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# A new species of Indian kino tree from the Early Eocene forests of northwestern India

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**Two impressed leaflet remains described here as a new species *Pterocarpus emarginaticus* Patel, Rana and Khan sp. nov., showing close resemblance with the extant leaflets of *Pterocarpus marsupium* Roxb. (Fabaceae), commonly known as the Indian kino tree, have been recorded from the Early Cenozoic sedimentary sequences of the Gurha opencast lignite mine (Early Eocene, Palana Formation), Rajasthan, northwestern India. The diagnostic macromorphological characteristics of the fossil leaflets are elliptical to obovate shape, microphyll size, acute base, characteristic emarginate apex, pulvinate petiolule, entire margin, *brochidodromous* secondary veins, presence of thin intersecondary veins and reticulate tertiary veins. This is reliable fossil evidence of leaflets similar to modern *P. marsupium* from India and abroad. The occurrence of this species and the earlier reported angiosperm, including Fabaceae taxa from the same formation, suggest the existence of a tropical, warm and humid climate during deposition.**

**Keywords:** Fossil leaflets, opencast mine, *Pterocarpus emarginaticus*, *Pterocarpus marsupium*, sedimentary sequences.

PTEROCARPUS Jacq. is a pantropical tree belonging to the family Fabaceae, subfamily Papilionoideae and tribe Dalbergieae[1,2]. The genus is subdivided into two groups based on

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winged versus unwinged fruits. Polhill and Raven[3] placed *Pterocarpus* in the tribe Dalbergieae, while Lavin *et al*.[1] placed this taxon in the *Pterocarpus* clade, together with majority of the genera in Dalbergieae sensu Polhill. *Pterocarpus*, comprising 41 species, commonly grows in tropical lowland evergreen rainforests to seasonally dry forests, its native range includes the tropics and subtropics[4]. *Pterocarpus marsupium* Roxb. is well known for its excellent timber and bark with medicinal properties in peninsular India[5]. Unfortunately, it is now placed in the Red Data Book ('Near Threatened' category).

Among the fossiliferous localities of northwestern India, the Gurha opencast lignite mine in Rajasthan is a significant fossiliferous site for angiosperm plant remains[6–14]. Although Fabaceae is the second largest and most important angiosperm family in the tropical deciduous forests of Rajasthan[15], only two legume megafossils have been reported to date[7]. Here, we report and describe *Pterocarpus emarginaticus* Patel, Rana and Khan sp. nov. leaflet specimens (having an affinity with the modern leaflets of the Indian kino tree species, *P. marsupium*) collected from the early Eocene sedimentary sequences (Palana Formation) of Rajasthan and consider its palaeoclimatic significance. This study adds more information to the fossil history of Fabaceae during the Indian Cenozoic.

Two fossil leaflets were recovered by handpicking from a thin, laminated, maroon shale of the Gurha opencast lignite mine (lat. 27°52′25.91″N, long. 72°52′10.48″E) located 70 km southwest of Bikaner and 16 km northwest of Shree Kolayat Ji, Rajasthan (Figure 1). The lignite-bearing subsequence of the mine belongs to the Palana Formation, characterized by the association of ash bed at the base followed by lignite, carbonaceous shale, variegated clay and maroon shale (Figure 1)[13,16]. The palynological evidence assigns an Early Eocene age (~55–52 Ma) to the Palana Formation[17].

Photographs showing detailed physiognomic characters of impressed leaflets and their comparable modern taxa were taken using a camera (Nikon D 5500 DSLR) and a microscope (Olympus digital micro pad 777), and edited using CorelDraw X7 (Figure 2 *a*–*i*). The terminologies adopted by Dilcher[18] were followed for describing the studied leaflets. Specimens are deposited at the Vertebrate Paleontology Laboratory, Department of Geology, H. N. B. Garhwal University, Srinagar, Uttarakhand, India.

*Systematic description*

Order: Fabales Bromhead
Family: Fabaceae Lindl.
Subfamily: Papilionoideae DC.
Tribe: Dalbergieae (DC.) Cardoso *et al.*
Genus: *Pterocarpus* Jacq.
*Pterocarpus emarginaticus* Patel, Rana and Khan sp. nov. (Figure 2 *a*).
Etymology: The specific epithet '*emarginaticus*' is given for the emarginate apex of the recovered fossil leaflet specimens.
Holotype: GU/R/B/G/6028A (Figure 2 *a*)
Paratype: GU/R/B/G/6028B (Figure 2 *b*)
Type locality: Laminate maroon shale bed of Gurha opencast lignite mine, Bikaner (lat. 27°52′25.91″N, long. 72°52′10.48″E), Rajasthan, northwestern India.
Type horizon and age: Palana Formation (Early Eocene).
Specific diagnosis: Leaflets nearly asymmetrical, microphyll, elliptical to obovate; apex emarginate; acute base; petiolule long and stout; margin entire; pulvinus distinct on petiolule of leaflet; secondary veins brochidodromus having characteristic loops towards the leaflet margin; intersecondaries thin; random reticulate tertiary veins.
Description: Leaflets simple, nearly asymmetrical, well-preserved, microphyll in size, preserved length about 24.80 mm and width 15.54 mm; elliptical to obovate in shape; apex emarginate having a shallow broad distinct notch at the tip (Figure 2 *a*, *b* and *d*); base acute (Figure 2 *a*, *b* and *f* ); coriaceous in texture; margin entire (Figure 2 *a* and *b*), leaflet petiolule (Figure 2 *a*, *b* and *f* ) well distinct, long, stout, slender, glabrous and 13.97 mm in length; pulvinate, attachment of petiolule is marginal; prominent pulvinus (Figure 2 *a* and *f* ) present at the base of the leaflet petiolule, pulvinus smooth, 0.6 cm in length and 0.6 wide; primary vein prominent, moderate in thickness, solid, straight and thick at the base and gradually thinning near the leaflet apex (Figure 2 *a* and *b*); venation pinnate; secondary veins thin, seemingly 10–12 pairs visible with an angle

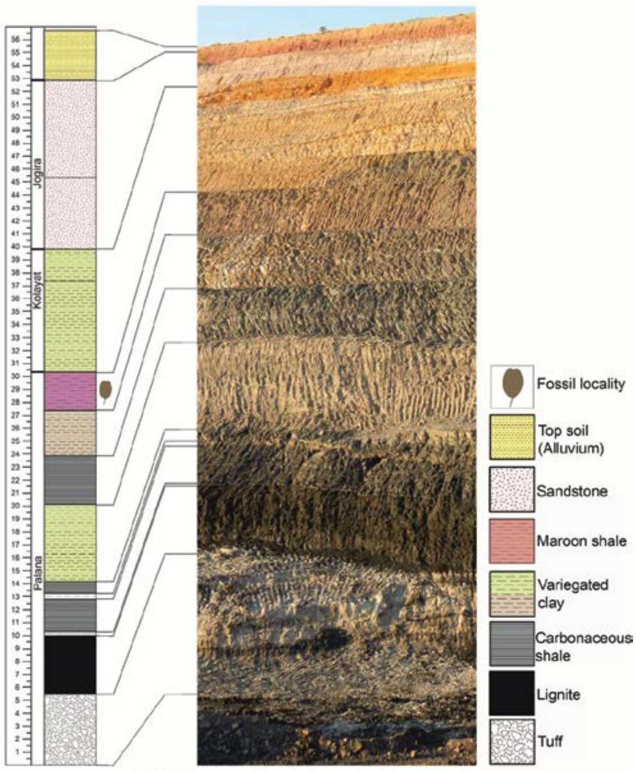


**Figure 1.** Stratigraphy and sedimentological lithology of the section exposed in the Gurha opencast lignite mine near Bikaner, western Rajasthan, India.

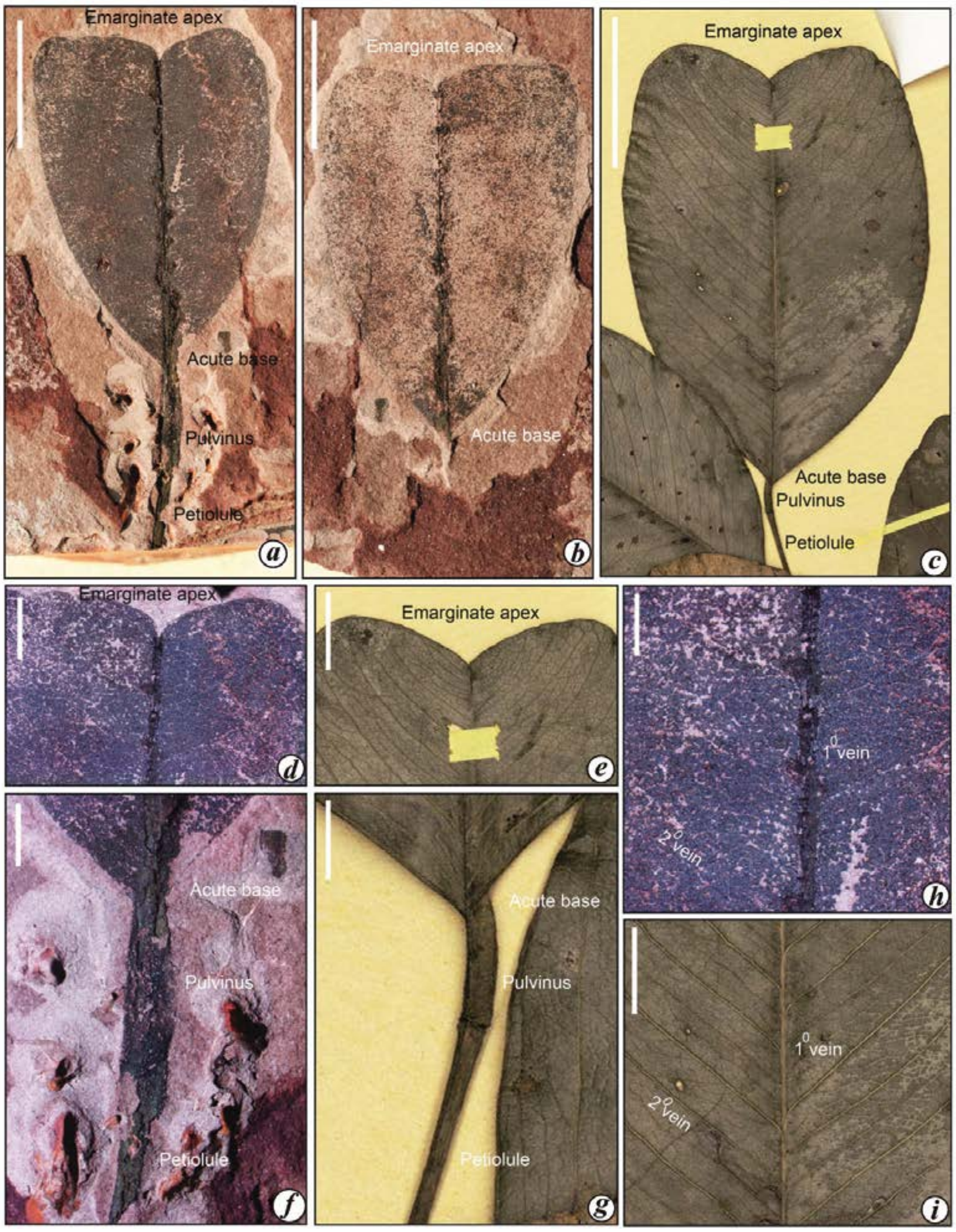


**Figure 2.** *Pterocarpus emarginaticus* Patel, Rana and Khan sp. nov. and *Pterocarpus marsupium*. ***a***, ***b***, Fossil leaflets of *P. emarginaticus* (scale bar = 1 cm); ***c***, modern leaflet of *P. marsupium* (scale bar = 1 cm); ***d***, enlarged portion of the apex of *P. emarginaticus* (scale bar = 2 mm); ***e***, enlarged portion of the apex of *P. marsupium* (scale bar = 2 mm); ***f***, enlarged portion of the basal part of *P. emarginaticus* (scale bar = 2 mm); ***g***, enlarged portion of the basal part of *P. marsupium* (scale bar = 2 mm); ***h***, enlarged portion of the fossil leaflet (scale bar = 2 mm); ***i***, enlarged portion of the modern leaflet (scale bar = 2 mm).

uniformly curved up, prominent, ascending, irregularly spaced, alternate to sub-opposite, mostly alternate branched (Figure 2 *a* and *h*), brochiodromous, arching loops formed near the margin, angle of divergence of secondary veins moderately acute; intersecondary veins thin (Figure 2 *h*); tertiary veins prominent, more likely random reticulate (Figure 2 *i*), most tertiary veins branching from the secondary veins and looping to nearby tertiary veins; quaternary veins very faint and alternate.

The most distinctive macromorphological features such as microphyll size, emarginate apex, acute base, entire margin, long, stout petiolule, brochidodromous nature of the secondary veins, presence of intersecondary veins and the randomly reticulate tertiary veins of the Eocene specimens indicate their similarity with the extant leaflets of Fabaceae. Additionally, the presence of well-preserved pulvinus at the base of the leaflet petiolule strongly indicates their affinity with this dicot family. To determine the exact similarity of the recovered Eocene specimens, extant leaflets/leaves of several angiosperms having a prominent emarginate apex were critically examined (due to morphological variability of leaves/leaflets, we examined more than 15 of them for each taxon). It was found that nine species, viz. *Pterocarpus marsupium* Roxb., *Cassia roxburghii* DC., *Dalbergia paniculata* Roxb., *Indigofera monieriana* Pignal & Queiroz, *Afzelia quanzensis* Welw., *Bauhinia purpurea* L. (Fabaceae), *Searsia glauca* (Thunb.) Moffett (Anacardiaceae), *Eucalyptus camphora* Baker (Myrtaceae) and *Sapindus emarginatus* Vahl (Sapindaceae) were similar to the fossil specimens. The fossil leaflet specimens could be distinguished from *B. purpurea* by the typical elliptical–obovate-shaped lamina and pinnate brochidodromous venation. However, *B. purpurea* has a bilobate-shaped lamina and a campylodromous type of secondary venation. *D. paniculata* and *C. roxburghii* can be distinguished by the presence of an asymmetric base in contrast to the acute base of the fossil specimens. *E. camphora* differed in having a tapering base and the absence of pulvinus. *S. emarginatus*, *I. monieriana*, *A. quanzensis* and *S. emarginatus* differed in having a short petiolule (less than 5 mm), while the fossil specimens had a well-developed long petiolule (13.97 mm). Based on leaflet macromorphology (size, apex, base and venation pattern), *P. marsupium* (herbarium sheet number P00074941) showed the closest similarity to the Eocene specimens (Figure 2 *c*, *e*, *g* and *i*). However, the fossil specimens were different from the leaflets of *Pterocarpus marsupium* and had nearly asymmetrical lamina, while *P. marsupium* had a symmetrical lamina.

**Figure 3.** Reconstruction of *P. marsupium* twig with attached leaflets based on external morphological features of both fossil specimens and closest extant taxon.

The fossil specimens reported in this study were distinct from the earlier reported two fossil species of *Pterocarpus*. *Pterocarpus eocenicus* reported by Ambwani[19] from the Palaeocene sediments of Meghalaya, North East India, had eucamptodromous venation compared to brochidodromus venation in the present fossil leaflets. Additionally, the latter differed from *P. eocenicus* in having a characteristic pulvinus at the base of the petiolule. On the other hand, *P. ovatus* described by Awasthi and Lakhanpal[20] from the latest Neogene (Pliocene) sediments of Bihar, India, differed in having an acute apex and obtuse base. However, the Eocene specimens had a characteristic emarginate apex and acute base. Here we describe them under the specific name, *P. emarginaticus* Patel, Rana and Khan sp. nov. We have also reconstructed the disarticulated vegetative (leaflet) parts of the fossil specimens to determine which extant species were most similar to the Eocene fossil specimens reported here (Figure 3).

Extant *P. marsupium*, the nearest living relative of the Eocene specimens, is a deciduous tree growing at elevations from 200 to 500 m (refs 21, 22). It prefers a pH between 6 and 7, an open sunny location and well-drained soil. This taxon is native to southern and eastern Asia and is found in moist or dry mixed deciduous tropical forests[22]. It is worth noting that *P. marsupium* is now growing in or near the fossil locality[15]. Due to ideal climatic conditions, it is now flourishing in other parts of India, including the north-western region.

The occurrence of fossil leaflets similar to *P. marsupium* from early Eocene sedimentary strata of Rajasthan, along with other Fabaceous taxa (*Saraca asoca* and *Cajanus crassus*) from the same formation[7], provides important evidence for the evolution of the legume family since the Palaeogene. *P. marsupium* is found mainly in lowland tropical areas under a warm and humid climate with a mean annual temperature from 22°C to 34°C and mean annual precipitation from 1000 to 2500 mm (ref. 22). So, the recovery of this Eocene species and the previously reported plant mega and microfossil assemblage[6–14,23] from the same fossil locality indicate the survival of tropical, warm and humid climatic conditions in the ancient forests of Rajasthan during the early Eocene. This conforms with earlier reported quantitative climatic parameters using CLAMP analysis of the physiognomic characters of fossil leaf remains[24].

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# Effect of defoliation on tree growth of *Populus deltoides* Bartr. ex Marsh in India

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**To assess the impact of artificial leaf defoliation of *Populus deltoides* on its different growth parameters, a study was conducted on G-48 clone under field condition and four defoliation treatments, i.e. 25%, 50%, 75% and 100%, were done in addition to control. Defoliation pattern was simulated with insect defoliator *Clostera* spp. feeding and the experiment was conducted from July to December. Significant variation was observed in tree height and DBH growth loss in all the treatments with respect to control, and 24.16–66.03% volume increment loss was observed under 25–100% leaf defoliation respectively.**

**Keywords:** Artificial defoliation, *Clostera* species, growth loss, *Populus deltoides.*

POPULUS *deltoides* Bartr. ex Marsh. (family: Salicaceae), commonly known as poplar or eastern cottonwood, is a native of North America and has been introduced to the temperate world, viz. Europe, Australia and many countries of Southeast Asia[1–5]. *P. deltoides* clones and its hybrids were introduced in India by the Forest Research Institute, Dehradun, Uttarakhand, during 1959 to 1976 and successfully grown in about 2.7 lakh ha farmland in the subtropical regions of the country with a short rotation of 5–8 years[6,7]. *P. deltoides* has become popular among Indian farmers due to its easy propagation, fast-growth, short rotation and suitability for agroforestry. It has been extensively grown by the farmers of the sub-tropical regions of northwestern

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