using a black curtain (Fig. 1). Under this setup, we carefully removed about 20 cm of surface material to collect cobbles that had not been

Figure 1. Sampling cobbles (~40m up from riverbed) from a ~20m thick fluvial deposit under dark condition (under the black cloth), opposite to Chauras (left bank of Alaknanda River) at Srinagar. Inset photo shows the complete fluvial section.

exposed to sunlight. These were sealed in black bags and labelled. We also hammered aluminium tubes into sand lenses to collect undisturbed sand samples for age dating.

Understanding how OSL dating works with cobbles

To determine when these cobbles were last deposited by floods, we use a technique called Optically Stimulated Luminescence (OSL) dating. Minerals like quartz and feldspar inside the cobbles store radiation induced luminescence signal over time due to natural radioactive decay. When exposed to sunlight, this signal is "reset" or bleached. Once buried, the signal starts accumulating again. The deeper inside the cobble, the lesser exposure to sunlight, forming a curved luminescence depth profile (LDP). The extent of bleaching and dose accumulation helps us estimate how long the cobble has been buried. In the lab, when we stimulate these cobbles with light, they emit photons proportional to the dose they've received, this gives us the time since their last exposure to sunlight, which corresponds to the timing of the flood.

Ratura, Kaleshwar, and Nandprayag fieldwork

The next morning, we reached Ratura, passing through the scenic confluence of the Mandakini and Alaknanda rivers at Rudraprayag. Here, the valley opens slightly, allowing better visibility of sediment exposures along the riverbanks, although many were hard to access. We stopped at a site on the right bank, just below the top of the T-1 terrace, and observed two major terraces: T-1 and T-2. The upper terrace (T-2) stood nearly 120 meter above the riverbed. We followed a narrow trail up to a village situated at the terrace top, where we found a well-preserved section with cobbles oriented in one direction and capped by a 2-meter-thick layer of coarse sand. We collected samples from both terraces, documenting their characteristics.

After an hour's drive, we arrived at Kaleshwar, near the confluence of the Pindar and Alaknanda rivers at Karnaprayag. Here, a prominent terrace rose about 30 meters above the riverbed. This T-1 terrace contained a 12-meter-thick sequence of cobble layers, interbedded with thin sand lenses, and a hardened sand layer at the base. We climbed 5–6 meters up a steep, loose gully of unsorted clasts to collect cobbles.

By evening, we reached Nandprayag, where the Nandakini River joins the Alaknanda. The river here flows more rapidly due to the steeper valley gradient. We found two terraces (T-1 and T-2) along the right bank. Cobbles were collected from both. We also came across a trench exposing about 2 meters of sand topped by a debris flow layer. Since the debris made cobble sampling difficult, we collected only sand samples from this site.

Geomorphological transition up the valley

As we moved from the Lesser Himalayas to the Higher Himalayas, we noticed a clear transition in the landscape. Elevation increased, river gradients steepened, and the Alaknanda's flow velocity rose significantly. Floodplain sediments became coarser,

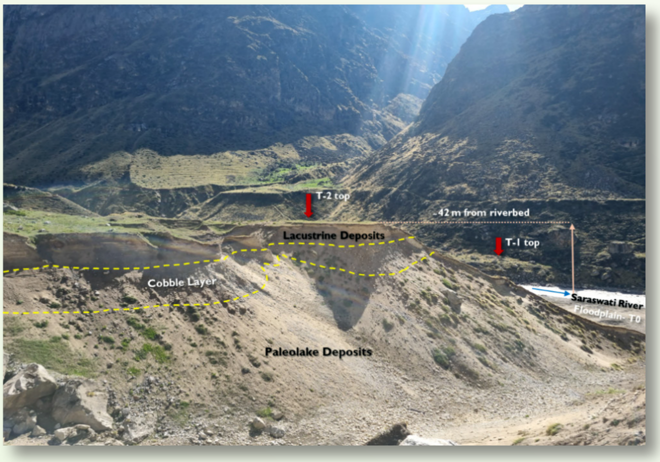


Figure 2. Fluvial section (~42 m thick) exposed in the right bank of the Saraswati River at Balwan, upstream of Mana. Well-rounded cobble layer (in between yellow dotted lines) present ~20 m above riverbed.

dominated by large boulders and cobbles. However, the river valley narrowed, and the number of terraces decreased. This shift marks a fundamental change in how floods behave, and sediments are deposited in the upper reaches of the river.

Badrinath and Balwan's observations

We began the next day under a clear sky and made our way to Badrinath, passing Helang and entering the Higher Himalayan Crystalline (HHC) zone, marked by granitic bedrock. Beyond Vishnuprayag, where the Dhauliganga meets the Alaknanda, the landscape dramatically changed, steep snow-covered peaks surrounded the valley. The Alaknanda roared with high-velocity flow, and its floodplains were strewn with boulders, cobbles, and coarse sands. Near Hanuman Chatti, we passed the Vishnuprayag Hydropower Dam, which was severely damaged during the 2013 flood.

Upon reaching Badrinath, we observed a single extensive terrace 30–40 meter thick, on both riverbanks, resting directly on bedrock. The river here flows at over 3000 meters above sea level, just 10–12 km from its glacial source in the Satopanth group of glaciers. The terrace top was almost flat and extended laterally up to the hillslope. We found well-rounded cobbles, many larger than 30 cm, aligned in one direction, with sand lenses between layers indicating fluctuating flood energy during deposition.

Fieldwork at Mana and Balwan

The next day, we headed beyond Badrinath toward Mana village, following the Saraswati River upstream toward Balwan. No active glaciers were visible below 4500 meters above sea level. The valley had a classic U-shape along the hillslopes, typical of glacial landscapes, but narrowed into a V-shape near the river, suggesting fluvial modification. On the right bank at Balwan, we discovered a remarkably well-preserved section, 40 meters thick (Fig. 2). It contained a distinct fluvial layer full of rounded cobbles (ranging from 3 cm to over >30 cm in diameter), extending over 50 meters downstream. This was sandwiched between lacustrine deposits, made up of thin alternating layers of silt, sand, and clay, evidence of an ancient lake (Fig. 3a). We documented the lithology in detail and collected samples of sand (Fig. 3b), cobbles, and organic-rich clay for dating and sediment analysis.

Field observations at Chatoli

We began descending downstream from Balwan, reaching Nandprayag by evening. The next morning,

Figure 3. (a) Top fluvial section at Balwan showing the debris flow deposit (~1m thick) from top followed by lacustrine deposits (alternate laminated sand-silt layers) and cobble layer below it. Yellow dotted line shows the contact of lake deposits and fluvially deposited cobble layer, (b) Sand samples collected in aluminum tubes from one of the sand layers in lower lake deposits.

we continued to Chatoli, a field site near Nandprayag. This was one of the most physically demanding sections we encountered. The slope was steep, and the sediments were loosely packed, making the climb both difficult and dangerous, especially under the intense daytime heat. The exposed section was nearly 50 meters high above the riverbed. The floodplain here was narrower and dominated by large boulders. We noted that bedrock was visible just 100 meters downstream, suggesting minimal lateral river migration.

Final stop at Gauchar

Our final field stop was Gauchar, located downstream of Karnaprayag. Here, the Alaknanda River valley widens slightly, and bedrock exposures are prominent above the riverbed. On the right bank, the T-1 terrace had been heavily modified due to ongoing railway construction, making it unsuitable for study. However, we identified two higher terraces, T-2 and T-3. The T-3 terrace contained a well-developed fluvial deposit about 30–40 meters above the riverbed, composed of well-rounded cobbles (mostly 3–10 cm in diameter) and three prominent interbedded sand lenses. We collected samples from both terraces. With that, our fieldwork officially concluded, celebrated with some relaxed moments and group photographs.

Our journey along the Alaknanda River, from its glacial source near Mana to the floodplains of Gauchar, reveals a striking archive of extreme flood events preserved in river terraces and sedimentary deposits. The presence of well-rounded cobbles high above the current riverbed, stratified flood sequences, and sand lenses across multiple sites point toward past megafloods of exceptional intensity, likely driven by glacial lake outbursts or abrupt climatic shifts. By applying luminescence dating techniques and detailed sediment analysis, we aim to determine when these events occurred and how powerful they were. Understanding these past flood events is crucial not only for reconstructing Himalayan palaeo-environments but also for improving modern flood risk assessment in the face of accelerating climate change. As the river carved its story into the landscape, we now carry those stories back through each sample, hoping to turn ancient chaos into modern insight.

About authors

Mr Prakash R. Jena is a PhD scholar at the Dept. of Earth Sciences at IIT Kanpur, working under the collaborative supervision of Dr Rabiul H. Biswas and Dr S. Nawaz Ali. His research focuses on reconstructing Quaternary megafloods of Alaknanda River in the Higher Himalayas.

Mr Arbaz N. Pathan, is a research scholar at the Dept. of Earth Sciences, IIT Kanpur. His research interest is to study past climate change in the Himalayan region, especially the late Quaternary evolution of glaciers in Lahul and Spiti.

Dr Rabiul H. Biswas is Assistant Professor at the Dept. of Earth Sciences, IIT Kanpur. He is a geochronologist specializing in Luminescence and ESR dating to investigate Earth surface processes across meteorites, sediments, and bedrock. He has pioneered methods including cosmic ray exposure dating, volcanic ash dating, and a TL-based feldspar thermochronometer (EPSL) to isolate climate-driven erosion.

Dr S. Nawaz Ali is Scientist 'E' at the BSIP, Lucknow. He focuses on Himalayan landscape evolution, particularly in glacial and paraglacial areas. His optical dating work has revealed LGM glaciations under monsoonal regimes, challenging existing climatic models.

Why Talk Science?

Insights from Dr C. M. Nautiyal on the Vital Role of Science Communication

Interview by Dr Nimish Kapoor

DR Chandra Mohan Nautiyal is a distinguished scientist and a passionate science communicator with a long and impactful association with the Birbal Sahni Institute of Palaeosciences (BSIP). As the Scientist-in-Charge of the Radiocarbon Laboratory at BSIP, Dr Nautiyal contributed significantly to the advancement of palaeosciences through precise dating techniques crucial for understanding history of Earth, civilisation and climate. Beyond his scientific research, post-superannuation from BSIP, he served as a consultant to the Indian National Science Academy (INSA), New Delhi, helping to shape and promote scientific literacy across the country. His unique combination of deep scientific expertise and dedication to popularizing science makes him an influential voice in fostering scientific temper and bridging the gap between researchers, policymakers, and the public.

As part of the Birbal Sahni Institute of Palaeosciences (BSIP), Science Communication for Public Engagement and Partnership Activities (SCoPE) Programme under the Media Project, a brainstorming

Dr C.M. Nautiyal delivered the keynote address at the brainstorming session on 'Popular Science Books on Palaeosciences and Audio Podcast Series' on July 11, 2025 at the BSIP.

A session on *'Popular Science Books on Palaeosciences and Audio Podcast Series'* was organised on 11th July, 2025. Dr C. M. Nautiyal (CMN) delivered a special address on the theme, setting the tone for lively discussions and exchange of ideas. On the same day, he was interviewed by Dr Nimish Kapoor (NK), who delved into Dr Nautiyal's perspectives on why talking science is not only essential for societal progress, but also critical for the advancement of scientific institutions. This insightful Q&A captures his thoughts on the urgent need for effective science communication and how scientists can meaningfully engage with both the public and decision-makers.

NK: Dr Nautiyal, you've written extensively about why it is important to talk about science. Could you share your core reasons?

CMN: Science and technology have been galloping at a pace that baffles. However, despite the deep impact on our lives, not many realise the need to keep it constantly nourished. The need to talk science to people stems from several considerations. If S&T advanced to present level, it is due to sustained efforts by generations. These efforts were supported by the taxpayers' money. This alone is an important reason to tell people what is being done with that money.

However, communicating science to people is important for several other reasons, some for their own benefit and some for the benefit of S&T.

In today's world, everyone needs knowledge of some basic science even to navigate through everyday life smoothly. To keep good health, to be able to use gadgets efficiently, to use resources optimally and tune to the rapidly changing environment, everyone is required to have some basic scientific knowledge. But as science requires reasoning, it also shapes attitude.

Prof. Mahesh G. Thakkar, Director, BSIP (center, upper photo), chaired the brainstorming session on 'Popular Science Books on Palaeosciences and Audio Podcast Series' on 11th July, 2025 at the BSIP, attended by the PIs and Co-PIs of the academic projects.

NK: You mention not just knowledge, but also attitude. Can you explain that?

CMN: Absolutely. Aside from scientific knowledge, people ought to have scientific attitude. Without that, the society can't progress. Taking science to people helps in achieving this goal.

The scientific and logical approach, however, is not limited to the practitioners of science, though it is expected that those who practice science, will naturally grow to be organized, systematic and rational.

From my research and experience, I have observed that scientific temper is as vital as knowledge of scientific facts. For society to make rational decisions, whether on health, environment, or use of technology, it needs this attitude—a habit of questioning, evaluating evidence, and avoiding superstition or irrational fears.

NK: How did the COVID-19 pandemic reinforce the importance of science communication?

CMN: Talking science to people is essential to make the society appreciate why continued support to science is important. During COVID, the number of people, including journalists, boomed who got interested in science. People began to understand bacteria and viruses and how they affect us. People practiced principles of hygiene and sanitation as never before. They followed the medical advice and maintained a healthy lifestyle.

All this became possible because scientists (including doctors) worked hard not only in the laboratories and hospitals, but also took the message to people through media and word of mouth. The experience of COVID-19 made people appreciate the value of science for human life. This wouldn't have been possible, had scientists not communicated to people.

However, public memory is short and people begin to forget the lessons. Therefore, there is strong need to maintain sustained efforts in communication.

NK: What challenges exist when communicating scientific research to the public and decision-makers?

CMN: Equally important thing is to note that those who decide funding seldom read research papers in which lot of sweat goes. Even if they did, hardly any would be able to understand them. This necessitates that the results of research and their significance should be disseminated in a form which they comprehend.

Newspapers, magazines, radio and TV in addition to social media like Facebook, X (Twitter), Blogs, websites, etc. are the available effective platforms to let the decision makers appreciate what researchers are doing.

Scientists are accustomed to write for the specialized readers—their peers. The language is, therefore, taut and full of jargon, which not many outside their area of specialization can understand. But if they want a common person to understand their work, it is different.

From my studies on science communication in India, I've seen how this 'language gap' is a real barrier. Many well-meaning researchers hesitate to step outside their scientific jargon and find it difficult to 'translate' their work for general audiences or policy makers. Overcoming this is a major challenge.

NK: How can scientists improve their communication to public audiences?

CMN: While writing (or speaking) for common people, one has to remind oneself that the public may not know even the basics. So, while conveying the gist of your research, things should be described in the terms they'd understand. Skip the fine details, except when that is where your main contribution lies. They should be given a broad picture of the field, indicating the gap you saw, and then be explained what and how you have filled in that gap. Highlight why it is important and mention how it will help the society now, or in long term.

If your research is purely academic at present, try to help them appreciate its beauty and how it enhances our understanding of nature.

A good way would be to explain your work to your spouse or parents, for instance, or some of those who know no science, or to someone else who'd give you some honest feedback. For TV and radio, available time is short. If the time duration is defined, then practice with a stopwatch, available on smart phones.

Writing for public media also enhances the communication ability of scientists and it comes handy when they face the media, the project assessment boards, or other committees, such as for awards. It becomes very important, therefore, to have an ability of communicating to them the worth of your work, whether completed, or proposed to be initiated.

NK: What platforms or outlets are available for science communication, especially in India?

CMN: There are many options in print, broadcast and social media. For Hindi write-ups, *Aavishkar* (New Delhi), *Electronikee Aapke Liye* (Bhopal), *Jal Chetna* (Roorkee), *Vaigyanik* (Mumbai), *Vigyan* (Prayagraj), *Vigyan Aapke Liye* (Ghaziabad), and *Vigyan Pragati* (New Delhi) are good magazines.

For English, there are *Science Reporter* (CSIR-NISCPR, New Delhi), *Invention Intelligence* (NRDC, New Delhi) and *Science India* (by Vigyan Bharati). Institutes also have newsletters, and many state S&T Councils publish magazines, such as *Vigyan Sampreshan* (UCoST, Dehradun). Hindi and English newspapers occasionally publish science articles and interviews too.

Television channels and YouTube platforms are also great options for disseminating science. Podcasts are an effective platform with little investment, where scientists can have informal conversations on topics of common interest like how climate changes, how monsoons started, role of Himalayas in it, or how life evolved. During natural disasters, weather-fluctuations or major events related to science also, media looks for potential communicators.

NK: Speaking in front of cameras or microphones can be intimidating. How can scientists overcome this?

CMN: Not everyone is immediately comfortable with these media. Speaking in front of a camera or on mic can scare some. But practice and preparation will help.

You may keep main points on a sheet in big letters in front, or on computer screen. For voice media like radio, you may keep a script and read it out but in a relaxed conversational manner. Avoid technical vocabulary.

For TV, looking into the lens and speaking is not easy. The *mantra* is to appear spontaneous though actually be prepared. If it is in interview form, have a good idea of possible questions and prepare accordingly. Remember, you are not compelled to reply instantly. Have a deep breath, think, and then respond.

Good visuals are a delight to watch. For visual-dominant media like TV, use them in plenty. Microscope photographs of microfossils, pollen grains, or spores can be used to generate curiosity. Who will not be thrilled to see a fossil of a banana, dinosaur egg, or huge leaf impressions, alongside micrographs of nearly invisible hair-thin structures with amazing features? Words should complement the visuals rather than repeating.

NK: How does science communication benefit the scientists themselves and their institutions?

CMN: Talking to public about our science will enhance ourselves. This is not only a duty towards the taxpayer, but also essential for the growth of our research field, as well as our institution. It also contributes towards the growth of scientifically informed citizens whose attitude with curiosity will sustain the society as a society with scientific temper.

At the BSIP, for example, we have a huge array of modern equipment beyond the imagination of those who think only of a small optical microscope for studying fossils. These instruments themselves can be talked about, highlighting their hidden potential.

The canvas for scientists here is huge. Increasing number of platforms, availability of helpful media experts at the Institute should help us reach out to people. This will not only educate people, but also enhance the images of the scientists and the Institute.

Institutions like Agharkar Research Institute have put a lot of information about their collections of fossils and other material on their website. The BSIP can also have a virtual museum, or virtual instrument-laboratory on its website

NK: Finally, what would be your message to young scientists regarding science communication?

CMN: The process of answering public questions is self-rewarding. Sometimes, the expert also gets to have new insight in own field when they ponder over them from a third person's perspective. They get an overall perspective of the significance of their research and get ideas for future direction.

Researchers at the BSIP have so many fascinating areas to choose from, be it palaeobotany explaining evolution of vegetation as continents moved or climate changed. Similarly, they can address the meeting of biology and astro-science. Topics like how earthquakes occur, how coal and oil formed, why climate changes, or stories of past changes emerging from lake sediments can fascinate the public. Everyone must gear up to act, because sustained science communication is brain-food for the society and for our own growth as scientist.

Excellent communication ability is a portable skill. It will be an asset even if after PhD someone changes his/ her field of work.

NK: We extend our sincere thanks to Dr Nautiyal for enlightening our readers on the importance of talking about science.

About Interviewer

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

Dr Swati Tripathi of BSIP, Lucknow, Selected for the Prestigious INSA Young Associate Award 2025

It is a matter of immense pride for the city of Lucknow that the Indian National Science Academy (INSA), New Delhi, has selected **Dr Swati Tripathi**, Scientist-E at the Birbal Sahni Institute of Palaeosciences (BSIP), for the INSA Young Associate (IYA) Award for the year 2025. This prestigious honor is recognition of Dr Tripathi's exceptional contributions to scientific research and her steadfast dedication to academic excellence. The INSA Young Associate Award is one of the highest recognitions conferred on promising young scientists in India, aimed at encouraging and nurturing excellence in science and technology. It is awarded to scientists working in India for their notable contributions, with special emphasis on work carried out within the country. However, significant contributions made abroad that benefit Indian science and technology are also considered. Founded in January 1935, INSA has played a pivotal role in promoting science in India and in leveraging scientific knowledge for human welfare and national development.

Mr Piyal Halder of BSIP, Lucknow, Selected as the ECS Representative of the Geochemistry, Mineralogy, Petrology and Volcanology (GMPV) Division of European Geosciences Union (EGU) for 2025-2027

Congratulations to **Mr Piyal Halder**, Ph.D. student of Dr Anupam Sharma, Scientist-G, for being selected as the ECS Representative of the Geochemistry, Mineralogy, Petrology and Volcanology (GMPV) Division of European Geosciences Union (EGU) for 2025-2027. Mr. Piyal has been one of its ECS members since 2022. He and his Co-Representative, Bartosz Puzio, will take over the charge from the present ECS Representative, Simona Gabriali, on 1st May in the Division Meeting of the EGU General Assembly, 2025. Mr. Piyal is also involved in the Communication Committee of the European Association of Geochemistry (EAG - one of the organisers of the Goldschmidt Conference) since 2024.

Invited Talk by Dr Swati Tripathi at IESD, BHU

Dr Swati Tripathi, Scientist-E at the Birbal Sahni Institute of Palaeosciences (BSIP), delivered an invited talk entitled "Palaeoclimatic signatures and dietary analysis in the Indo-Burma Region, based on pollen fingerprints" at the Institute of Environment & Sustainable Development (IESD), Banaras Hindu University, on May 9, 2025. During her visit, Dr Tripathi engaged with postgraduate and doctoral students, fostering an interactive dialogue on contemporary vegetation-climate models and their implications on proxy based past climatic fluctuations, and future forecasting. The session also addressed pressing concerns regarding the conservation of threatened faunal species in the context of ongoing climatic changes and anthropogenic pressures. The talk offered valuable insights into the role of palaeoenvironmental studies in informing sustainable development and biodiversity conservation strategies.

Invited Talk by Dr Nimish Kapoor at IUCTE, Varanasi

Dr Nimish Kapoor, Scientist and Co-coordinator, SCoPE Unit, BSIP, delivered an invited talk during the Six-Day Short Term Programme on "Developing MOOCs and Engaging Digital Content" organized by the Inter-University Centre for Teacher Education (IUCTE), Banaras Hindu University, Varanasi, on May 27, 2025.

Dr Kapoor conducted two sessions on "Script Writing and Storyboarding for Digital Content Creation" and "Visual & Data Verification and Analysis." His first session highlighted how effective script writing and structured storyboarding act as the foundation of impactful MOOCs.

In his second session, Dr Kapoor emphasized the importance of fact-checking, data accuracy, and visual verification in the digital education ecosystem. The talk offered participants practical insights into script writing, storyboarding, and data verification for digital content. Dr Nimish Kapoor's unique blend of science communication and digital pedagogy made the sessions highly engaging and relevant.

INQUA 2027

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

Coring operation at Surha Lake

Call for Authors – Palaeoscience Today

Quarterly Popular Science Magazine of 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.

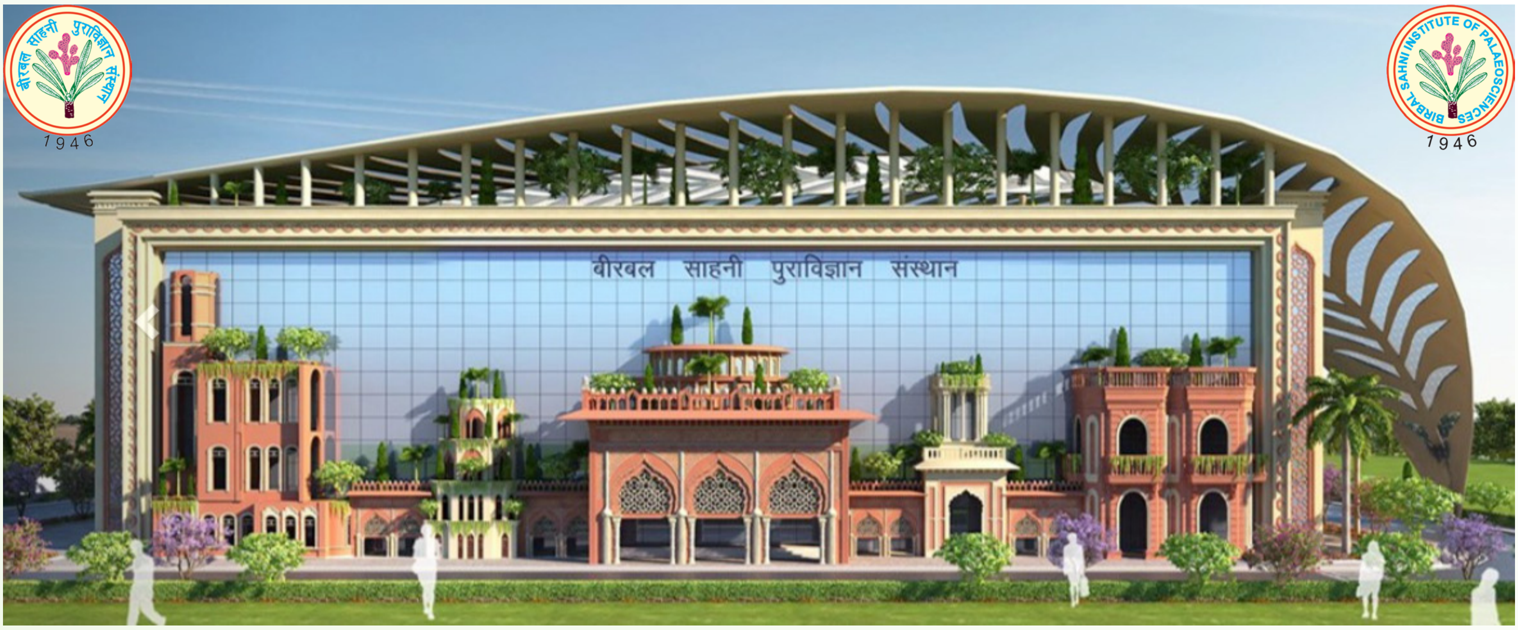
Submission Details – Where to Send Your Contribution

- **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*


B.SAHNI



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