Ficus palaeoracemosa sp. nov. – A new fossil leaf from the Kasauli Formation of Himachal Pradesh and its palaeoclimatic significance

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A new fossil leaf impression is described from the Early Miocene sediments of Kasauli–Kalka road section, Himachal Pradesh. The characteristic leaf venation pattern suggests that it has a close affinity with *Ficus* L., particularly with *F. racemosa* L. (= *F. glomerata* Roxb.). Its presence indicates a warm and humid climate in the region during the deposition of sediments, in contrast to the present day cooler and less humid climate.

1. Introduction

Ficus L. (Moraceae) has diversified extensively in terrestrial ecosystems having high evolutionary capacity in which primitive forms are retained together with more advanced ones (Corner 1969), and is known for its unique inflorescence and obligate pollination mutualism with fig wasps (Agaonidae) (Cook and Rasplus 2003). Of the five tribes of Moraceae, *Ficus* L. belongs to the tribe Ficeae which is monotypic with a pantropical distribution having ∼750 species (Rohwer 1993; Mabberley 1997).

The Kasauli Formation is well exposed in Kasauli and surrounding areas and measures over 2136 m in thickness (Chaudhri 1969). The age of the formation is assigned to Early Miocene (Sahni 1953; Pascoe 1964; Kapoor *et al* 1988; Guleria *et al* 2000b). The detailed geological information regarding the Kasauli Formation is given by Bhatia (1982).The lithology of the formation is well documented (Chaudhri 1968; Srivastava and Casshyap 1983; Mathur *et al* 1996). The Kasauli Formation mainly comprises of grey to greenish sandy siltstones and grey to brown or buff or greenish micaceous sandstones with shaly and silty partings (Mathur *et al* 1996). The Kasauli sediments represent deposition in an alluvial plain with rapidly shifting shallow braided streams (Singh 1978). Occurrence of plant fossils from this formation was first reported by Medlicott (1864). Later, some fragments of a palm leaf referred to *Sabal major* Heer were figured by Feistmantel (1882). Subsequently Sahni (1953, 1964); Chaudhri (1969); Arya and Awasthi (1994, 1996); Awasthi *et al* (1996); Mathur *et al* (1996); Guleria *et al* (2000a, 2000b); Arya *et al* (2001, 2004) and Srivastava and Guleria (2004) reported a number of taxa from these sediments (table 1). The present paper describes a new fossil leaf of *Ficus* L. from this formation, along with its palaeoclimatic significance.

2. Methodology

During a field excursion to different sections of Kasauli Formation, a very well preserved fossil leaf impression was observed on Kasauli–Kalka road

Keywords. *Ficus racemosa*; climate change; Early Miocene; fossil *Ficus*; Kasauli Formation; Himachal Pradesh; India.

J. Earth Syst. Sci. **120**, No. 2, April 2011, pp. 253–262

Table 1. *Plant megafossils known from the Kasauli Formation of Himachal Pradesh.*

Fossil species	Modern comparable forms	References
Pteridophyta		
Polypodiaceae		
Arthromeris kasauliensis	*Arthromeris*	Arya *et al* (2001)
Pteridaceae		
Acrostichum lanzaeanum	*Acrostichum*	Awasthi *et al* (1996)
Dicotyledons		
Anacardiaceae		
Gluta miocenica	*Gluta tavoyana*	Arya and Awasthi (1996)
Semecarpus palaeoanacardium	*Semecarpus anacardium*	Srivastava and Guleria (2004)
Anonaceae		
Fissistigma shankerii	*Fissistigma verrucosum*	Mathur *et al* (1996)
Apocynaceae		
Tabernaemontana misraii	*Tabernaemontana recurva* and *T. coronaria*	-do-
Tabernaemontana sahnii	*T. coronaria*	-do-
Clusiaceae		
Garcinia kasaulica	*Garcinia speciosa*	Arya and Awasthi (1996)
Kayea sp.	*Kayea floribunda*	Mathur *et al* (1996)
Mesua tertiara	*Mesua ferrea*	-do-
Combretaceae		
Combretum sahnii	*Combretum apetalum*	Arya and Awasthi (1996)
Dipterocarpaceae		
Dipterocarpus siwalicus	*Dipterocarpus*	Guleria *et al* (2000b)
Ebenaceae		
Diospyros barogensis	*Diospyros montana*	Mathur *et al* (1996)
Euphorbiaceae		
Mallotus philippensis	*Mallotus philippensis*	Srivastava and Guleria (2004)
Phyllanthus palaeoreticulatus	*Phyllanthus reticulatus*	Arya and Awasthi (1996)
Fabaceae		
Bauhinia kasaulica	*Bauhinia variegata*	Arya and Awasthi (1994)
B. krishnanunnii	*B. phoenicea*	Guleria *et al* (2000b) Mathur *et al* (1996)
Cassia dayalii	*Cassia javanica* and *C. timoriensis*	Mathur *et al* (1996)
C. miosiamea	*C. siamea*	Guleria *et al* (2000b)
C. satsangii	*Cassia*	Mathur *et al* (1996)
Dalbergia daghotaensis	*Dalbergia sisoo*	-do-
D. umeshii	*D. tamarindifolia*	-do-
Leguminophyllum kasauliensis	Legume leaf	Guleria *et al* (2000b)
Millettia singhii	*Millettia brandisiana*	Mathur *et al* (1996)
Millettia sp.	*M. pachycarpa*	-do-
Tephrosia kasauliensis	*Tephrosia candida*	Srivastava and Guleria (2004)
Lauraceae		
Litsea sastryi	*Litsea citrata*	Mathur *et al* (1996)
Persea sibdasii	*Persea lanceolata*	-do-
Meliaceae		
Amoora palaeowallichii	*Amoora wallichii*	Guleria *et al* (2000b)
Chukrasia himachalensis	*Chukrasia tabularis*	Srivastava and Guleria (2004)
Heynea kasauliensis	*Heynea trijuga*	-do-
Moraceae		
Ficus kasaulica	*Ficus gibbosa* and *F. quercifolia*	Mathur *et al* (1996)
F. banogensis	*F. tomentosa*	-do-
Myrtaceae		
Syzygium kasauliensis	*Syzygium jambos* and *S. heyneana*	Arya *et al* (2001)
Polygonaceae		
Trilobanthus miocenicus	*Antigonum*	Arya *et al* (2004)

Table 1. (*Continued*).

Fossil species	Modern comparable forms	References
Rubiaceae		
Mitragyna tertiara	*Mitragyna parvifolia*	Guleria *et al* (2000a)
M. sahnii	-do-	-do-
Rutaceae		
Murraya khariensis	*Murraya exotica*	Mathur *et al* (1996)
Sapindaceae		
Schleichera sp.	*Schleichera trijuga*	-do-
Solanaceae		
Kasaulipushpam radiatus	*Solanum nigrum*	Arya *et al* (2004)
K. sahnii	-do-	-do-
Monocotyledons		
Arecaceae		
Amesoneuron sahnii	–	Guleria *et al* (2000a)
Palmophyllum sp.	–	Chaudhri (1969)
Sabalites microphylla	–	Sahni (1964)
Sabalites sp.	–	Mathur *et al* (1996)
Marantaceae		
Donax kasauliensis	*Donax cannaeformis*	Srivastava and Guleria (2004)
Poaceae		
Bambusa siwalica	*Bambusa nutans*	Guleria *et al* (2000b)

section near a slaughterhouse situated below the Kashmiri Mohalla (30°53′52.4″N, 76°57′24.1″E; alt. 1686 m asl). The impression in silty sandstone was badly cracked and too fragile to be isolated. Therefore, after clearing the dust from the surface of the leaf, the fossil was photographed under the sunlight using Canon SX110 digital camera. Because the original material was destroyed during the extraction, its figure is used as the type material as per article 9.6 of the International Code of Botanical Nomenclature (Mcneill 2006). The neotype in the form of a high resolution image is deposited in the museum of the Birbal Sahni Institute of Palaeobotany, Lucknow. The terminology used in describing the fossil leaf is based on Hickey (1973, 1979); Dilcher (1974); Hickey and Wolfe (1975); and the Leaf Architecture Working Group (1999).

3. Systematic description

Class: Magnoliopsida
Order: Rosales
Family: Moraceae
Genus: Ficus L.
Species: Ficus palaeoracemosa, Srivastava, Srivastava and Mehrotra, sp. nov.

Description: Leaf complete, simple, symmetrical, mesophyll, elliptic; preserved lamina length 12.44 cm, maximum width 6.18 cm near the middle position; apex acute; base symmetrical, obtuse, normal; margin entire; texture, appearing chartaceous; attachment with petiole normal, petiole length 1.52 cm; venation pinnate, eucamptodromous; primary vein moderate in thickness, slightly curved; secondary veins six pairs visible, 0.77–3.59 cm apart, distance decreasing upwards, alternate to sub-opposite, moderately thick, angle of divergence moderate acute (52°–63°) (the basal pair of secondaries which is thinner than the mid-vein gives the false impression of basal acrodromous venation), lowermost secondary veins opposite, more acute than middle ones, predominantly uniform but a few secondaries abruptly curved joining super-adjacent secondaries with percurrent tertiary veins; intersecondary veins present, simple; tertiary veins percurrent, simple, convex, oblique in relation to mid-vein, close, angle of origin AA-OA; quaternary veins and further fine features not preserved.

Neotype: Specimen no. BSIP 39833.
Horizon: Kasauli Formation.
Locality: Kasauli–Kalka road near a slaughterhouse below Kashmiri Mohalla, Solan District, Himachal Pradesh.
Age: Early Miocene.
Material: One well-preserved specimen.

Affinities: The characteristic features of the present fossil leaf, specifically the elliptic shape, entire margin, pinnate eucamptodromous venation, one pair of secondary veins arising from the base of the primary vein and percurrent tertiary

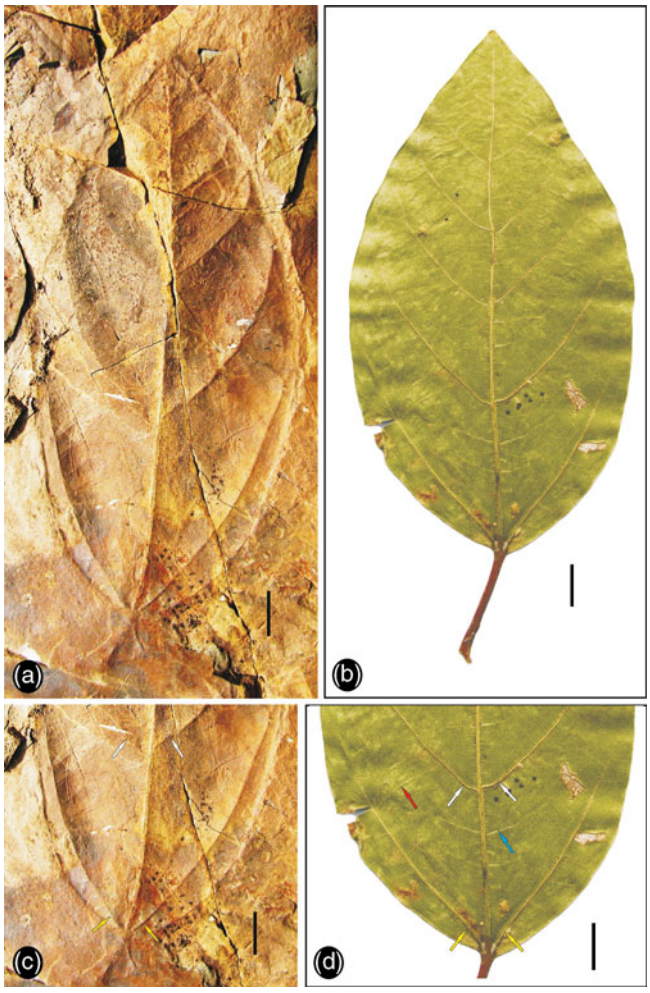

Figure 1. **(a)** A fossil leaf of *Ficus palaeoracemosa* sp. nov. showing shape, size and venation pattern; (**b**) modern leaf of *Ficus racemosa* L. showing similar shape, size and venation pattern; **(c)** basal portion of fossil leaf showing lateral secondary veins (yellow arrow denotes lateral secondary veins and white arrow denotes upper secondary veins); **(d)** basal portion of modern leaf showing similar lateral secondary veins (yellow arrow denotes lateral secondary veins; white arrow denotes upper secondary veins; blue arrow denotes intersecondary vein; and red arrow denotes percurrent tertiary vein) (Bar scale = 1 cm).

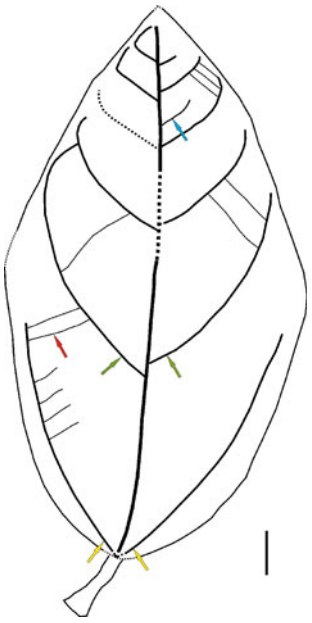

Figure 2. Text-diagram of *Ficus palaeoracemosa* sp. nov. (yellow arrow denotes lateral secondary veins; green arrow denotes upper secondary veins; blue arrow denotes intersecondary vein; and red arrow denotes percurrent tertiary vein) (Bar scale = 1 cm).

veins indicate its affinity with the genus *Ficus* L. of the family Moraceae. Comparison was made with herbarium material in the Central National Herbarium, Howrah, the Forest Research Institute, Dehradun and the Birbal Sahni Institute of Palaeobotany, Lucknow. The characteristic venation pattern and character by character evaluation (qualitative analysis) suggest its close affinity with the modern leaf of *Ficus racemosa* L. (syn. *F. glomerata* Roxb.) (Herb. sheet no. BSIP 13354).

The genus *Ficus* L. is well known in the fossil record from all over the world. The earliest record of *Ficus*-like leaf is known from the Lower Cretaceous of Maryland and described by Fontaine (1889) under the generic name *Ficophyllum.* It has also been reported from the Siwalik sediments of Nepal (Prasad 1990; Prasad and Awasthi 1996; Konomatsu and Awasthi 1999), Cretaceous to Late Pliocene sediments of China (Li *et al* 1995; Li and Zheng 1995; Sun *et al* 1995), Cretaceous, Oligocene and Miocene of Mexico (Cevallos-Ferriz and Ramírez-Garduño 1998; Martínez-Hernández and Ramírez-Arriaga 1999; Martínez-Cabrera *et al* 2006), Middle Eocene sediments of Tennessee, USA (Potter 1976) and Quaternary sediments of Central and South America (Burnham and Graham 1999).

A large number of species of *Ficus* L. are known from various Cenozoic exposures of the world and are enlisted in table 2. Of these, three species and three indeterminate species of *Ficus* are reported from the Dagshai and Kasuali formations of Himachal Pradesh by Mathur *et al* (1996), but none of them shows true affinities with *Ficus.* In *F. kumarhattiensis* (on its assumed similarity with *F. racemosa*), it is not clear from the description and photographs if its lowest pair of secondaries arises from the base of the leaf as in the modern leaf and the present fossil species. In *F. kasaulika* the leaf is very small (2.4 cm) with more acute secondary veins in comparison to its modern counterpart *F. gibbosa. F. banogensis* in having four pairs of secondary veins and obtuse base differs from *F. tomentosa* (modern comparable species) which bears cordate base and nine pairs of secondaries. *Ficus* sp. A, B and C are also based on very small and fragmentary specimens and do not show any unique characteristic feature of the genus

Table 2. *Comparative chart of the known fossil leaves of Ficus from the Cenozoic sediments of India and abroad.*

Fossil species	Modern comparable forms	Apex	Base	Margin	Size	Shape	Balance	Venation pattern	Angle of divergence of secondary veins	Inter-secondary veins	Tertiary veins
Ficus arnottiana (Mahajan and Mahabale 1973)	*Ficus arnottiana*	Attenuate	Cordate	Entire	Mesophyll	Ovate	Symmetrical	Brochidodromous	Moderate acute	NG	Reticulate
F. banogensis (Mathur *et al* 1996)	*F. tomentosa*	NP	Obtuse	Entire	Mesophyll	Narrow ovate	Symmetrical	Brochidodromous	Moderate acute	Absent	Percurrent and orthogonal reticulate
F. benjamina (Prasad *et al* 2002)	*F. benjamina*	NP	Obtuse	Entire	Mesophyll	Elliptic	Asymmetrical	Brochidodromous	Wide acute-right angle	Present	Percurrent
F. caricites (Trivedi 1980)	*F. carica*	Round	NP	Dentate	NG	Elliptic	Symmetrical	Brochidodromous	Moderate acute	NG	Reticulate
F. champarense (Lakhanpal and Awasthi 1984)	*F. cunia*	NP	Auriculate	Entire	Microphyll	Elliptic	Inequilateral	Eucamptodromous	Moderate acute-right angle	NG	Forked percurrent
F. cherrapunjiensis (Ambwani 1991)	*F. mysorensis*	NP	Cordate	Entire	Mesophyll	Wide ovate	Symmetrical	Eucamptodromous	Wide acute-right angle	Present	Percurrent
F. cunia (Puri 1947)	*F. cunia*	NP	Auriculate, asymmetrical	Entire	NG	NG	NG	Eucamptodromous	Obtuse	NG	Percurrent
F. curticeps (Singh and Prasad 2008)	*F. rumphii*	Attenuate	NP	Entire	Mesophyll	Narrow ovate	Symmetrical	Craspedodromous	Wide acute	NG	Percurrent
F. eomysorensis (Tripathi *et al* 2002)	*F. mysorensis*	NP	NP	Entire	Microphyll	Elliptic	Symmetrical	Eucamptodromous	Wide acute	Present	Percurrent
F. glaberrima (Bande and Srivastava 1990)	*F. foveolata*	NP	Round	Entire	Mesophyll	Elliptic	Symmetrical	Brochidodromous	Moderate acute	Present	Orthogonal reticulate
F. glomerata (Mahajan and Mahabale 1973)	*F. racemosa*	Blunt	Acute	Entire	Mesophyll	Elliptic	Symmetrical	Eucamptodromous, brochidodromous	Moderate acute	Present	Percurrent
F. kachchhensis (Lakhanpal and Guleria 1981)	*F. tomentosa*	NP	Cordate	Entire	Mesophyll	Wide ovate	Symmetrical	Eucamptodromous	Moderate acute	Absent	Percurrent

Table 2. (*Continued*).

Fossil species	Modern comparable forms	Apex	Base	Margin	Size	Shape	Balance	Venation pattern	Angle of divergence of secondary veins	Inter-secondary veins	Tertiary veins
F. kasaulica (Mathur *et al* 1996)	*F. benghalensis*	Acute	Obtuse	Entire	Microphyll	Ovate	Symmetrical	Eucamptodromous	Moderate acute	Present	Random reticulate
F. khariensis (Lakhanpal and Guleria 1982)	*F. infectoria*	NP	NP	Entire	Mesophyll	Narrow ovate-lanceolate	Symmetrical	Brochidodromous	Moderate-wide acute	Present	Percurrent and reticulate
F. kumarhattiensis (Mathur *et al* 1996)	*F. racemosa*	Acute	Obtuse	Entire	Microphyll	Narrow ovate	Symmetrical	Eucamptodromous	Moderate acute	Present	Orthogonal reticulate
F. microcarpa (Srivastava 1998; Singh and Prasad 2008)	*F. microcarpa*	Acuminate	Cuneate	Entire	Microphyll	Narrow elliptic	Symmetrical	Eucamptodromous, brochidodromous	Moderate acute	Present	Percurrent
F. miocenicus (Konomatsu and Awasthi 1999)	*F. benghalensis*	Obtuse	Obtuse	Entire	Mesophyll	Elliptic	Symmetrical	Eucamptodromous	Moderate acute	NG	Percurrent
F. nepalensis (Prasad 1990)	*F. glaberrima*	NP	Obtuse	Entire	Mesophyll	Elliptic	Symmetrical	Brochidodromous	Moderate acute	Present	Percurrent
F. oodlabariensis (Prasad *et al* 2004; Prasad 2006)	*F. benjamina*	Wide acute	NP	Entire	Microphyll	Elliptic	Symmetrical	Brochidodromous	Moderate acute	Present	Percurrent
F. precunea (Prasad 1990; Prasad *et al* 2004)	*F. cunea*	Acute	Auriculate	Entire	Mesophyll	Ovate	Asymmetrical	Eucamptodromous	Moderate acute	Not visible	Forked percurrent
F. praecurticeps (Agarwal 2002)	*F. curticeps*	NP	Round	Entire	Mesophyll	Orbiculate elliptic	Slightly asymmetrical	Eucamptodromous-brochidodromous	Moderate-wide acute	Present	Percurrent
F. raptiensis (Prasad and Awasthi 1996)	*F. hispida*	NP	Obtuse	Entire	Mesophyll	Elliptic	Symmetrical	Eucamptodromous	Moderate acute	Absent	Percurrent
F. religiosities (Trivedi 1980)	*F. religiosa*	Attenuate	NP	Entire	Mesophyll	Elliptic	Symmetrical	Eucamptodromous, brochidodromous	Moderate acute	NG	Reticulate
F. retusoides (Agarwal 2002; Antal and Awasthi 1993; Prasad 1990)	*F. retusa*	Acuminate	NP	Entire	Microphyll	Wide elliptic	Symmetrical	Brochidodromous	Wide acute	Present	Percurrent and reticulate

F. rumphii (Singh and Prasad 2008)	*F. rumphii*	Attenuate	NP	Entire	Mesophyll	Narrow ovate	Symmetrical	Craspedodromous	Wide acute	NG	Percurrent
F. tomentosa (Bande and Srivastava 1990)	*F. tomentosa*	Mucronate	Obtuse	Entire	Microphyll	Elliptic	Symmetrical	Craspedodromous	Moderate acute	Present	Percurrent and orthogonal reticulate
Ficus sp. A (Mathur *et al* 1996)	*F. racemosa*	Acute	Obtuse	Entire	Microphyll	Narrow ovate	Symmetrical	Eucamptodromous	Moderate acute	Present	Orthogonal reticulate
Ficus sp. B (Mathur *et al* 1996)	*F. tomentosa*	NP	Obtuse	Entire	Microphyll	Wide elliptic	Symmetrical	Eucamptodromous	Moderate acute	Present	Percurrent and orthogonal reticulate
Ficus sp. C (Mathur *et al* 1996)	*F. benghalensis*	Acute	Acute	Entire	Nanophyll	Elliptic	Symmetrical	Craspedodromous	Moderate acute	Present	Percurrent and reticulate
F. palaeoracemosa sp. nov.	*F. racemosa*	Acute	Obtuse	Entire	Mesophyll	Elliptic	Symmetrical	Eucamptodromous	Moderate acute	Present	Percurrent

NP: not preserved; NG: not given.

Ficus. Hence, all the specimens designated to the genus *Ficus* from Dagshai and Kasauli formations are doubtful. The other known species differ from our fossil in a combination of characters (table 2). Therefore, it is being described under a new species *F. palaeoracemosa* sp. nov., the specific epithet is after the modern species *F. racemosa*.

4. Discussion and conclusion

Most of the species of *Ficus* L. are distributed in the tropical areas of India in warm and humid climates. The diversity of *Ficus* L. species in India during the Tertiary and Quaternary periods increases from the Palaeocene onwards and was at its peak during the Miocene (figure 3a). During the Cenozoic, *Ficus* L. was distributed all over India. It has been reported from the Palaeocene of Meghalaya (Ambwani 1991), Eocene and Early Miocene of Kutch (Lakhanpal and Guleria 1981, 1982), Late Oligocene–Early Miocene of Himachal Pradesh (Mathur *et al* 1996), Miocene of Neyveli Lignite deposits, Tamil Nadu (Agarwal 2002), Middle Miocene of Bilaspur, Himachal Pradesh (Prasad 2006), Middle Miocene of Kathgodam, Uttarakhand (Prasad *et al* 2004), Middle Miocene of Kalagarh, Uttarakhand (Prasad 1993), Middle Miocene–Pliocene of Darjeeling District, West Bengal (Antal and Awasthi 1993), Pleistocene of Kashmir (Puri 1947), Pleistocene of Palamu District, Jharkhand (Bande and Srivastava 1990; Srivastava 1998; Singh and Prasad 2008), Late Pleistocene to Sub-Recent from Maharashtra (Mahajan and Mahabale 1973) and the Late Holocene of Sirmur District, Himachal Pradesh (Prasad *et al* 2002).

Ficus racemosa L. is an evergreen-to-occasionally deciduous, moderate-to-large tree found throughout India except for a few places, such as extreme western, northern and eastern parts of India where either humidity or temperature is very low (Pearson and Brown 1932) (figure 3b). It usually grows in ravines, along river banks and marshy places and is a good indicator of underground water (Mahajan and Mahabale 1973). About 80 species of *Ficus* are found in India (Pearson and Brown 1932). Based on the modern distribution of *F. racemosa* L. (figure 3b), it may be inferred that a tropical and humid climate is necessary for its growth. This indicates that during the deposition of the sediments in Kasauli Formation, the climate was tropical and humid which is in contrast to the cooler and less humid climate prevailing there today. It is likely that the climate of Kasauli was changed because of the uplift of the Himalayas resulting in the shifting of the species to nearby areas having a more equable climate. The presence

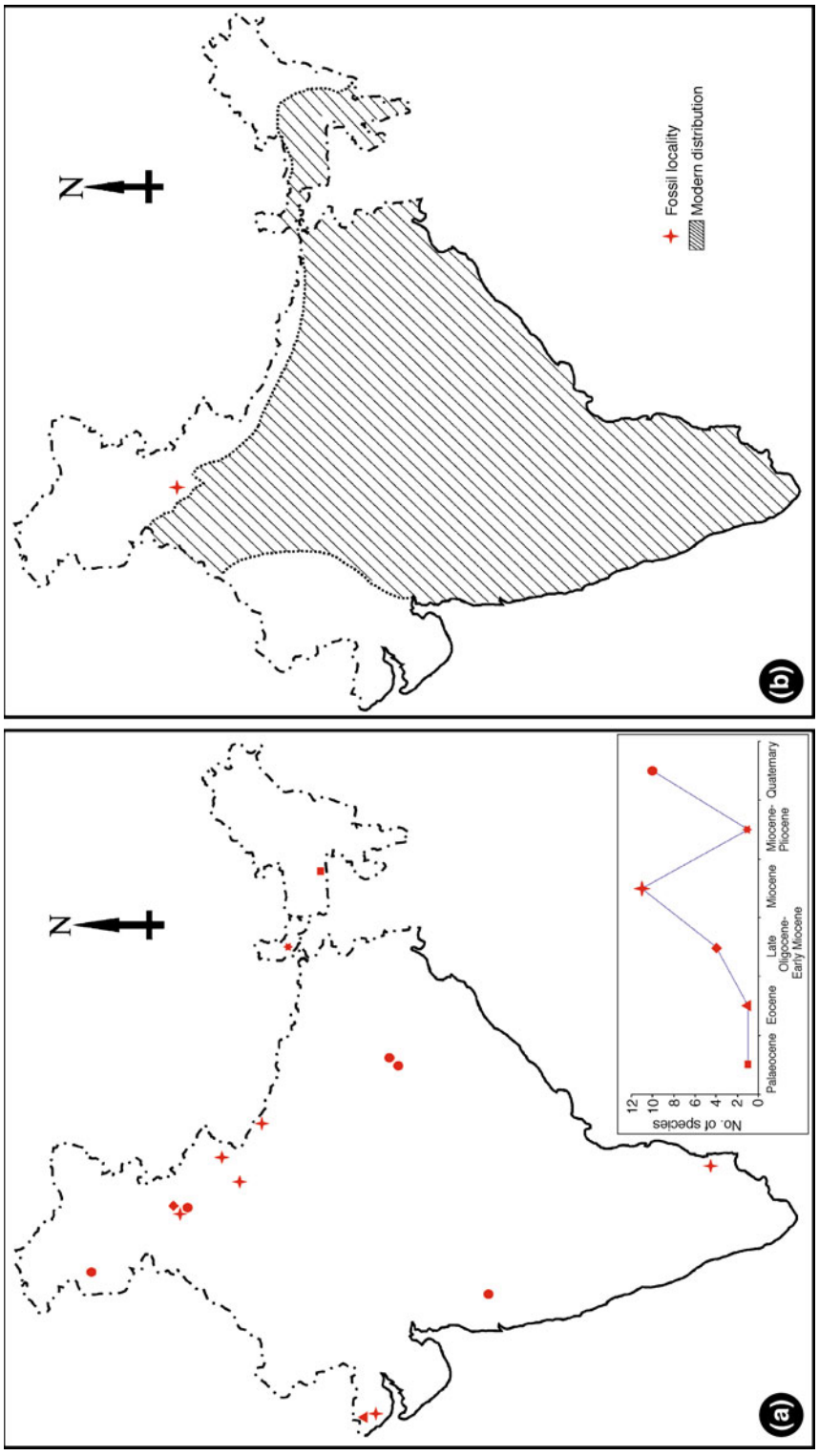

Figure 3. **(a)** Megafossil record of *Ficus* spp. from India and the line graph showing the diversity of *Ficus* spp. during the Cenozoic; **(b)** Modern distribution of *Ficus racemosa* L. and the present fossil locality in red astrick (modified after Pearson and Brown 1932).

of the other known taxa from the Kasauli Formation, Himachal Pradesh, namely, *Amoora, Chukrasia, Dipterocarpus, Fissistigma, Heynea, Kayea, Mesua, Mitragyna, Semecarpus* and *Tephrosia* also support our findings.

Acknowledgements

The authors are thankful to Dr N C Mehrotra, Director, Birbal Sahni Institute of Palaeobotany, Lucknow for providing necessary facilities and permission to carry out this work. They are also grateful to the anonymous reviewers for their constructive suggestions to improve the manuscript. Thanks are also due to Ms Swati Dixit for her help.

References

Agarwal A 2002 Contributions to the fossil leaf assemblage from the Miocene Neyveli lignite deposits, Tamil Nadu, India; *Palaeontographica* **B261** 167–206.

Ambwani K 1991 Leaf impressions belonging to the Tertiary age of north-east India; *Phytomorphology* **41(1&2)** 139–146.

Antal J S and Awasthi N 1993 Fossil flora from the Himalayan foot-hills of Darjeeling District, West Bengal and its palaeoecological and phytogeographical significance; *Palaeobotanist* **42(1)** 14–60.

Arya R and Awasthi N 1994 A new species of *Bauhinia* from the Kasauli Formation (Lower Miocene), Kasauli, Himachal Pradesh; *Geophytology* **24(1)** 59–62.

Arya R and Awasthi N 1996 Leaf impressions from Kasauli Formation, Kasauli, Himachal Pradesh and their palaeoecological and palaeoenvironmental significance; Proc. Symp. NW Himalaya and Foredeep; *Geol. Surv. India Spec. Publ.* **21** 271–276.

Arya R, Guleria J S and Srivastava R 2001 New records of plant fossils from the Kasauli sediments of Himachal Pradesh, north-west India; *Phytomorphology* **51(1)** 63–69.

Arya R, Ambwani K, Sahni N and Sahni A 2004 First mammal and additional fossil flowers from the Kasauli Formation, Kasauli, Himachal Pradesh; *J. Geol. Soc. India* **64** 317–324.

Awasthi N, Guleria J S, Prasad M and Srivastava R 1996 Occurrence of *Acrostichum* L., a coastal fern in the Tertiary sediments of Kasauli, Himachal Pradesh, north-west Himalaya; *Palaeobotanist* **43(2)** 83–87.

Bande M B and Srivastava G P 1990 Late Cenozoic plant-impressions from Mahuadanr Valley, Palamu District, Bihar; *Palaeobotanist* **37(3)** 331–366.

Bhatia S B 1982 Facies, fauna and flora of the Lower Tertiary of north-west Himalaya: A synthesis; *J. Palaeont. Soc. India Spec. Publ.* **1** 8–20.

Burnham R J and Graham A 1999 The history of neotropical vegetation: New developments and status; *Ann. Missouri Bot. Gard.* **86** 546–589.

Cevallos-Ferriz S R S and Ramírez-Garduño J L 1998 Las plantas con flor en el registro fósil; *Ciencias* **52** 46–57.

Chaudhri R S 1968 Stratigraphy of the Lower Tertiary formations of Punjab Himalyas; *Geol. Mag.* **105** 421–430.

Chaudhri R S 1969 Some leaf impressions from the Kasauli Series of the Simla Hills; *Curr. Sci.* **38** 95–97.

Cook J M and Rasplus J-Y 2003 Mutualists with attitude: Coevolving fig wasps and figs; *Trends Ecol. Evol.* **18** 241–248.

Corner E J H 1969 *Ficus; Phil. Trans. Roy. Soc. London B* **255** 567–570.

Dilcher D L 1974 Approaches to the identification of angiosperm leaf remains; *Bot. Rev.* **40** 1–157.

Feistmantel O 1882 Note on remains of palm leaves from the (Tertiary) Murree and Kasauli beds of India; *Rec. Geol. Surv. India* **15(1)** 51–53.

Fontaine W M 1889 The Potomac or younger Mesozoic flora: Text and Atlas; *Monograph U.S. Geol. Surv.* **15** 1–377.

Guleria J S, Srivastava R and Arya R 2000a Occurence of fossil *Mitragyna* in the Early Miocene of Himachal Pradesh, India; *Palaeobotanist* **49** 485–489.

Guleria J S, Srivastava R and Prasad M 2000b Some fossil leaves from the Kasauli Formation of Himachal Pradesh, north-west India; *Himalayan Geol.* **21(1&2)** 43–52.

Hickey L J 1973 Classification of the architecture of dicotyledonous leaves; *Am. J. Bot.* **60** 17–33.

Hickey L J 1979 A revised classification of the architecture of dicotyledonous leaves; In: *Anatomy of the dicotyledons* (eds) Metcalf C R and Chalk L (Oxford, UK: Clarendon Press), pp. 25–39.

Hickey L J and Wolfe J A 1975 The bases of angiosperm phylogeny: Vegetative morphology; *Ann. Missouri Bot. Gard.* **62** 538–589.

Kapoor R, Dogra N N and Singh R Y 1988 Palynology of the Kasauli Formation in the type area in Solan District, Himachal Pradesh; *J. Palaeont. Soc. India* **33** 105–115.

Konomatsu M and Awasthi N 1999 Plant fossils from Arung Khola and Binai Khola formations of Churia Group (Siwalik), west central Nepal and their palaeoecological and phytogeographical significance; *Palaeobotanist* **48** 163–181.

Lakhanpal R N and Awasthi N 1984 A Late Tertiary florule from near Bhikhnathoree in West Champaran District, Bihar; In: *Proceedings of the Symposium on Evolutionary Botany and Biostratigraphy (A.K. Ghosh Commem. Vol.)*, (eds) Sharma A K *et al* (New Delhi: Today and Tomorrow's Print. and Publ.), pp. 587–596.

Lakhanpal R N and Guleria J S 1981 Leaf-impressions from the Eocene of Kachchh, Western India; *Palaeobotanist* **28–29** 353–373.

Lakhanpal R N and Guleria J S 1982 Plant remains from the Miocene of Kachchh, Western India; *Palaeobotanist* **30(3)** 279–296.

Leaf Architecture Working Group 1999 Manual of leaf architecture – morphological description and categorization of dicotyledonous and net-veined monocotyledonous angiosperms (Washington DC, USA: Smithsonian Institution).

Li H, Li W and Liu J 1995 Quaternary floras; In: *Fossil floras of China through the geological ages*, Chapter 12, (ed.) Li Xingxue (Guangzhou, China: Guangdong Science and Technology Press), pp. 552–588.

Li H and Zheng Y 1995 Paleogene floras. In: *Fossil floras of China through the geological ages*, Chapter 10 (ed.) Li Xingxue (Guangzhou, China: Guangdong Science and Technology Press), pp. 455–505.

Mabberley D J 1997 *The plant book, a portable dictionary of the vascular plants*; 2nd edn, (Cambridge: Cambridge University Press).

Mahajan D R and Mahabale T S 1973 Quaternary flora of Maharashtra – 1. The Pravra River basin, district Ahmednagar, Maharastra; *Geophytology* **2(2)** 175–177.

Martínez-Cabrera H I, Cevallos-Ferriz S R S and Poole I 2006 Fossil woods from Early Miocene sediments of the El Cien Formation, Baja California Sur, Mexico; *Rev. Palaeobot. Palynol.* **138** 141–163.

Martínez-Hernández E and Ramírez-Arriaga E 1999 Palinoestratigafía de la región de Tepexi de Rodríguez, Puebla, México-implicaciones cronoestratigráficas; *Rev. Mex. Cienc. Geol.* **16** 187–207.

Mathur A K, Mishra V P and Mehra S 1996 Systematic study of plant fossils from Dagshai, Kasauli and Dharamsala formations of Himachal Pradesh; *Geol. Surv. India, Palaeontologia Indica, N.S.* **50** 1–121.

Mcneill J 2006 International Code of Botanical Nomenclature (Vienna code). *Regnum Vegetabile* **146**, A.R.G. Ganter Verlag KG.

Medlicott H B 1864 On the geological structure and relations of the southern portion of the Himalayan range between the river Ganges and Ravee; *Geol. Surv. India Memoir* **3(2)** 97–99.

Pascoe E H 1964 *A Manual of the Geology of India and Burma*, 3rd edn., Geol. Surv. India (Calcutta: Government of India Press).

Pearson R S and Brown H P 1932 *Commercial Timbers of India.* **1 & 2** (Calcutta: Government of India Central Publication Branch).

Potter F W 1976 Investigations of angiosperms from the Eocene of southeastern North America: Pollen assemblages from Miller Pit, Henry County, Tennessee; *Palaeontographica* **B157** 44–96.

Prasad M 1990 Fossil flora from the Siwalik sediments of Koilabas, Nepal; *Geophytology* **19(1)** 79–105.

Prasad M 1993 Siwalik (Middle Miocene) woods from the Kalagarh area in the Himalayan foot hills and their bearing on palaeoclimate and phytogeography; *Rev. Palaeobot. Palynol.* **76** 49–82.

Prasad M 2006 Siwalik plant fossils from the Himalayan foot hills of Himachal Pradesh, India and their significance on palaeoclimate; *Phytomorphology* **56(1&2)** 9–22.

Prasad M and Awasthi N 1996 Contribution to the Siwalik flora from Surai Khola sequence, western Nepal and its palaeoecological and phytogeographical implications; *Palaeobotanist* **43(3)** 1–42.

Prasad M, Chauhan M S and Sah M P 2002 Morphotaxonomic study on fossil leaves of *Ficus* from Late Holocene sediments of Sirmur District, Himachal Pradesh, India and their significance in assessment of past climate; *Phytomorphology* **52(1)** 45–53.

Prasad M, Ghosh R, Tripathi P P 2004 Floristics and climate during Siwalik (Middle Miocene) near Kathgodam in the Himalayan foot-hills of Uttranchal, India; *J. Palaeont. Soc. India* **49** 34–93.

Puri G S 1947 The occurrence of a tropical fig (*Ficus cunia* Buch-Ham) in the Karewa beds at Liddarmarg, Pir Panjal range, Kashmir, with remarks on the Sub-Tropical forests of the Kashmir valley during the Pleistocene; *J. Indian Bot. Soc.* **26(3)** 131–135.

Rohwer J G 1993 Moraceae; In: *The families and genera of vascular plants* (eds) Kubitzki K, Rohwer J G and Bittrich V (Berlin: Springer-Verlag), pp. 438–453.

Sahni B 1953 Angiosperm leaf-impressions from the Kasauli bed, N.W. Himalayas; *Palaeobotanist* **2** 85–87.

Sahni B 1964 *Revisions of Indian fossil plants. Part III – Monocotyledons*; Monogr. 1, Birbal Sahni Inst. Palaeobot., Lucknow.

Singh I B 1978 On some sedimentological and palaeoecological aspects of Subathu–Dagsai–Kasauli succession of Simla Hills; *J. Palaeont. Soc. India* **21–22** 19–28.

Singh S K and Prasad M 2008 Fossil leaf-impressions from the Late Tertiary sediments of Mahuadanr valley, Latehar District, Jharkhand, India; *Palaeobotanist* **57** 479–495.

Srivastava G P 1998 Impact of Himalayan uplift on the Late Cenozoic flora of India; *Geophytology* **27(1&2)** 97–102.

Srivastava V K and Casshyap S M 1983 Evolution of pre-Siwalik Tertiary basin of Himachal Himalaya; *J. Geol. Soc. India* **24** 134–147.

Srivastava R and Guleria J S 2004 Leaf impressions from Kasauli sediments of Himachal Pradesh and their palaeoenvironmental significance; *Geophytology* **32(1&2)** 97–106.

Sun G, Cao Z, Li H and Wang X 1995 Cretaceous floras; In: *Fossil floras of China through the geological ages*, Chapter 9 (eds) Li Xingxue (Guangzhou, China: Guangdong Science and Technology Press), pp. 411–452.

Tripathi P P, Pandey S M and Prasad M 2002 Angiospermous leaf impressions from the Siwalik sediments of the Himalayan foot hills, near Jarwa, U.P. and their palaeoclimatic significance; *Biol. Mem.* **28(2)** 79–90.

Trivedi T K 1980 Identification of the fossil leaf impressions from Mewar state; *Botanique* **9(1&4)** 169–174.

MS received 9 September 2010; revised 5 January 2011; accepted 5 January 2011