Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 13 [12] November 2024: 09-13

Online ISSN 2277-1808
Journal's URL: http://www.bepls.com
CODEN: BEPLAD

ORIGINAL ARTICLE **OPEN ACCESS**

Fossil Plant Leaves of the Early Eocene Kapurdi Formation, Rajasthan: Evidence for Tropical Evergreen Vegetation and Climate Implications

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ABSTRACT
The discovery of angiospermous fossil leaves in the Kapurdi Formation of the Barmer Basin, Rajasthan, has significantlycontributedtotheunderstandingofpalaeoclimateandpalaeoecology during the Early Eocene epoch (~55 Ma). This study presents systematic descriptions of dicotyledonous fossil leaves found in Fuller's Earth beds and explores their implications for environmental conditions, monsoonal evolution, and biogeographic history of the Indian subcontinent during its tectonic journey from Gondwana to Asia.
Keywords–*Plant fossil, Kapurdi formation, Eocene, Fuller's earth.*

Received: 04. 10.2024 Revised: 26.10.2024 Accepted: 30.11.2024

INTRODUCTION

The emergence of angiospermous fossil flora in India is generally traced back to the Late Cretaceous period, approximately 70–60 million years ago, within the context of the Lameta Formation and Deccan Intertrappean Series in Madhya Pradesh. A wide range of plant fossils— including stems, roots, leaves, fruits, seeds, flowers, pollen, and spores—has been discovered from multiple sites in the Deccan Intertrappean beds across Betul, Seoni, Mandla, and Chhindwara districts of Madhya Pradesh, as well as Nagpur and Yavatmal in Maharashtra [1]. Most of these fossils are petrified specimens; however, a limited number of leaf impressions have also been recorded [2-10]. In addition, petrified leaf remains from the same region have been described in other studies as well [2, 7, 10].

Palynological evidence from the Late Palaeocene to Early Eocene sediments of Rajasthan has been documented in several works [15-18]. Geological surveys and analyses of the Barmer district are available in previously published reports [19, 20]. Faunal investigations further suggest that the Akli Formation dates to the Late Palaeocene–Early Eocene, while the Kapurdi Formation is assigned an Early Eocene age [21-23].The present study focuses on the paly no flora found in the Fuller's Earth deposits of the Kapurdi Formation and aims to interpret the depositional environment and geological age of this sedimentary unit.

MATERIAL AND METHODS

Fossiliferous samples were systematically collected from the Fuller's Earth beds of the Kapurdi Formation, exposed at the Hazi Thaku Kha and Jagdish Khatri mines in the Bhadkha area of Barmer District, Rajasthan (Fig. 1 and Fig. 2). Leaf fossils were extracted carefully using geological hammers and chisels, and the stratigraphic context and GPS coordinates were recorded. Inthelaboratory, specimens were cleaned with a soft brush and water to removead hering matrix, then photographed using a Nikon DSLR camera under diffused lighting to enhance visibility of key morphological features such as midrib, venation, margin, apex, and base (Pl. 1, Pl. 2). Leaf architecture was described using standard palaeobotanical terminology, focusing on shape, size, apex, base, margin type, venation pattern, and petiole structure following established leaf architecture classification systems [24, 25]. Taxonomic identification was carried out by comparing fossil leaves to published fossil floras and modern analogues using the Nearest Living Relative (NLR) approach [26, 27]. Although the Climate Leaf Analysis Multivariate Program (CLAMP) method was not applied quantitatively, qualitative assessment of leaf physiognomy supported palaeoclimatic interpretations consistent with tropical humid conditions during the Early Eocene [28].

In addition, palynological data from near by boreholes (MK327andMK332) previously, Studied by Tripathi and colleagues were reviewed to support vegetation and climate interpretations based on pollen assemblages including *Spinizonocolpites*, *Retiverrumonosulcites*, and *Acanthotricolpites* [29]. These taxa, along with the presence of *Cocos nucifera*, suggest a coastal tropical ever green forest type under high rainfall and warm climate regimes, further substantiated by comparative palaeobotanical and palaeo-environmental research across Rajasthan and western India [30].

Systematic Paleontology

Kingdom: Plantae, Linnaeus, 1753 [31] Class: Angiosperm, Linnaeus,1753 [32] Group: Dicotyledons, Ray, 1656 [33].

DESCRIPTION

The plant leaf fossils are well preserved in Fuller's Earth bed at Kapurdi area. Leaf structure is clearly distinct, outer margin well preserved, Midrib in strait line, veins are arranged in articulate form, apex is slightly pointed and medium in size (Pl. 1 and Pl. 2).

Horizon: Kapurdi Formation (Fig.2).

Locality: Hazi thaku kha and Jagdish khatri Fuller's Earth mine, Bhadkha district, Barmer (Fig. 1).

Age*:* Early Eocene.

Material: Three well preserved leaf (Pl.1andPl.2)

Fig. 1 location map of Study area.

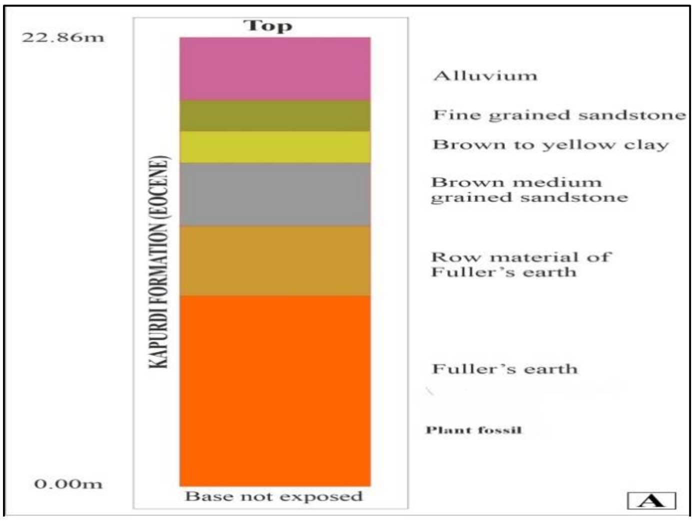

Fig. 2 Stratigraphic section of Kapurdi Formation.

RESULT AND DISCUSSION

The palynological assemblages recovered from Upper Palaeocene to Lower Eocene borehole samples drilled near Jalipa and Kapurdi in Barmer District, Rajasthan, exhibit close similarity to the Bhadkha Fuller's Earth assemblage [18, 19]. These assemblages contain shared taxa such as *Kapurdipollenites*, *Retiverrumonosulcites*, *Acanthotricolpites*, and *Spinizonocolpites* species [18]. Additionally, Zone A palynological assemblages identified from subsurface sequences of other boreholes (MK 327 and MK 332) drilled near Kapurdi also bear strong resemblance to the Bhadkha palynoflora assemblage [20].

Angiosperm leaf architecture was analyzed using the systematic approaches developed by Dilcher [20] and Hickey [21], facilitating reliable taxonomic placement and palaeo-environmental interpretation. Furthermore, climate inferences were drawn using methodologies such as the Coexistence Approach [33] and leaf physiognomic analyses [19, 17], allowing reconstruction of past terrestrial climates. These techniques have been successfully applied in palaeobotanical studies of Eocene formations in western India [34, 30].

The origin and diversification of tropical rainforests are thought to have occurred during the Late Cretaceous to early Paleogene, heavily influenced by plate tectonic processes [35]. This evolutionary trend is clearly evidenced by fossil records from western India, as fossils serve as direct indicators of both past life and environmental conditions. Traditionally, Cenozoic palaeobotanical research and the interpretation of climate change through floristic transitions have operated on the assumption of a relatively stable relationship between taxa and climate. In the present study, we examine the dynamics of plant leaves and *Cocos* remains around ~55 million years ago (Ma) to shed light on the evolutionary and biogeographic patterns of early Cenozoic flora in the Indian subcontinent.

During the early Eocene, the western region of the Indian subcontinent was positioned near the equator, experiencing persistently humid (everwet) climatic conditions [36]. The Nearest Living Relatives (NLRs) identified from the Kapurdi Formation in the Barmer Basinare.

Predominantly ever green species, including several taxa that currently in habit coastal ecosystems. This suggests that tropical ever green and littoral forests flourished in the region during the period of sediment deposition [37].

In contrast, both sedimentological and morphological data from leaf fossils recovered from the early Eocene Gurha lignite mine (Bikaner) point toward a strong seasonality in rainfall. This seasonal precipitation pattern is interpreted as an early form of monsoon climate [26], although it differed significantly from the modern South Asian monsoon [30, 33]. According to Spicer [34], at low paleo attitudes (less than 10°), seasonality was primarily controlled by latitudinal shifts in the Intertropical Convergence Zone (ITCZ), rather than by orographically intensified circulation. Hence, as the Indian plate crossed the equator, it experienced ITCZ-driven seasonal variations, with no evidence of modern-style monsoonal systems.

Surprisingly, different stratigraphic layers from the Gurha lignite deposit reveal signs of a cooler thermal regime [32], a deviation from what would typically be expected in a near-equatorial setting during a globally warm (‘hothouse’) phase. Additionally, the occurrence of highly diverse angiosperm leaves across all four palyno zones of the Gurha lignite deposit indicates the presence of rich tropical vegetation, likely near coastal zones, frequently impacted by wildfires under a markedly seasonal climate [37].

Fossil plants from the Barmer Basin also reinforce the presence of a tropical humid environment in the early Eocene. The assemblage includes many evergreen taxa, such as *Cocos nucifera*, a classic coastal species, further confirming the existence of near shore, tropical climatic conditions during this time. These palaeobotanical records from early Eocene India offer vital insights into the development of the South Asian Monsoon (SAM), a major component of both regional precipitation patterns and the global atmospheric circulation system. Recent hypotheses propose that the SAM may have emerged when India shifted from the Southern Hemisphere in the Paleocene into the Northern Hemisphere during the Eocene [36].

This tectonic movement, accompanied by changes in land-sea distribution, up lift of the Himalayas and the Tibetan Plateau, and the initiation or intensification of the Asian monsoon system, led to substantial transformations in regional climate and vegetation. Such climatic transitions are reflected in the dramatic change from the tropical evergreen forests of the early Eocene to the current semi-arid to arid conditions of western India.

Onageologi caltimes cale, these palaeo-biogeographic developments have significantly in fluence biodiversity patterns. The establishment of dispersal routes not only facilitated biotic exchange but also likely stimulated species diversification. As it migrated northward across the equator, the Indian plate functioned as a ‘bioticferry’, transporting Gondwanan and other continental biota in to Asia. The most intense phase of faunal exchange between India and Asia occurred between 50 and 35Ma, followed by a decline in faunal migration into India, possibly due to competitive exclusion by biota already adapted to the region's hot and humid conditions [37].

Plate 1 Field photograph Showing the close-up view of plant leaf.

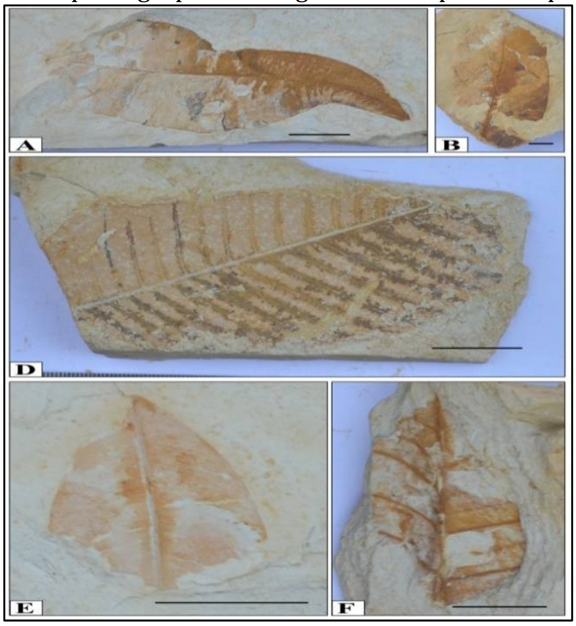

Plate 2 Photograph Showing the plant fossils represents angiosperm leaves with clearly distinct midrib and reticulated form of veins (From A-F) (scale bar – 1 cm).

CONCLUSION

A palynological analysis was conducted on subsurface samples collected from four well sections drilled near Kapurdi in the Barmer District of Rajasthan. The documented paly no flora is abundant and diverse, comprising angiosperm leaves and fruits, showing strong similarity to those found in Paleocene-Eocene deposits of both Kutch and Rajasthan. The majority of the identified paly no taxa are currently restricted to tropical and subtropical regions. The high presence of angiosperm leaves and Cocos fruits suggests that the area surrounding the sediment deposition site experienced substantial rainfall. Additionally, it is inferred that the sediments were laid down in a coastal environment.

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CITATION OF THIS ARTICLE

S. L Nama and Anjali Rathore. Fossil Plant Leaves of the Early Eocene Kapurdi Formation, Rajasthan: Evidence for Tropical Evergreen Vegetation and Climate Implications. Bull. Env. Pharmacol. Life Sci., Vol 13 [12] November 2024: 09-13