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Diversified Early Eocene floral and faunal assemblage from Gurha, western Rajasthan: Implications for palaeoecology and palaeoenvironment

Raman Patel[1] Hukam Singh[2] Mahesh Prasad[2] Priya Agnihotri[2] Rajendra Singh Rana[*1] Mohd Waqas[1]

[1]Department of Geology; H.N.B. Garhwal University, Srinagar (Garhwal)-246174
Uttarakhand, India
[2]Birbal Sahni Institute of Palaeosciences, 53, University Road, Lucknow-226007
Uttar Pradesh, India
Corresponding author's e-mail: rajendra.rana1@gmail.com

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ABSTRACT

Here we report a record of well preserved and diversified fossil leaves and insect impressions which was previously unknown from the early-Eocene sedimentary sequences of Gurha Lignite Mine, Western Rajasthan, India. A detailed morphotaxonomical study on these fossil leaves revealed the occurrence of a variety of floral assemblages consisting of several phytogeographically and palaeoclimatically significant taxa such as *Clausena* (Rutaceae), *Ficus* (Moraceae), *Grewia* (Malvaceae), *Eugenia* (Myrtaceae), *Ziziphus* (Rhamnaceae), *Mangifera* (Anacardiaceae) and *Lagerstroemia* (Lythraceeae). The overall floral assemblage suggests the prevalence of tropical warm and humid climate during the deposition of the sediments which was suitable for the existence of moist deciduous to evergreen forests. Certain fossil insect impressions have also been reported for the first time such as Ephemeroptera (Mayfly *naiad*), Baetidae (wing) and Hymenoptera (Formica) from Western Rajasthan. These insects aim to achieve higher temperature for their survival, suggesting prevalence of a tropical and warm environmental condition during the early-Eocene. Such floral and faunal elements indicate co-existence and abundance of the biota in this locality.

Key-words: Fossil flora and fauna, Gurha mine, Rajasthan, Early Eocene, palaeoecology, biogeography

INTRODUCTION

Among all the Paleocene-Eocene sedimentary sequences occurring in various localities of India, the Palaeocene-Eocene Palana Formation is itself unique for its highly diversified floral records. The recovered floral assemblages are of great interest, particularly for terrestrial plant fossil records. The studied Gurha open-cast lignite mine is situated about 70 km southwest of Bikaner (72°.52'10.38" E, 27°52'32.06" N). Previously, a good amount of plant fossils comprising fossil leaves, fruits and macro and micro floral assemblages have been recorded from the Gurha open cast lignite mine (Shukla *et al.*, 2014b, Kumar *et al.*, 2016). Vertebrate fishes as well as impressions of the certain insects (spider, mayfly, etc) in the shale sedimentary section have also been reported (Patel *et al.*, 2018). In view of their biostratigraphic implications and their thermal power generation these deposits of the lignite associated sedimentary sequences are highly significant. The lignite deposit of the Gurha open cast mine comes under the Palana Formation of Early Eocene age.

Prior to this work, palaeobotanical studies have been done by Shukla *et al.* (2014 a, 2014b, 2014c, 2014d, 2016, 2018), Kumar *et al.*, (2016), Guleria (1984, 1990, 1992, 1996), Guleria and Shukla (2011). In Bikaner-Nagaur basin, the Paleocene-early Eocene interval is represented by the Palana-Kolayat Formations. This basin has also been extensively studied for biostratigraphy, mainly on the basis of foraminifers (Kalia and Sharma, 1985; Khosla, 1973, Kulshreshtha *et al*; 1989). The vertebrates have been recovered only from the Palana Formation (Paliwal, 1999 and Kumar *et al*; 2005). Diverse early Eocene vertebrates along with macro and micro floral assemblage have now been reported from the Cambay Basin, Gujarat, India (Rana *et al*; 2008; Kumar *et al*; 2010; Rose *et al.,* 2006, 2014, Singh *et al.*, 2010, 2014, 2015).

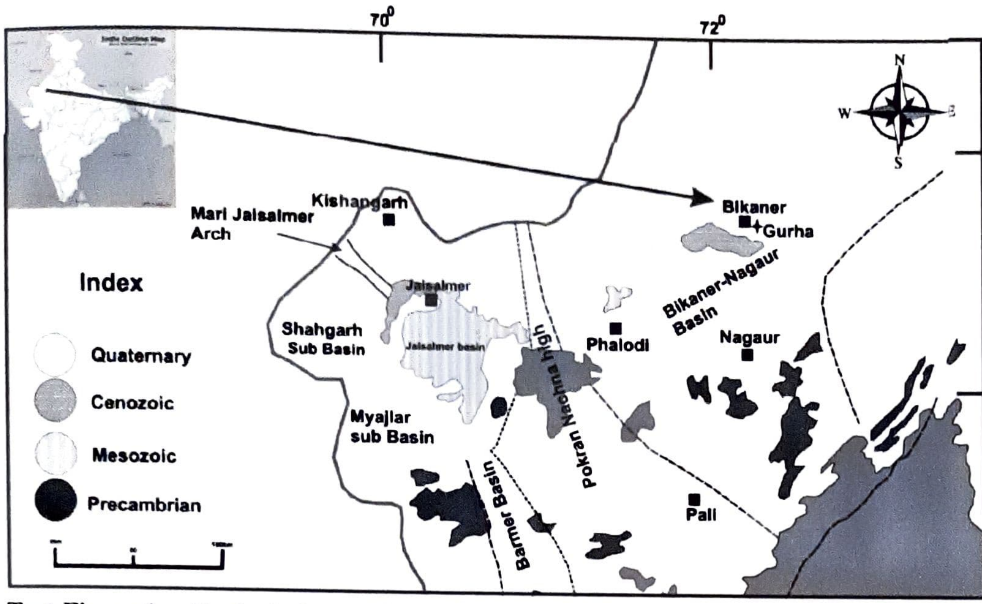
Amongst the faunal impressions, mayfly naiad (Ephemeroptera) have been reported, their species first catalogued by Hubbard and Peter (1978). Order belongs to Uniramia, sub-phyla of Arthropods including hexapods (insects) on the basis of exoskeleton and jointed appendages. The first recorded mayfly nymphs are from the Late Carboniferous (Fenton, 1989), highest degree of diversity dated from the Jurassic. Evolved forms, still-water to running water, occurred before the Cenozoic Era (McCafferty, 1990). Fossil nymphs had functional mouthparts (Carpenter, 1992) while modern adults have vestigial ones. Adults have a short lifespan of nearly 1-2 days, which is why classification is generally done on the basis of its nymphal forms (Sinitshenkova, 1991). Terrestrial Formicidae ant impression has also been documented. They are amongst the socially significant group of insects, accompanying other decomposers and detrivores. Early records of social insects were put forward by W.M Wheeler (1910), much later by Wilson as part of their comprehensive work. The origins are well documented in Cretaceous amber and later rising to dominate in Tertiary amber and rock impressions. They showcase a wide array of behavioral and morphological motives, while maintaining individually cohesive eusocial societies (Hölldobler and Wilson 1990). There are no known solitary ants. In the present communication we have reported the mega floral assemblages and insect impressions from the Gurha open cast Lignite Mine and have discussed their palaeoclimatic and phytogeographic significance.

GEOLOGICAL SETUP

According to field survey, January 2018, the subsurface Gurha lignite mine consists of lignite seam one (2.0 m) at the base, then pebbly ash bed (11.0 m), whitish-grey ash bed, which is not in bedded form and also associated with lignite, followed by the Palana Formation which consists of lignite seam two (12.5 m) at the base of ash bed, carbonaceous shale (7.5m) intercalated with thin siliceous clay nodular bed, fine laminated pale-yellowish-grey shale associated with thin band of dirty maroon sandstone and maroon shale (5.0 m), respectively (Text-Figure 1b). The grey-color shale (7.0 m) is overlain by maroon shale. The thickness of these beds is variable in the opencast lignite mine. The Palana Formation is overlain by the Kolayat Formation which consists of yellowish variegated clays (12.0 m) with thinning lamellated reddish compact sandstone, which is overlain by variegated sandy clay (24.0 m) with lenses of sandstone and sandy shale of the Jogira Formation and the top is recent alluvium and soil (3.5 m). The sedimentological as well as palaeontological data suggests that the Palana Formation was deposited in a fluvio-lacustrine environment with the influence of volcanism at the base. The Palana Formation is richly fossiliferous with plant leaves, rare fishes, and invertebrates. The characteristic pollen assemblages viz., *Sastripollenites trilobatus*, *Ratariacolporites plicatus*, *Clavaperiporites jacoberi*, *C. densus*, *Trianguloritesbellus*, *Dermatobrevicolporites exaltus* and *Kielmeyerapollenites eocenicus* reported from the Palana Formation indicate an early Eocene (Ypresian) age (Shukla et al. 2014b). A similar pollen assemblage is also known from the early Eocene Naredi Formation of the Kutch Basin (Kar and Saxena, 1981; Kar, 1985), and the Cambay Formation of the Cambay Basin (Kumar, 1996; Rao *et al.*, 2013); and a late Paleocene-early Eocene age was reported for the lignite and associated sediments of Rajasthan in general (Kar and Sharma, 2001).

MATERIAL AND METHOD

The specimen was recovered by hand picking from the thin, laminated, maroon shale, carbonaceous shale bed and sandstone of the Palana Formation exposed in the Gurha opencast lignite mine, Bikaner District,



Text-Figure 1 a. Geological map of the study area.

Rajasthan. The Palana Formation has yielded abundant plant remains and rare fish fossils The specimen was studied using a Leica MZ-6 microscope and photographs were taken using a Nikon D5500 DSLR camera and Olympus digital micro pad 777. After taking the photographs we have drawn the outline with the help of "Corel Draw" X7 software. The identification of the fossil materials was carried out with the help of herbarium specimens at the Department of Botany, HNB Garhwal University, Srinagar, Uttrakhand. Identification has also been carried out through the direct collection of known plant specimens from nearby area as well as through already published and online data. For the description of fossil leaves the terminology given by Hickey 1973; Dilcher, 1974; Pole (1991); Ash *et al.*,1999 has been followed. All the fossil specimens and photographs/negatives have been deposited at Department of Geology, HNB Garhwal University, Srinagar, Uttarakhand. Museum cataloged GU/R/B/G indicates, Garhwal University/ Rana/ Bikaner/Gurha for the studied fossil leaves and insects.

SYSTEMATIC PALAEOBOTANY

Order- Malvales

Family-Malvaceae

Genus- *Grewia* Linn.

Grewia eocenica n. sp.

(Text-Figure 2 a, b)

Material - One complete leaf specimen, well preserved on thin layered maroon shale.

Diagnosis-Fossil leaf symmetrical, orbicular in shape with cordate base, serrated to crenate margin, acuminate apex, actinodromous venation, secondary veins 5-6 pairs, alternate to opposite, thin, with 35°-40° angle of divergence, percurrent tertiary veins wide oblique to right angle in relation to primaries, close to distant.

Description – Fossil leaf symmetrical, orbicular, base cordate; margin serrate to crenate; apex not preserved, seemingly acuminate; size 12.9 cm in length and 11.5 cm in width; petiole indistinct; venation actinodromous; 6-7 primaries originated from the base with angle of divergence 35°-110°. Middle primary vein nearly straight and three pair's lateral primary veins are slightly curved to straight; secondary veins 5-6 pairs, alternate to opposite, thin, with 35°-60° angle of divergence, curved upward toward the margin, branched; intrasecondary veins absent; tertiary veins comparatively thin, angle of origin usually RR, percurrent, rarely branched, oblique to right angle in relation to primaries, close to distant.

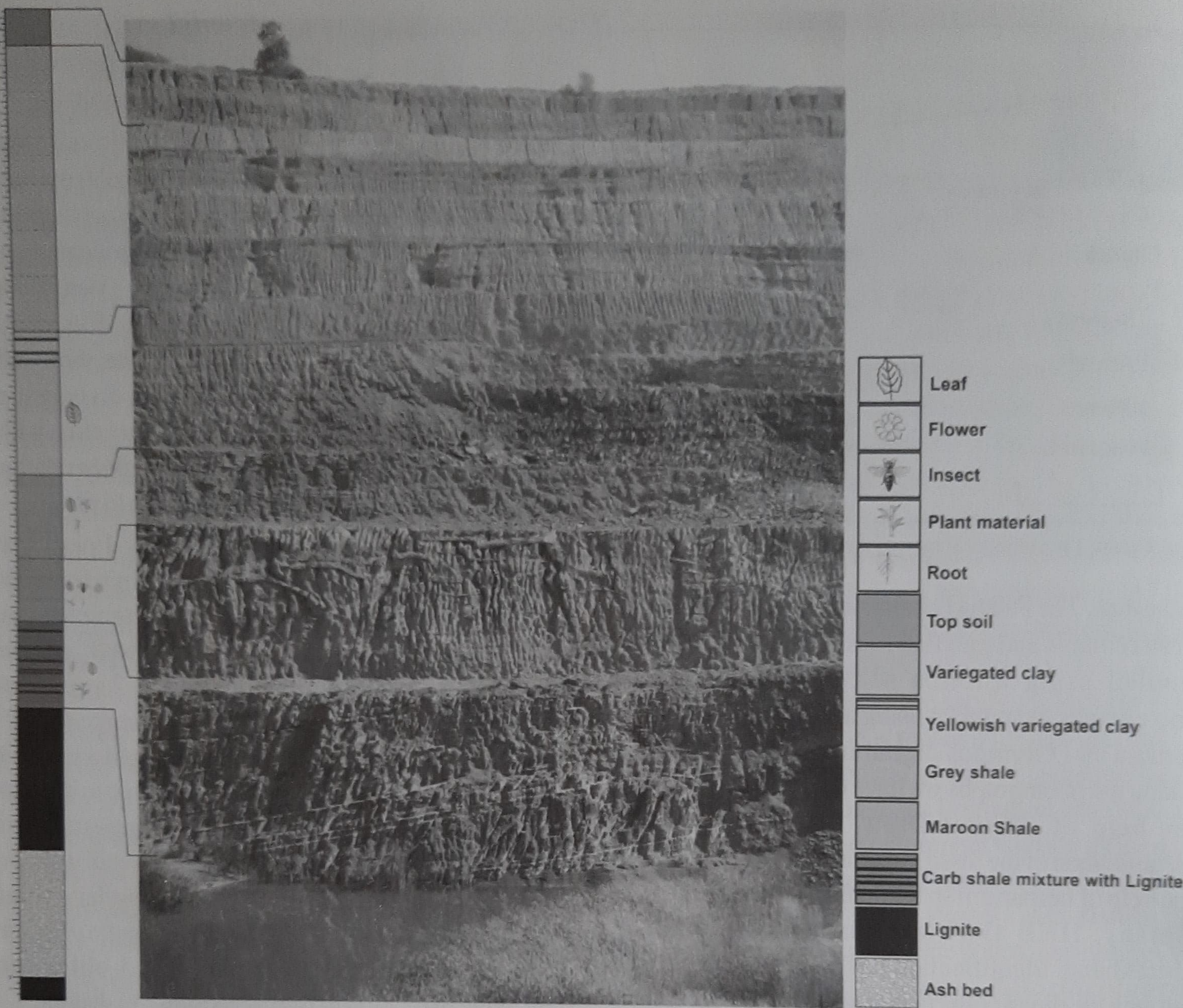
Holotype- Geology Deppt, HNB Garhwal University Museum No. GU/R/B/G/6001.

Locality - Gurha open cast lignite mine, Bikaner, Rajasthan, India.

Horizon & Age - Palana Formation, Early Eocene.

Etymology- The specific name is after 'Eocene' age of the fossil.

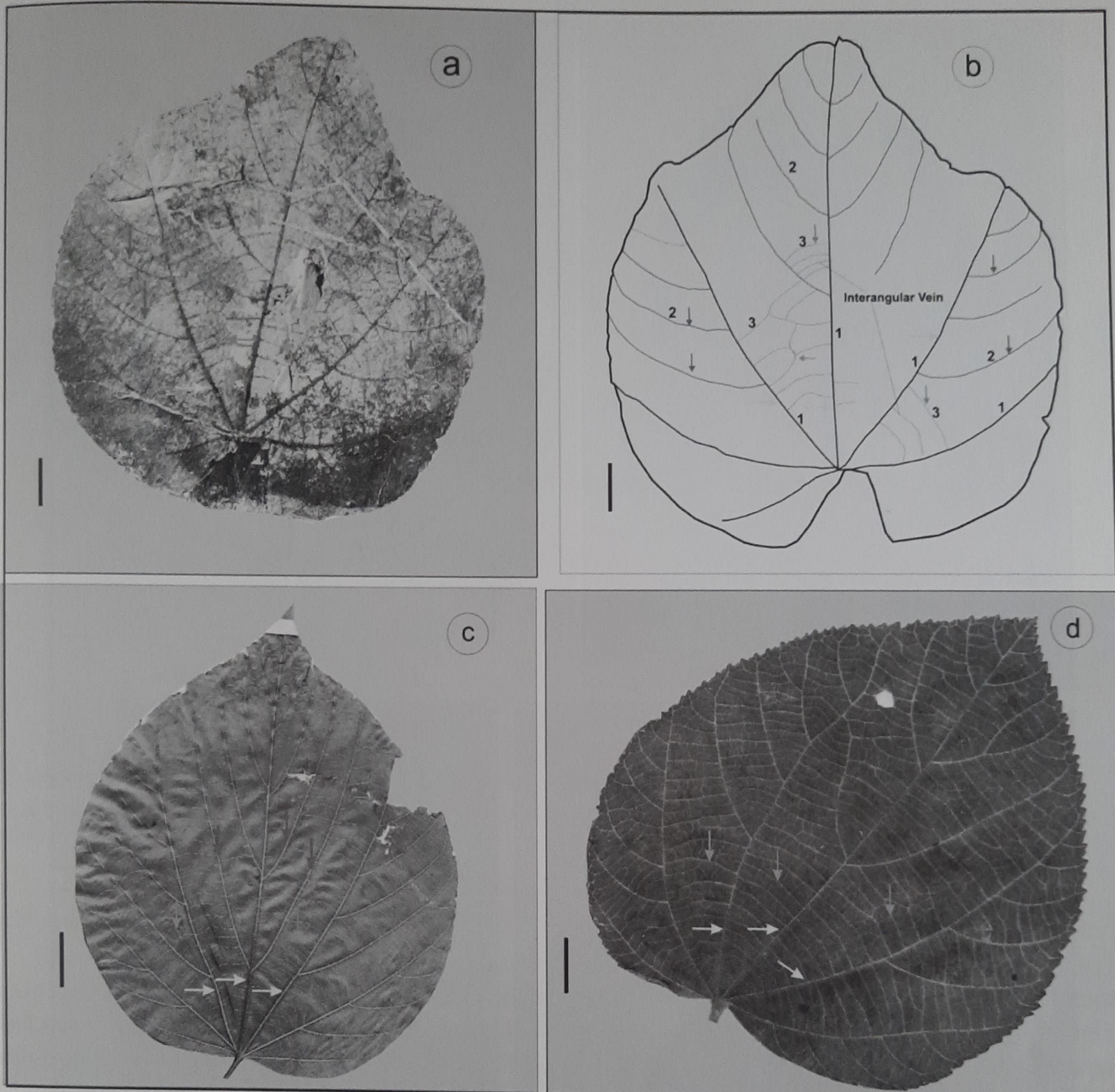
Remarks- The most important features exhibited by the present fossil leaves, like bilaterally symmetrical, orbicular shape, cordate base, actinodromous venation, 5-6 primary veins, one mid primary and other laterals rising at leaf base and sending off secondaries towards the margins, narrow to wide acute angle of divergence of opposite to sub-opposite secondary veins, presence of intersecondary veins, RR percurrent,



Text-Figure 1 b. Lithostratigraphic section of the studied Gurha lignite mine.

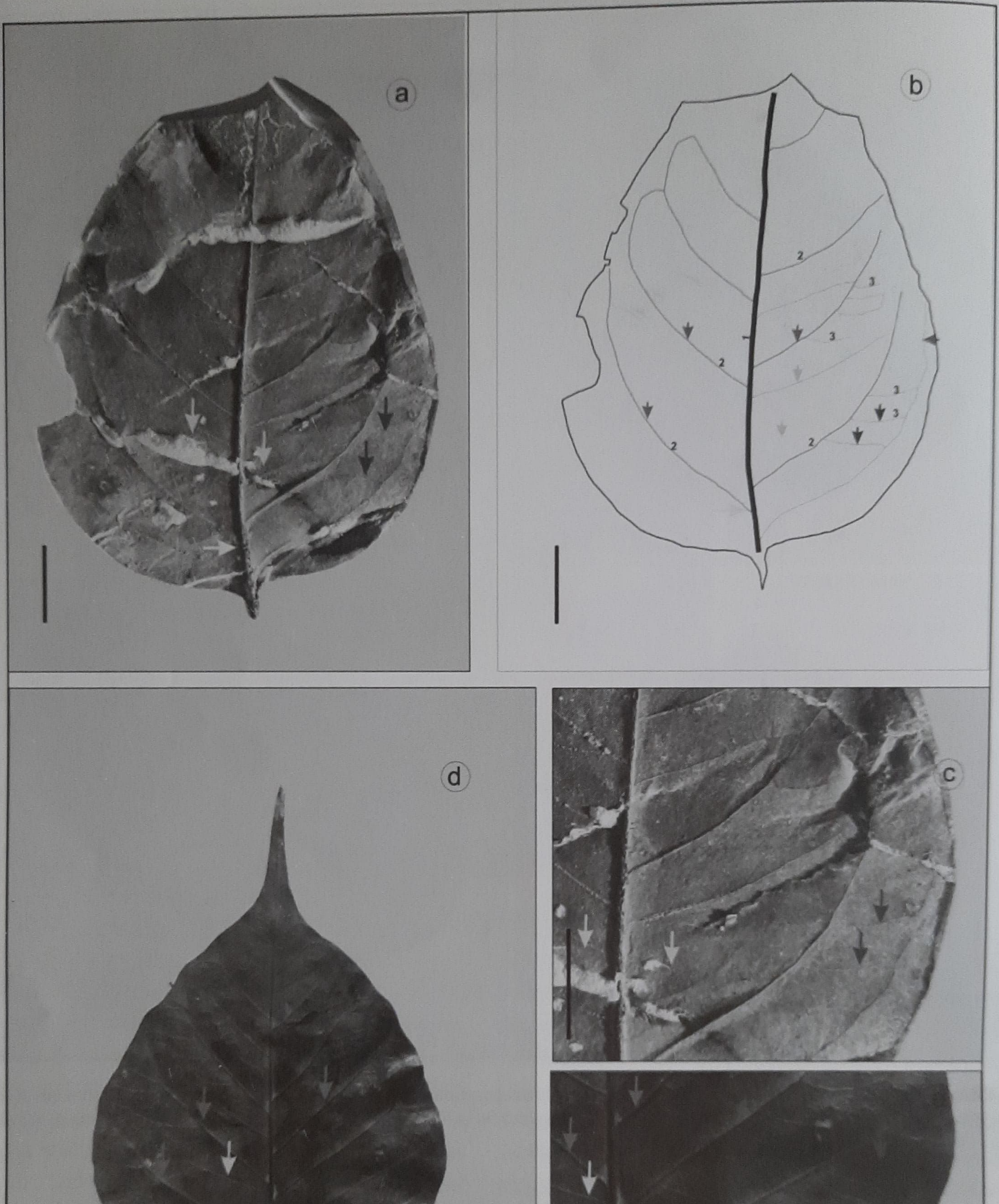
branched and nearly distant tertiary veins, suggest affinity with modern leaves of genus *Grewia* L. of family Tiliaceae. A critical study of Herbarium sheets of different species of this genus showed that the leaves of *Grewia asiatica* (Text-Figure 2d) come in closest similarity with the present fossil leaf in having similar shape, size and venation pattern. The present fossil leaf also shows some superficial similarity with the modern leaves of *Kleinhovia hospita* L. of the family Malvaceae in shape and size but differ entirely in the venation pattern. The secondary veins and at least two lateral veins arise more acutely than the fossil leaf.

Fossil leaves resembling the genus *Grewia* L. were earlier reported from the Cenozoic sediments of India and Nepal. Two fossil leaves were reported from the Siwalik sediments of Darjeeling District, West Bengal under the name *Grewia ghishia* from Ghish river section (Antal & Awasthi, 1993) and *Grewia tistaensis* (Antal & Prasad, 1998) from Sevoke Road section near Tista River Bridge. Both differ from the present fossil leaf in being of smaller size having different type of serrations. Fossil leaf reported as *G. tiliaefolia* Vahl. from late Cenozoic sediments of Mahuadanr, Palamau District, Jharkhand (Srivastava *et al.*, 1992) differs from the present fossil leaf especially in nature of base. Fossil leaves like *Grewia mallotophylla* described from Siwalik of Arung Khola, west Nepal (Konomatsu & Awasthi, 1999) *Grewia sahnii* and

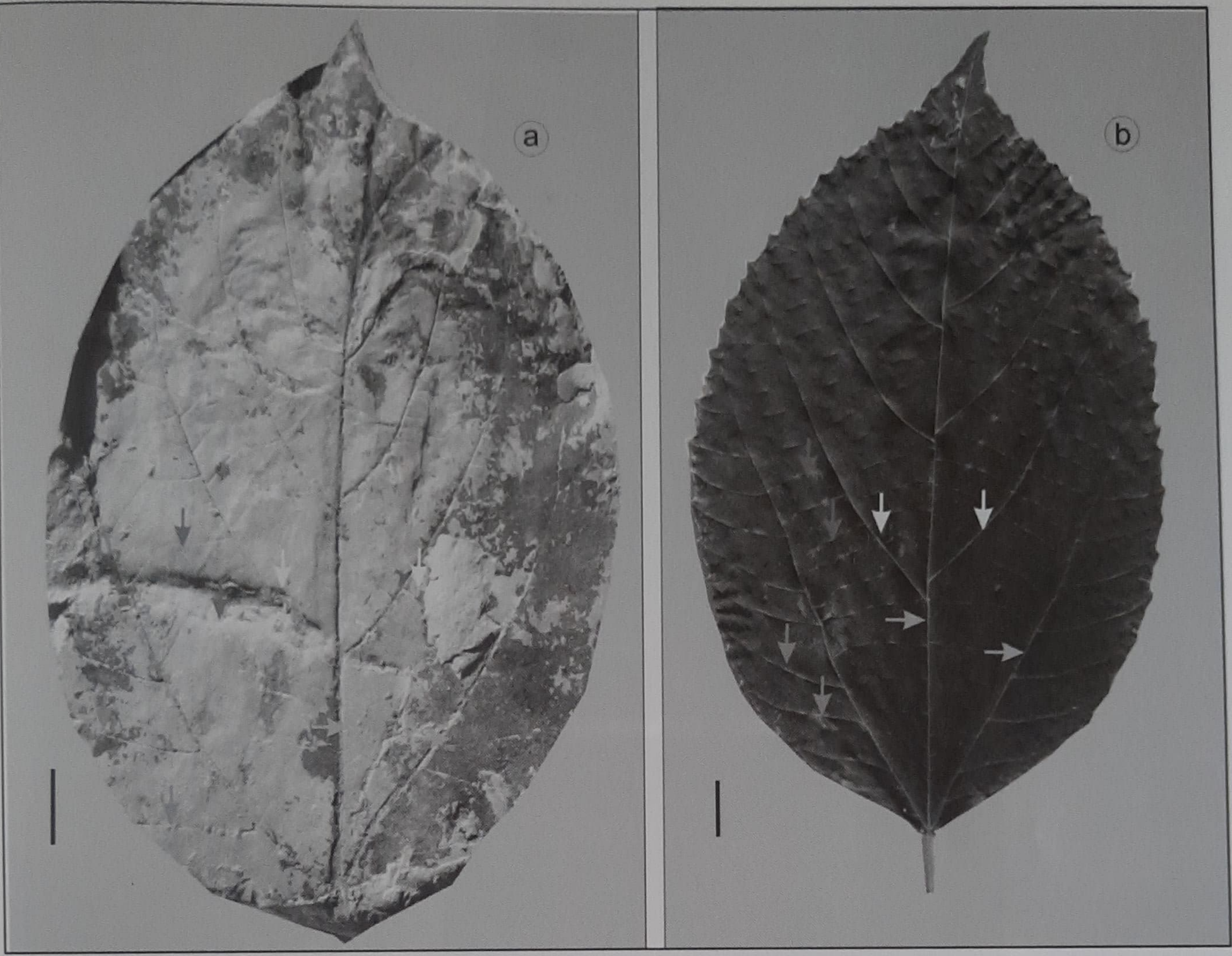


Text-Figure 2 (a). Fossil specimen (GU/R/B/G/6001); (b). Trace image; primary venation (yellow arrow); secondary venation (pink arrow); tertiary venation (blue arrow) bar scale = 0.6 cm; (c). *Kleinhovia hospita* L. modern leaf showing difference in venation pattern; (d). *Grewia asiatica*-Modern comparable leaf.

Grewia garoensis from Tura formation of Meghalaya, India (Mehrotra, 2000a) differ from the present fossil leaf in the nature and number of their primary and secondary veins. A comparison of the present fossil with another species *Grewia kathgodamensis* (Prasad *et al.*, 2004) from Siwalik of Uttarakhand, India, revealed that the two leaves were quite different as the latter was of small size and showed a different lateral veins pattern. Two fossil leaves, *G. palaeodisperma* and *G. miopaniculata,* which have recently been reported from Siwalik of Arjun Khola area, western Nepal (Prasad *et al.*, 2019) also differ from the present fossil leaf in being narrow elliptic to oblong shape, with entirely different venation pattern. Therefore, the present fossil



Text-Figure 3 (a). Fossil specimen GU/R/B/G/6002; (b). Trace image; primary venation (yellow arrow); secondary venation (pink arrow); tertiary (violet arrow), red arrow (secondary veins, brochidodromous) bar scale= 0.8 cm; (c). part of fossil leaf showing detail of venation pattern. (d). *Ficus religiosa*- modern comparable leaf. (e). Part of modern comperable leaf showing detail of similar of venation pattern.



Text-Figure 4 (a). Fossil specimen, GU/R/B/G/6003; primary venation (light blue arrow) secondary venation (yellow & dark blue arrow); tertiary venation (red arrow); bar scale= 1cm; (b). *Grewia optiva* modern comparable leaf.

leaf is described as *Grewia eocenica* n. sp.

The extant genus *Grewia* L. consists of 150 species growing specifically in the tropical region of Asia, Africa and Australia. *Grewia* is confined to the tropical and sub-tropical regions of the Old World, i.e. Africa, Madagascar, Arabia, India, Myanmar, Ceylon, Andaman-Nicobar, Malaya Peninsula, East Indies, Indo-China, extending to North Australia. The genus is fairly represented in India. About 34 species are found in the Indian sub-continent. *Grewia asiatica,* with which the fossil resembles closely, is a small tree distributed in dry savanahs in the east and southern parts of Africa (Mabberley, 1997).

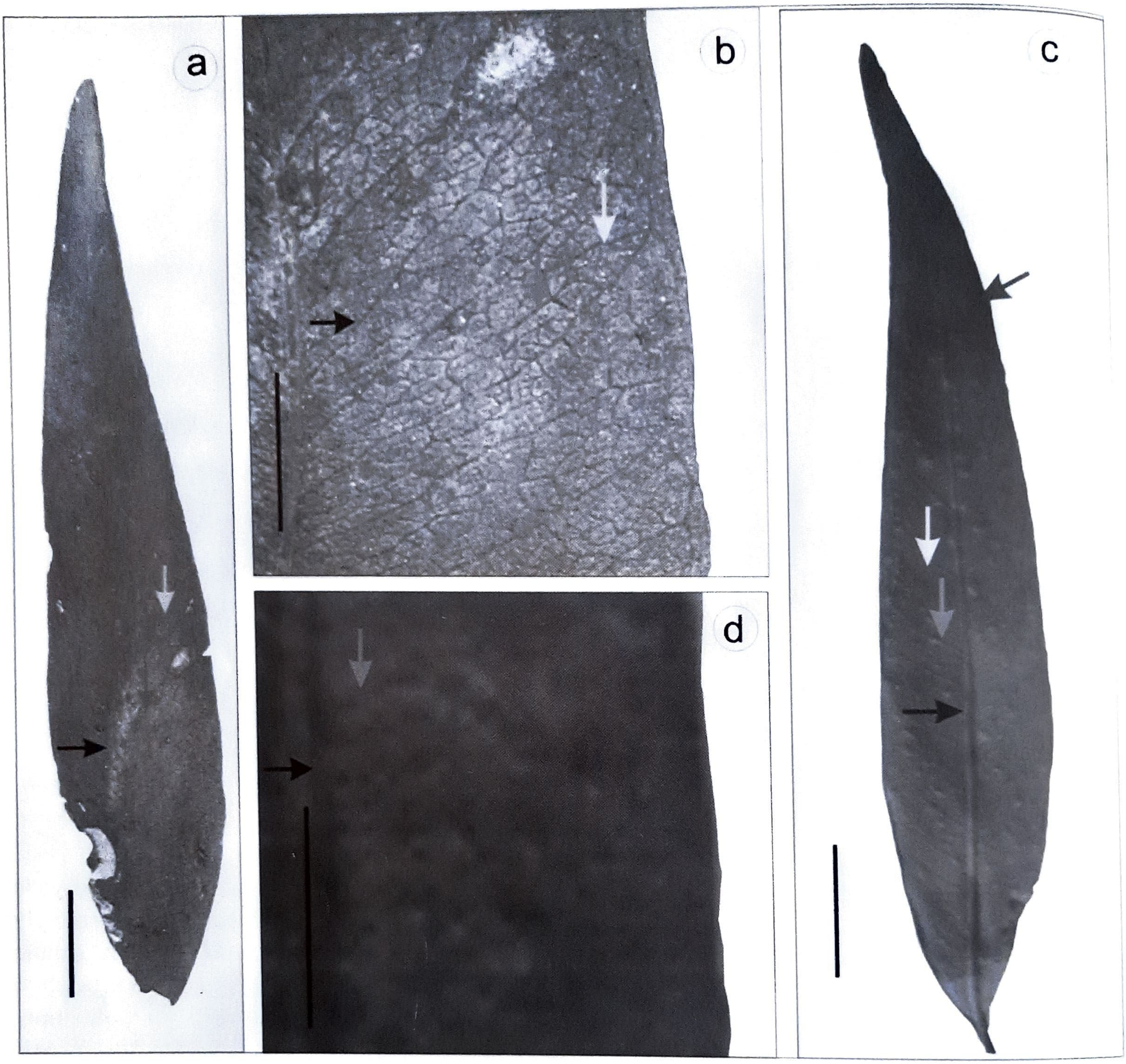
Grewia bikanerensis n. sp.

(Text-Figure 4 a)

Material - One well preserved fossil leaf on maroon shale.

Diagnosis- Fossil leaf simple, symmetrical, wide elliptic, preserved size 9.9x7.9 cm, apex seemingly acute, margin serrate, venation pinnate, simple craspedodromous, secondary veins 6-7 pairs, up to 2.5 cm apart, angle of divergence 40° - 60°, uniformly curved up, basal pair of secondary veins run upwards for a long distance and giving off branches; tertiary veins fine, angle of origin RR, percurrent, oblique to right angle in relation to midvein, close to nearly distant.

Description - Fossil leaf simple, symmetrical, wide elliptic; preserved size 9.9x7.9 cm; apex slightly broken, seemingly acute; base seemingly obtuse; margin serrate; texture chartaceous; venation pinnate, simple craspedodroumous; primary vein single stout, almost straight; secondary veins 6-7 pairs, less than 0.5 -2.5 cm apart alternate to opposite, angle of divergence 40°-60°, acute, uniformly curved up and unbranched,



Text-Figure 5. (a). Fossil specimen GU/R/B/G/6004, (b). close view of lamina, (c), (d). modern leaf. (scale= 1.5 cm).

basal pair of secondary veins run upwards for a long distance and giving off branches running towards margin; tertiary veins fine, angle of origin RR, percurrent, straight to sinuous, branched, oblique to right angle in relation to midvein, predominantly alternate, close to nearly distant. Further details not distinct.

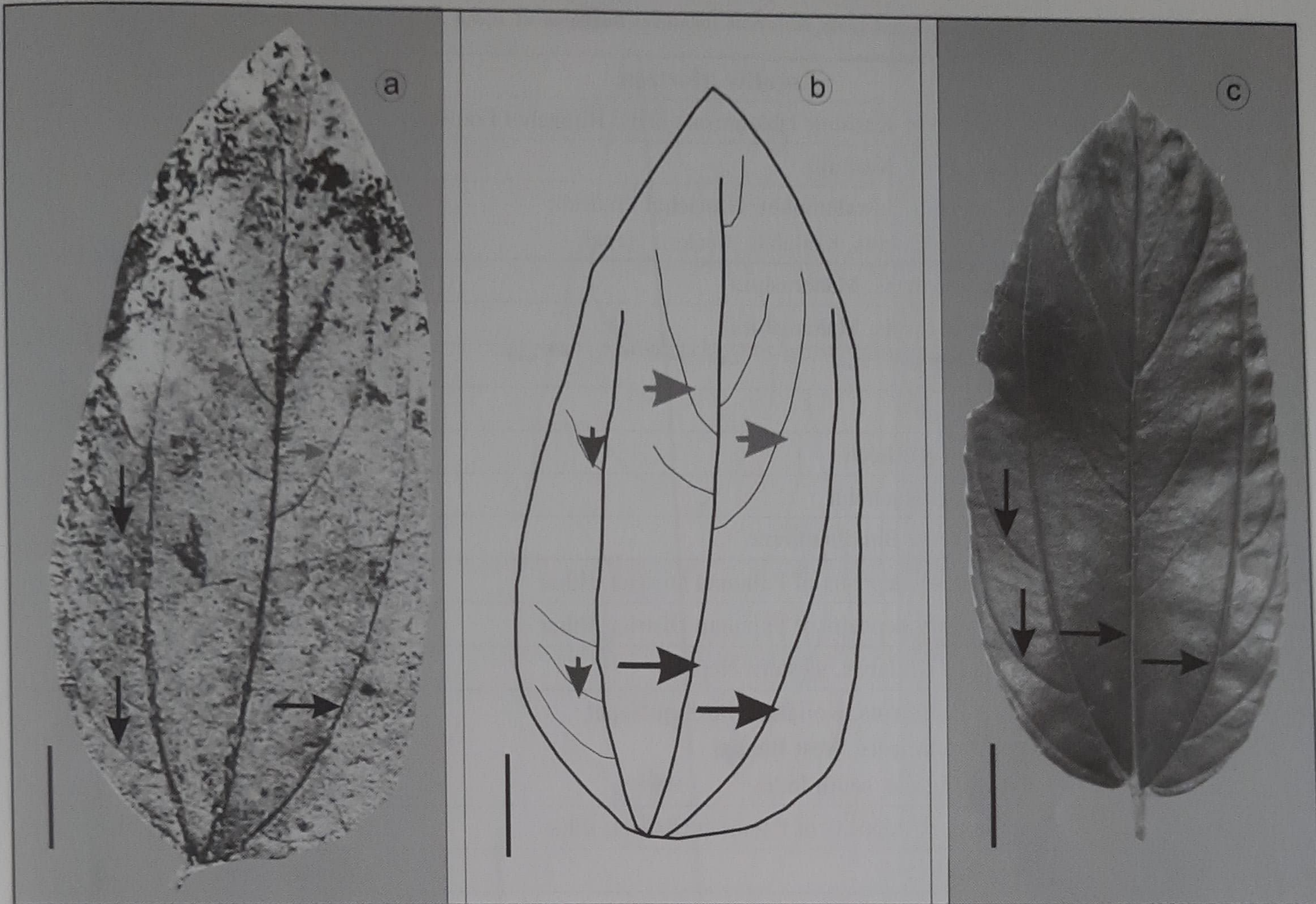
Holotype- Geology Deppt, HNB Garhwal University Museum No. GU/R/B/G/6003.

Locality - Gurha open cast lignite mine, Bikaner, Rajasthan, India.

Horizon & Age - Palana Formation, Early Eocene.

Etymology- The specific name is after a famous town, Bikaner situated near the fossil locality.

Remarks- The characteristic features of the present fossil, such as wide elliptic shape with obtuse base,



Text-Figure 6 (a). Fossil specimen, GU/R/B/G/6005, (b). trace image; primary venation (black arrow); secondary venation (red arrow); tertiary venation (violet arrow), bar scale= 1.1 cm; (c). modern comparable leaf, *Ziziphus apetala*.

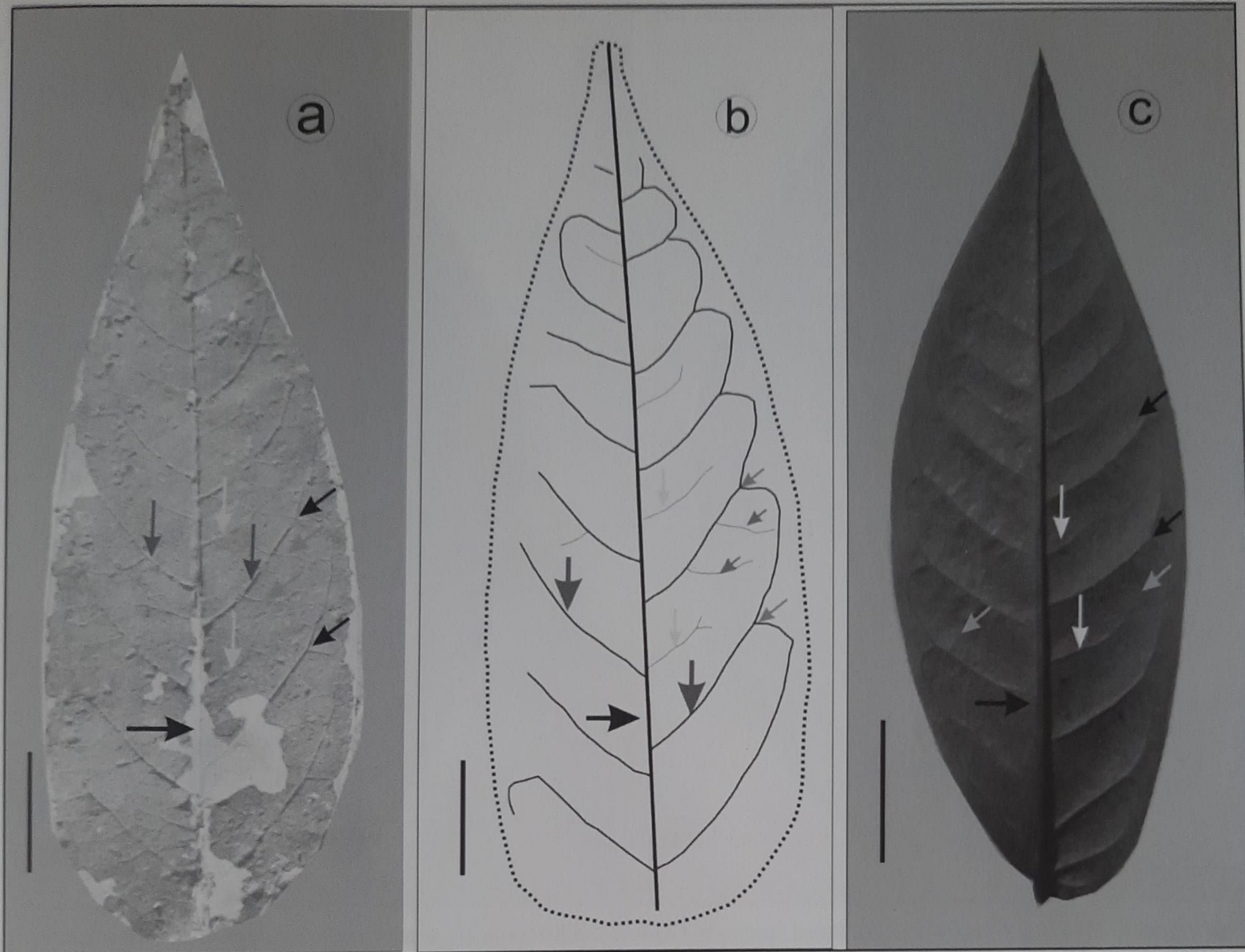
serrated margin, craspedodroumous venation, secondary venation, acute, uniformly curved up secondary veins, basal pair of which run upwards towards for a long distance and giving off branches running towards margin and percurrent, straight to sinuous, RR, nearly closed tertiary veins undoubtedly indicate its resemblance with the modern leaves of the genus *Grewia* Linn. of the family Tiliaceae. Among the different species of the genus *Grewia* Linn. the fossil shows closest affinity with the modern leaves of *Grewia optiva* (Herbarium sheet no. GUH 4564, Fig. 4 b). The fossil leaf also shows some similarity with the modern leaves of *Hibiscus rosasinensis* (Herbarium sheet no. GUH 4564) of the family Malvaceae, but the leaves of *Hibiscus rosasinensis* differs in having well serrated margin. It also possesses brochidodromous type of venation pattern as compared to craspedodroumous venation in the present fossil leaf.

So far, ten fossil leaves have been reported from the different Cenozoic localities of India and Nepal (mentioned earlier in this text). One of them, *G. eocenica* is described in this text showing close affinity with the extant species, *G. asiatica.* It differs from the present fossil leaf in nature of base and nuumber of basal secondaries. The other known fossil leaves have also been compared with the present fossil leaf and concluded that none of them show complete resemblance with this fossil. *Grewia tistaensis* Antal & Prasad, 1998 which is described from the Siwalik of Darjeeling District, West Bengal and showing modern affinity with *G. tiliaefolia* Vahl. resembles closely in shape and size but differs in nature and angle of basal pair of secondary veins. In view of this, the present fossil leaf is being described as *G. bikanerensis* n. sp.

Grewia optiva with which the fossil shows resemblance is a small tree distributed in the moist

Table- List of *Ficus* Linn. species recorded from different localities/horizons of India and Nepal

Fossil Species	Locality /Horizon	References
F. cunia	Karewa beds, Kashmir Dharamsala beds, Himachal Pradesh	Puri, 1947; Gupta & Jiwan, 1972
F. nemoralis	Karewa beds, Kashmir	Puri, 1948
F. precunia	Siwalik beds, Jawalamukhi, Himachal Pradesh; Siwalik sediments, Koilabas, western Nepal	Lakhanpal, 1968 Prasad, 1990a
Ficus arnottiana	Quaternary beds, Maharashtra	Mahajan & Mahabale, 1973
F. glomerata	Quaternary beds, Maharashtra	Mahajan & Mahabale, 1973
F. caricites	Mewar State	Trivedi, 1980
F. religiosities	Mewar State	Trivedi, 1980
F. kachchhensis	Eocene of Kachcch	Lakhanpal & Guleria, 1981
F. khariensis	Miocene of Kachchh	Lakhanpal & Guleria, 1982
F. champerensis	Siwalik beds, Bhikhnathoree	Lakhanpal & Awasthi, 1984
F. foveolata	Late Tertiary deposits of Palamau District, Bihar	Bande & Srivastava, 1990
F. glaberrima	Late Tertiary deposits of Palamau District, Bihar	Bande & Srivastava, 1990
F. nepalensis	Siwalik of Koilabas, western Nepal	Prasad, 1990a
F. retusoides	Siwalik sediments, Koilabas, western Nepal Siwalik sediments, West Bengal Neyveli Lignite, south India	Prasad, 1990a; Antal & Awasthi, 1993 Agarwal, 2002
F. tomentosa	Late Tertiary deposits of Palamau District, Bihar	Bande & Srivastava, 1990
F. cherrapunjiensis	Paleocene	Ambwani, 1991
Ficus sp. cf *F. tomentosa* Roxb.	Dagshai Formation, Himachal Pradesh	Mishra & Mathur, 1992
F. oodlabariensis	Siwalik of West Bengal	Antal & Awasthi, 1993
F. raptiensis	Siwalik sediments, Surai Khola, western Nepal	Prasad & Awasthi, 1996
F. barogensis	Kasauli Formation, Barog, Himachal Pradesh	Mathur *et al.*, 1996
F. banogensis	Dagshai Formation and Dharamsala Formation, Himachal Pradesh	Mathur *et al.*, 1996
F. kasaulica	Kasauli Formation, Barog, Himachal Pradesh	Mathur *et al.*, 1996
F kumarhattiensis	Dagshai Formation, Himachal Pradesh	Mathur *et al.*, 1996
Ficus sp.	Dagshai Formation, Solan District, Himachal Pradesh	Mathur *et al.*, 1996
F. prereligiosa	Mar Formation (Neogene), Bikaner District, Rajasthan	Mathur & Mathur, 1998
Ficus sp.	Mar Formation (Neogene), Bikaner District, Rajasthan	Mathur & Mathur, 1998
F. miocenica	Siwalik sediments, western Nepal	Konomatsu & Awasthi, 1999
F. benjamina	Quaternary beds of Sirmur District, Himachal Pradesh; Siwalik sediments of Himachal Pradesh	Prasad *et al.*, 2002 Prasad, 2006
F. eumysorensis	Siwalik sediments near Jarva, Uttar Pradesh	Tripathi *et al.*, 2002
F. precurticeps	Neyveli, Lignite, South India	Agarwal, 2002
F. microcarpa	Late Tertiary beds of Mahuadanr Valley, Jharkhand	Singh & Prasad, 2008
F. curticeps	Late Tertiary beds of Mahuadanr Valley, Jharkhand	Singh & Prasad, 2008
F. palaeoracemosa	Kasauli Formation, Himachal Pradesh	Srivastava *et al.*, 2011



Text-Figure 7 (a). Fossil specimen, GU/R/B/G/6006, primary venation (Black arrow); secondary venation (red arrow); intersecondary venation (yellow arrow); tertiary venation (green arrow); (b). trace image; bar scale= 1cm; (c). modern comparable leaf.

deciduous forests of entire region of India.

Order- Rosales

Family- Moraceae

Genus- *Ficus* Linn.

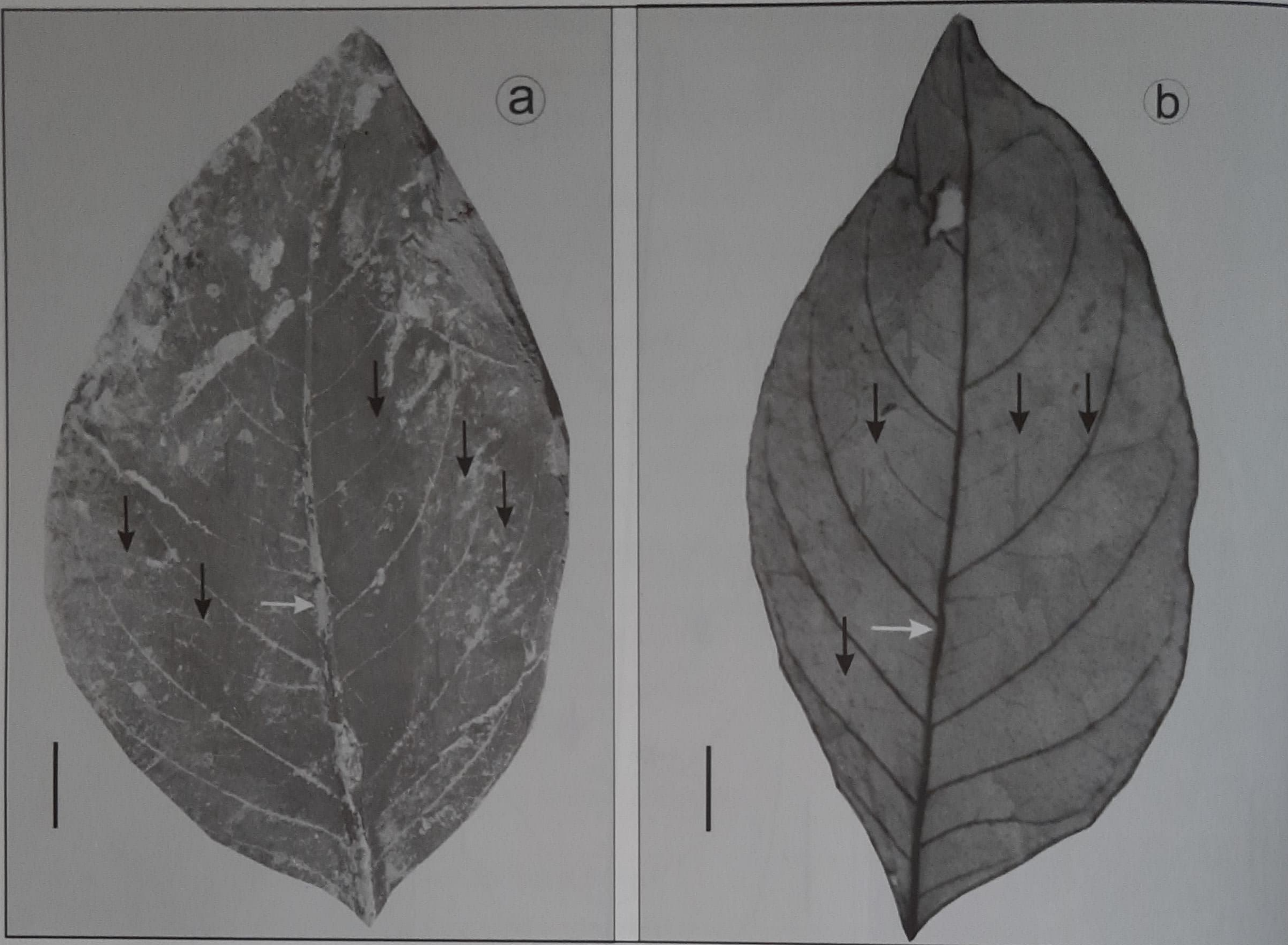
Ficus eoreligiosa n. sp.

(Text-Figure 3a,b,c)

Material- One almost complete leaf impression with counterpart (GU/R/B/G/6002) preserved on thin layered maroon shale.

Diagnosis- Fossil leaf simple, symmetrical, ovate shape with obtuse base, preserved size 10.1x8.5cm, entire margin, venation eucamptodroumous to brochidodromous, secondary veins 6-8 pairs, alternate, angle of divergence 40º-60º, seemingly unbranched, tertiary veins fine with angle of origin usually RR, percurrent, close.

Description - Fossil leaf simple, symmetrical, ovate; preserved size 10.1x8.5cm; apex broken; base obtuse; margin entire; petiole preserved, well distinct but broken; venation eucamptodroumous to brochidodromous; primary vein single, prominent almost straight, stout; secondary veins 6-8 pairs visible, up to more than 2cm apart, alternate, uniformly curved upward toward the margin, angle of divergence 40º-60º, intersecondary veins present, simple rare; tertiary veins fine with angle of origin usually RR, percurrent, oblique in relation to mid vein, predominantly alternate and close. Further details not seen.



Text-Figure 8. *Clausena hepatophylla* (a). Fossil specimen, GU/R/B/G/6007; primary venation (yellow arrow); secondary venation (red arrow); intersecondary venation (black arrow); bar scale= 1cm; (b) Modern counterpart.

Holotype- Geology Deppt, HNB Garhwal University Museum No. GU/R/B/G/6002.

Locality - Gurha open cast lignite mine, Bikaner, Rajasthan, India.

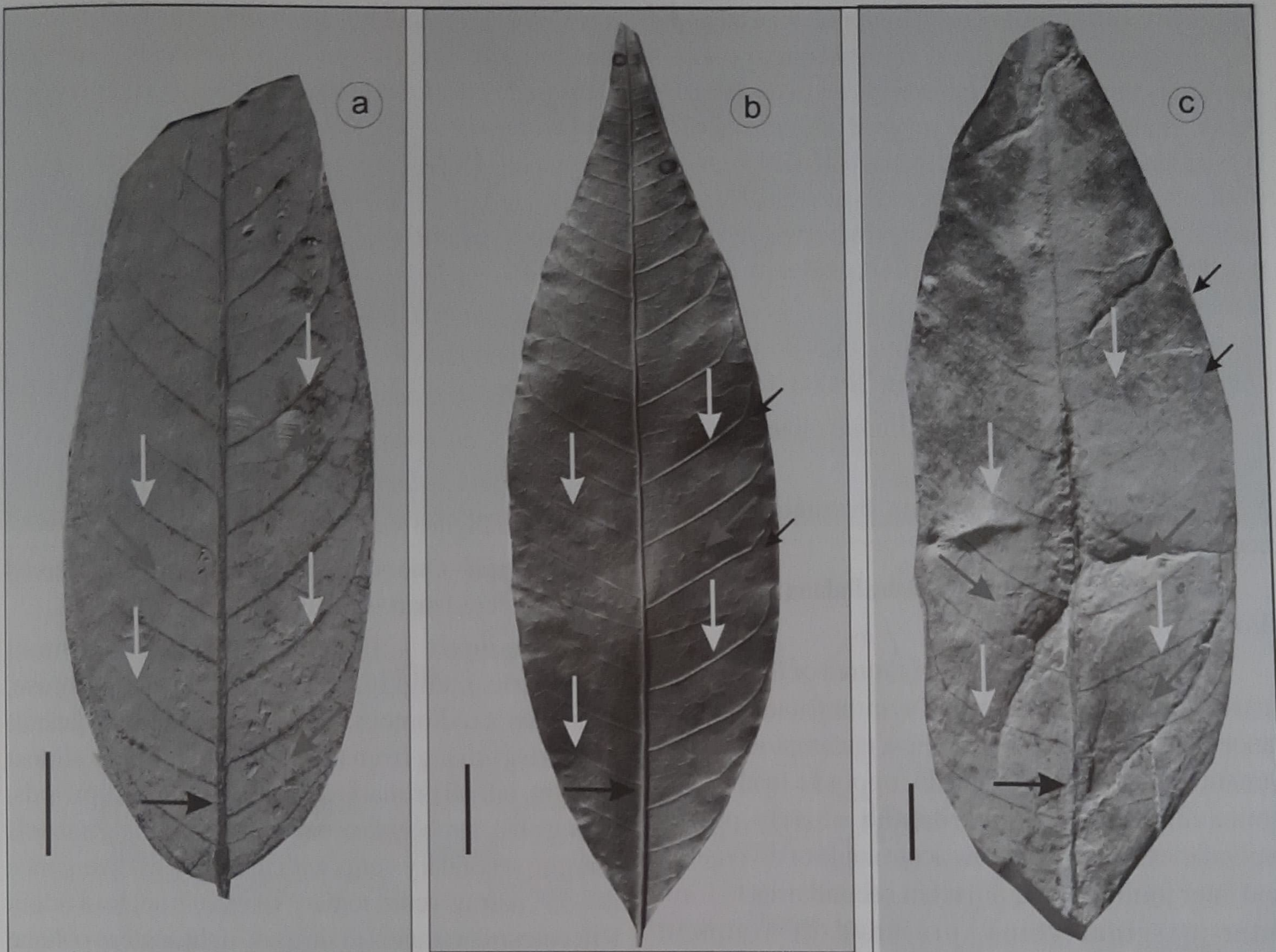
Horizon & Age - Palana Formation, Early Eocene.

Etymology- By adding a prefix 'eo' to the name of modern comparable species, *F. religiosa*.

Remarks- Morphological features such as symmetrical, ovate shape, eucamptodromous to brochidodromous venation pattern, secondary veins uniformly curving upwards and joining super adjacent secondaries forming a loop, presence of simple inter secondary veins, basal pair of secondaries arising with greater angle and running upwards towards the margin, usually RR, percurrent and close arrangement of tertiaries in the present fossil leaf show resemblance with the modern leaves of *Ficus religiosa* (specimen no. GUH 6084; Fig.3 d,e) of the family Moraceae.

So far, about 32 species of fossil leaves resembling *Ficus* Linn. are reported from the Cenozoic sediments of India and Nepal. They are listed below in Table. A comparison of the present fossil leaf with the species listed in the Table showed difference in shape, size and venation pattern, especially the nature of base and basal pair of secondary veins. Therefore, the present fossil leaf is described as new species *Ficus eoreligiosa*..

The genus *Ficus* L. consists of about 750 species distributed in India and tropics of both hemispheres especially Indo-Malaya to Australia, Africa and America. *Ficus religiosa* is a large tree distributed in



Text-Figure 9 (a) Fossil specimen, GU/R/B/G/6008; 9 (c) specimen, GU/R/B/G/6009; primary venation (black arrow); secondary venation (yellow arrow); tertiary venation (red arrow); bar scale= 1.6 cm; (b) modern leaf, *Magnifera indica*.

the semi evergreen forests of Assam, Cachar Hills and Tenasserim (Brandis, 1971).

Order – Myrtales

Family-Myrtaceae

Genus-*Eugenia* Linn.

***Eugenia eocenica* n. sp.**

(Text-Figure 5 a,b)

Material- Single, complete leaf specimen preserved on the thin layered carbonaceous shale.

Diagnosis- Leaf symmetrical, narrow lanceolate; preserved size 9.3x2.2cm; apex attenuate; venation pinnate, eucaptododromous, secondary veins more than 25 pairs visible with acute angle of divergence (about 40^0-55^0), very closely placed, opposite to alternate, uniformly curving upwards concavely to join super adjacent secondaries and forming inter-marginal vein all along the margins, intersecondary veins frequently present, tertiary veins very fine, angle of origin usually RR type, forming quadrangular to polygonal meshes indicating reticulate type.

Description - Leaf simple, almost symmetrical, narrow lanceolate; preserved size of leaf 9.3 cm long and 2.2 cm wide; apex attenuate; base seems to be acute; margins entire; texture chartaceous; venation pinnate, eucaptododromous; primary vein single, straight, weak; secondary veins more than 25 pairs visible with acute angle of divergence (about 40^0-55^0), very closely placed, opposite to alternate, uniformly curving upwards concavely to join super adjacent secondaries and forming inter-marginal vein all along the margins; unbranched, intersecondary veins frequently present, 1-2 veins in between two secondary veins; tertiary veins very fine, angle of origin usually RR type, sometimes percurrent, branched, and joined to intersecondary veins and its tertiary veins forming quadrangular to polygonal meshes indicating reticulate type, predominantly alternate, close, oblique in relation to midvein.

Holotype- Geology Deppt, HNB Garhwal University Museum No. GU/R/B/G/6004.

Locality - Gurha open cast lignite mine, Bikaner, Rajasthan, India.

Horizon & Age - Palana Formation, Early Eocene.

Etymology- After the age of the Palana Formation, 'Eocene'.

Remarks- Characteristic features of the present fossil leaf, such as almost symmetrical, narrow lanceolate shape, attenuated apex, eucamptodromous venation pattern, more than 25, opposite to alternate concavely curved upwards and closely placed secondaries showing narrow acute angle of divergence and later joining super adjacent secondaries to form inter-marginal veins, presence of frequent intersecondary veins, RR, sometimes percurrent, and reticulate type of tertiaries indicate closest resemblance with the modern leaves of *Eugenia occidentalis* (C.N.H. Herbarium sheet no. 66156; Fig. c & d) of the family Myrtaceae.

So far, only three fossil leaves resembling the genus *Eugenia* L. have been reported from the Cenozoic sediments of the Indian sub-continent. *Eugenia lamhiensis* (Prasad *et al.*, 2017) and *E. nepalensis* (Prasad *et al.*, 2019) from Middle Siwalik of Arjun Khola area, western Nepal and *Eugenia* sp. cf *E. americana* Makoy ex E. Morren from Middle Eocene of south-western Kachchh, Gujrat (Bajpai & Singh, 1987). A comparison of the present fossil leaf with previously reported ones revealed that the species *E. lamhiensis,* described from the Siwalik locality differed from the present leaf in having smaller and broader size. The other fossil leaf, *Eugenia* sp. cf *E. americana* is also small sized and falcate in shape, instead of being narrow lanceolate shape in the presently described fossil. Thus, the fossil leaf is described as a new species, *Eugenia eocenica* n. sp.

Genus *Eugenia* L. comprises of about 550 species distributed in the wet ever green forest of America, Australia, eastern New Guinea, eastern Bengal, North-east and South India. *Eugenia occidentalis* with which fossil resembles is found in the indian regions.

Order-Rasales

Family-Rhamnaceae

Genus-*Ziziphus* Juss

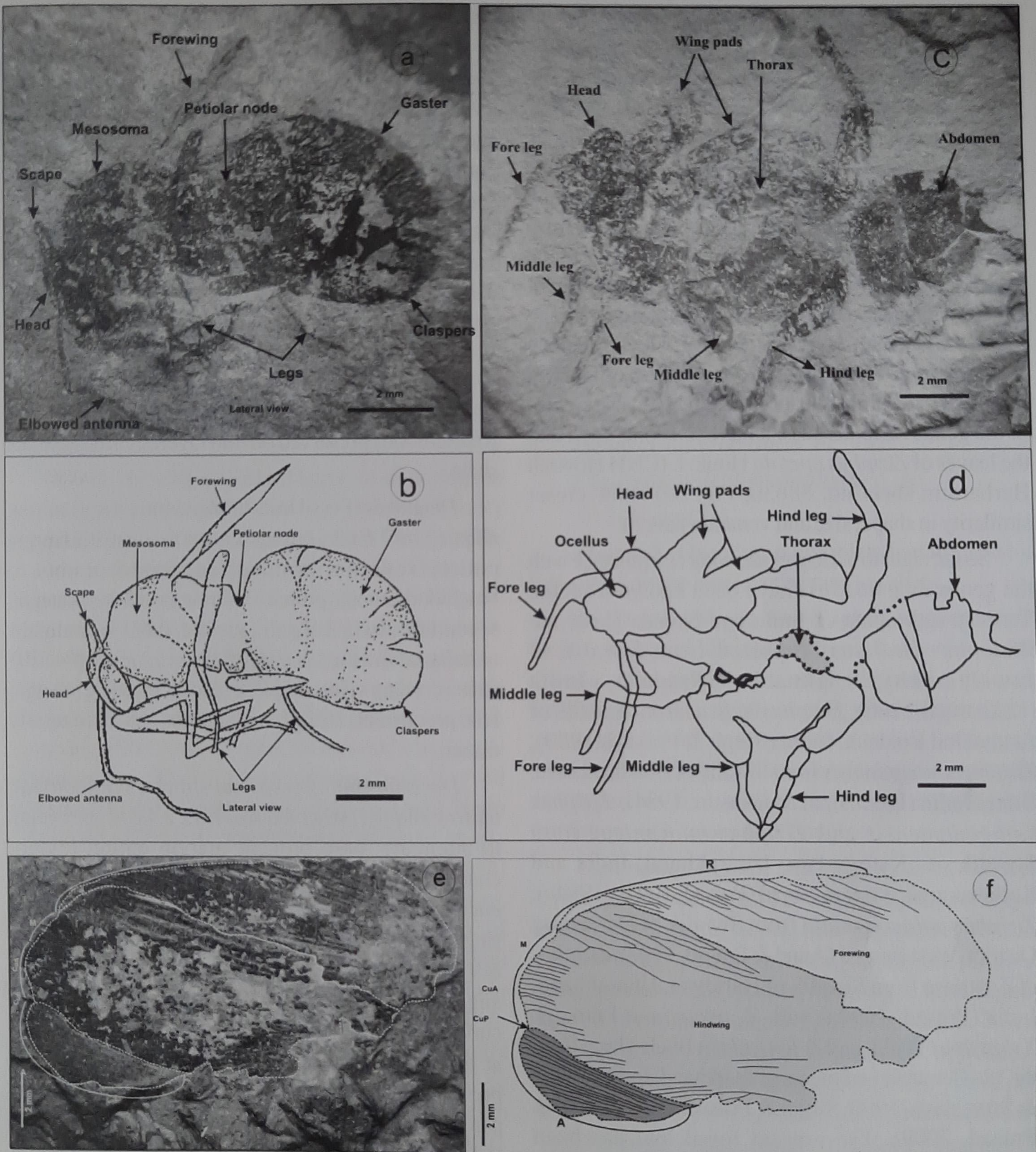
Ziziphus palaeoapetala Antal & Prasad, 1997

(Text-Figure 6 a, b)

Material - One complete leaf impression preserved on thin layered maroon shale.

Diagnosis - Fossil leaf simple, almost symmetrical, elliptic, size 9.6x42cm, base obtuse, venations acrodromous, three (one mid and two lateral) primaries arising from the base, mid primary almost straight, lateral primaries uniformly curved upwards, giving off a number of secondary veins running towards margin; secondary veins with the angle of divergence 40^0-55^0, narrow acute, tertiary veins with angle of origin RR, percurrent straight to sinuous, right angle to oblique in relation to primary veins, predominantly alternate and close.

Description -Fossil leaf simple, almost symmetrical, elliptic; size 9.6x4.2cm; apex acute; base obtuse; margin almost entire; texture chartaceous; petiole broken; venation acrodromous; primary veins three (one mid and two lateral primaries), arising from the base, mid primary almost straight, prominent, stout, lateral primaries uniformly curved upwards, giving off a number of secondary veins running towards margin; secondary veins arising from midvein are four in pairs visible from half of apical portion, with the angle of divergence 40^0-55^0, narrow acute, uniformly curved up and joined to the margin and few secondaries arising from lower half portion (poorly preserved) run upwards and joined to the lateral primaries; tertiary veins are poorly preserved with angle of origin RR, percurrent, straight to sinuous and sometimes branched, right angle



Text-Figure 10. a, b. *Formica* sp., (GU/R/B/G/ 3001), c, d. *Mayfly naiad* (GU/R/B/G/3002), e-f. Baetidae insect wing (GU/R/B/G/ 3004),

to oblique in relation to primary veins, predominantly alternate and close.

Holotype- Geology Deppt., HNB Garhwal University Museum No. GU/R/B/G/6005.

Locality - Gurha open cast lignite mine, Bikaner, Rajasthan, India.

Horizon & Age - Palana Formation, Early Eocene.

Remarks - The diagnostic features of the present fossil leaf such as elliptic shape, acute apex, almost entire margin, acrodromous venations and narrow acute angle of divergence of secondary veins show resemblance with the extant leaves of most of the species of *Grewia* Linn. of family Tiliaceae and *Ziziphus* Juss of the family Rhamnaceae. The leaves of *Grewia* Linn. differ from present fossil leaf in the nature and arrangement of the secondary veins. The secondary veins in the present fossil leaf arise from mid primary veins and are more in number and join to the lateral primary of their side. The feature was not found in the extant leaves of Grewia Linn. On a critical examination of all the available species of the genus *Ziziphus* Juss, it has been concluded that the leaves of *Ziziphus apetala* Hook. f. (CNH Howrah Herbarium sheet no. 88636; Fig. 6c) show closet similarity in shape, size and venation pattern.

So far, eight fossil leaves showing resemblance with the genus *Ziziphus* Juss have been known from the Tertiary sediments of India and Nepal. These are *Ziziphus siwalicus* reported from Siwalik of Jawalamukhi, Himachal Pradesh, India (Lakhanpal,1966); *Ziziphus indicus* from Siwalik of Arunachal Pradesh, India (Singh & Prakash,1980); *Ziziphus champarensis* from Siwalik of Bhikhnathoree, Bihar, India (Lakhanpal & Awasthi, 1984*); Ziziphus kathgodamensis* and *Ziziphus miocenicus* from Siwalik of Kathgodam, Uttarakhand, India and Koilabas area, western Nepal (Prasad, 1994b, 1994c); *Ziziphus palaeoapetala* from Siwalik of Darjeeling District, West Bengal (Antal & Prasad, 1997); *Ziziphus cf Z. rugosa* from Siwalik of Haridwar, Uttarakhand, India (Prasad, 1994a) and *Z. maurtiana* Lam., *Z. Xylopyrous* Willd. and *Z. funiculosa* Buch-Ham. from the late Cenozoic sediments of Jharkhand, India (Bande & Srivastava, 1990; Singh & Prasad, 2007; Singh & Prasad, 2009). The present fossil leaf has been compared with all the known species of the genus *Ziziphus* Juss and concluded that the fossil leaf, *Ziziphus palaeoapetala* Antal & Prasad described from Siwalik sediments of West Bengal shows closest similarity with our fossil in shape size and venation pattern. Thus, the present fossil leaf has been kept under the same species, *Ziziphus palaeoapetala* Antal & Prasad.

The genus *Ziziphus* Juss consists of about 86 species of spiny shrubs and small tree (Mabberley, 1997) and distributed in the warm temperate and sub-tropical regions throughout the world. It is more common in the Indo-Malayan regions. The comparable species, *Z. apetala* Hook. f. is a large struggling shrub or small tree distributed in Sikkim (Brandis,1971).

Family- Lythraceae

Genus- *Lagerstroemia* Linn.

Lagerstroemia eoparviflora n. sp.

(Text-Figure 7 a, b)

Material - One incomplete leaf impression (GU/R/B/G/6006) preserved on thin layered carbonaceous shale.

Diagnosis- Fossil leaf simple, symmetrical, narrow elliptic, size 7.6 x 2.4 cm, apex acute to attenuate; margin entire, venation pinnate, eucamptdromous to brochidodromous, primary vein single, almost straight, secondary veins 8-9 pairs visible, 0.6-1.6 cm apart, usually alternate, angle of divergence 60^0 - 70^0, intersecondary veins simple, tertiary veins angle of origin RR, percurrent, straight to sinuous, close to nearly distant.

Description: - Fossil leaf simple, symmetrical, narrow elliptic; preserved size 7.6 x 2.4 cm; apex acute to attenuate; base broken; margin entire; texture chartaceous; petiole not preserved; venation pinnate, eucamptdromous to brochidodromous; primary vein single, prominent, stout, almost straight; secondary veins 8-9 pairs visible, 0,.6-1.6 cm apart, usually alternate, angle of divergence 60^0 - 70^0, wide acute, uniformly curved up and joining to their superadjacent secondary at acute angle, unbranched; intersecondary veins present, simple; tertiary veins fine, angle of origin RR, percurrent, straight to sinuous, usually oblique in relation to mid vein, predominantly alternate and close to nearly distant.

Holotype- Geology Deppt., HNB Garhwal University Museum No. GU/R/B/G/6005.

Locality - Gurha open cast lignite mine, Bikaner, Rajasthan, India.

Horizon & Age - Palana Formation, Early Eocene.

Etymology- By adding a prefix 'eo' to the modern comparable species.

Remarks- Characteristic features of the present fossil leaf such as symmetrical, narrow elliptic shape, entire margins, eucamptodromous to brochidodromous, alternate, with wide acute angle of secondary veins, curving upwards to join super adjacent secondaries at acute angle, presence of intersecondary veins, RR percurrent, straight to sinuous, and close to nearly distant tertiary veins collectively suggest similarity with modern leaves of *Lagerstroemia parviflora* Roxb. of the family Lythraceae (C.N.H. Herbarium sheet no. 554935).

So far, about twelve fossil leaves resembling the genus *Lagerstroemia* L. have been described under the generic name *Lagerstroemia* L. from the Cenozoic sediments of mainly India and Nepal. These are *Lagerstroemia patelii* from Lower Eocene of lignite mine at Panandhro, Kachchh, Gujarat (Lakhanpal & Guleria, 1981), Lower Siwalik of Kathgodam, Uttarakhand (Prasad, 1994b) and Lower-Middle Siwalik of Darjeeling District, West Bengal (Antal & Awasthi, 1993) and Siwalik of Arjunkhola, Nepal (Prasad *et al.*, 2019); *L. neyveliensis* from Neyveli Lignite Mine-1, South Arcot district, Tamil Nadu (Agarwal, 2002); *L. jamraniensis* (Prasad *et al.*, 2004) and *L. himalayaensis* (Srivastava *et al.*, 2015) from Lower Siwalik of Kathgodam, Nainital District, Uttarakhand; *L. siwalika* from Lower Siwalik of Koilabas, western Nepal (Prasad, 1994a) and Neyveli Lignite Mine-1, South Arcot District, Tamil Nadu (Agarwal, 2002); *L. mioparvifolia* and *L. eomicrocarpa* (Dwivedi *et al.*, 2006) from the Siwalik sediments of Koilabas area, western Nepal; *L. corvinusii* from upper Miocene (Siwalik) of Arjun Khola area, western Nepal (Prasad, 2013); *L. imamurae* (Tanai and Uemura, 1991) from Oligocene of Honshu, Japan. Besides the above, three more fossil leaves viz., *L. parviflora* Roxb., *L. macrocarpa* Wall. ex Kurz and *L. lanceolata* Wall. showing affinity with the extant species, have been reported from the late Cenozoic sediments of Mahuadanr Valley, Jharkhand (Singh & Prasad, 2009 a,b,c,d). A comparative study of all the above known fossil species revealed that none of them show complete similarity with the present fossil leaf. Therefore, the Eocene fossil leaf has been described under a new species, *L. eoparviflora*.

The genus *Lagerstroemia* L. includes more than 53 species of trees and shrubs, distributed in the Indo-Malayan region, Tropical Africa, Asia, Polynesia and Pacific region. The modern comparable species, *Lagerstroemia parviflora* Roxb. is a large tree growing in moist deciduous forests of suh Himalayan tract, West Bengal, Assam and Myanmar (Brandis, 1971; Mabberley, 1997).

Family -Rutaceae

Genus- *Clausena* Burm. F.

Clausena paleohepatophylla n. sp.

(Text-Figure 8a)

Material - One almost complete leaf impression preserved on the thin layered maroon shale.

Diagnosis - Fossil leaf slightly asymmetrical, ovate, preserved size 10.5-6.6 cm, base wide acute, margin entire, venation eucamptodroumous, primary vein single, stout, slightly curved, secondary veins 6-7 pairs visible, 0.5-2.3cm apart, unbranched, with angle of divergence 50^0-70^0, intersecondary veins present, tertiary veins fine, with angle of origin usually RR, sometime AO, close to distant.

Description - Fossil leaf slightly asymmetrical, ovate; preserved size 10.5-6.6 cm; apex seemingly acute; base wide acute; margin entire; texture chartaceous; petiole broken; venation pinnate, eucamptodroumous; primary vein single, stout, slightly curved, secondary veins 6-7 pairs visible, 0.5-2.3cm apart uniformly curved up unbranched, opposite to alternate, with angle of divergence 50^0-70^0, basal pair of secondary are with greater angle; intersecondary veins present simple, frequent; tertiary veins poorly preserved, fine, with angle of origin usually RR, sometime AO, percurrent, straight to sinuous, predominantly alternate, oblique in relation to mid vein, close to distant.

Holotype- Geology Deppt, HNB Garhwal University Museum No. GU/R/B/G/6007.

Locality - Gurha open cast lignite mine, Bikaner, Rajasthan, India.

Horizon & Age - Palana Formation, Early Eocene.

Etymology- By adding a prefix 'paleo' to the modern comparable species.

Remarks- The diagnostic features of the fossil leaf, such as asymmetrical, ovate shape, medium size, wide acute base, entire margin, eucamptodroumous venation, 6-7 pairs, 0.5-2.3cm apart, unbranched, secondary veins with angle of divergence 50^0-70^0, presence of frequent intersecondary veins, and close to distant tertiary veins with angle of origin usually RR, sometime AO suggest its resemblance with the modern leaves of *Clausena hepatophylla* (C.N.H. Herbarium sheet no. 33388; Fig.8b) of the family Rutaceae. It has also been seen that the modern leaves of *Amaranthus bilitum,* (Herbarium sheet no. USFH 244623), *A. viridis* (Herbarium sheet no. USFH 240078), and *A. spinosus* (Herbarium sheet no. GUH 2276) show some superficial resemblance with the present fossil leaf but differ mainly in having more number of secondary veins arising more acutely.

As far as authors are aware there is record of only one fossil leaf, *Clausena miocenica* resembling the extant taxa, *Clausena anisum-olens* (Blanco) from the Siwalik sediments of Tanakpur area, Uttarakhand (Prasad *et al.*, 2017). This fossil leaf entirely differs from the present fossil in being small in size with elliptic shape as compared to larger size with ovate shape in the present fossil leaf. Thus, in being different from the known fossil, this fossil has been described as a new species, *C. paleohepatophylla*.

The genus *Clausena* Burm F. comprises about 25 species distributed in the old world, tropical Africa and Southeast Asia. The comparable species, *C. hepatophylla* distributed in the evergreen forests of India, Bangladesh, Myanmar and in Southeast Asian regions.

Order Sapindales

Family-Anacardiaceae

Genus-*Mangifera*

Mangifera someshwarica Lakhanpal & Awasthi, 1984

(Text-Figure 9 a, c)

Material – Two fossil leaves satisfactorily preserved on the thin layered maroon shale.

Diagnosis- Fossil leaves slightly asymmetrical, narrow elliptic, size 7.18 x 2.8cm and 16.3x5.6 cm, base acute, asymmetrical margin entire, venation, pinnate, eucamptodromous, primary vein single, straight, stout, secondary veins, 11 -13 pairs visible, alternate to opposite, 0.40-1.3 cm apart, angle of divergence 55^0-70^0, unbranched, uniformly curved up and joined to their supersdjacent secondary veins; intersecondary veins present, simple; tertiary veins fine, angle of origin usually RR, rarely AO, precurrent, alternate and close.

Description- Fossil leaves slightly asymmetrical, narrow elliptic; size 7.18 x 2.8cm and 16.3x5.6 cm; apex not preserved; base acute; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, prominent, straight, stout; secondary veins, 11 -13 pairs visible, alternate to opposite, distance between two seconadry veins 0.40-0.70 cm in one specimen and 1.17- 1.32 cm in other specimen, angle of divergence 55^0-70^0, unbranched, uniformly curved up and joined to their superadjacent secondary veins; intersecondary veins present, simple, poorly preserved; tertiary veins also poorly developed but easly recognized, angle of origin usually RR, rarely AO, precurrent straight to nearly sinuous, branched, oblique in relation to midvein, predominantly alternate and close.

Specimens- Geology Deppt., HNB Garhwal University Museum No., GU/R/B/G/6008. - GU/R/B/G/6009.

Locality - Gurha open cast lignite mine, Bikaner, Rajasthan, India.

Horizon & Age - Palana Formation, Early Eocene.

Remarks- The characteristic featurs of the fossil leaf such as asymmetrical basal region, elliptic shape, entire margin, eucamptodromous venation, straight, stout primary vein, wide acute angle of divergence of secondary veins, presence of intersecondary and RR-AO, percurrent, predominantly alternate and close tertiary veins are found common in the modern leaves of *Mangifera* Linn. of the family Anacardiaceae.

Several herbarium sheets of different species of this genus have been critically examined and it is concluded that the leaves of *Mangifera indica* Linn. (Herbarium sheet no.GUH 6557 and USFH 84240) show closest affinity with the present fossil leaves in shape, size and venation pattern.

So far, ten fossils leaf resembling the genus, *Mangifera* Linn. have been reported from the Tertiary sediments of India and abroad under two generic names, *Mangifera* Linn. and *Eumangiferophyllum.* The latter is represented by only one species, *E. damalgiriensis* from the Palaeocene of northeast India (Mehrotra *et al.*, 1998). The genus *Mangifera* Linn. comprises about nine fossil leaves, most of them described under *M. someshwarica* from Siwalik localities ie, Bhikhnathoree, Bihar (Lakhanpal & Awasthi, 1984), Suraikhola, Nepal (Awasthi & Prasad, 1990), Koilabas, Nepal (Prasad,1994), Serianaka, Uttar Pradesh (Prasad *et al.*, 1997) and from Oligocene of Makum Coalfield, Assam (Awasthi & Mehrotra, 1995). Two fossil leaves are described under form species, *M. takashimensis* (Matsuo, 1967), one from the Eocene of South-east Honshu, Japan and other is from the Palaeogene of Kyshu, Japan. A fossil leaf, *Mangifera suraikholaensis* is also reported from the Siwaliks of Suraikhola, Western Nepal (Prasad & Pandey, 2008). Besides, fossil woods, and fruit resembling this genus have also been known from the Cenozoic sediments of India (Lakhanpal *et al.*, 1981; Guleria, 1984; Singh *et al.*, 2018). On an examination of all the above fossil species of the genus *Mangifera*, it has been concluded that the leaves of *Mangifera someshwarica* Lakhanpal & Awasthi shows closet similarity in shape, size, margin and venation pattern. In view of this, the present fossil leaf has been reported under the same species, *Mangifera someshwarica* Lakhanpal & Awasthi.

The genus *Mangifera* Linn. comprises about 40-60 species distributed in Southeast Asia and Indo-Malayan regions (Mabberley, 1997). The comparable species, *M. indica,* Linn. is a large tree distributed in the forests of sub-Himalayan tract, Bangladesh, Myanmar, Thailand, Vietnam and Malayan peninsula (Gamble, 1972).

DISCUSSION

A detailed morphotaxonomical study on the fossil leaf assemblage recovered from the early Eocene sequence of Gurha Lignite Mine, Rajasthan, India revealed the occurrence of eight phytogeographically and palaeoclimatically important angiospermous fossil taxa showing their modern affinity with the extant species, *Grewia asiatica* and *G. optiva* of the family Tiliaceae, *Clausena hepatophylla* of Rutaceae, *Ziziphus apetala* of Rhamnaceae, *Mangifera indica* of Anacardiaceae, *Eugenia occidentalis* of Myrtaceae, *Lagerstroemia parviflora* of Lythraceae and *Ficus religiosa* of the family Moraceae.

Faunal assemblage of *formica* as an impression possessing opening at the posterior of gaster terminal, circular, usually surrounded by a fringe of hairs, scale-like petiole and gaster without a constriction between first and second segments. Mayfly naiad with wing pads above the body, long legs and segmented abdomen, convergent with odonata. They are sensitive to impure areas, imbalances in oxygen levels and water quality (Hubbard and Peters, 1978).

The timing of India-Asia collision is also controversial, but most evidence suggest it occurred around the Paleocene – Eocene boundary (Beck *et al.,* 1995; Garzanti *et al.,* 1996, Briggs; 2003, Clyde *et al.*, 2003). It has been also suggested that collision could have been the principal cause above PETM. The present day distribution of these modern equivalents suggest the existence of mixed deciduous type of forests under the prevalence of a tropical humid climate in the vicinity of fossil locality during Early Eocene.

Palaeoclimate- The Early Eocene is known for a marked global warming (Zachos *et al.*, 2001, 2003), known as the Paleocene–Eocene Thermal Maximum (Higgins and Schrag, 2006) and at that time the Indian subcontinent was located near the equator (<10°N) (Shukla *et al.*, 2014b). Studies on the flora of Gurha lignite mine indicate a mean annual temperature of ~24°C and a mean annual range of temperature of ~10°C. The cold month mean temperature of ~18°C was tropical by today's climate standards but cooler than experienced today at 9°N in southern India at sea level. Similarly, the Gurha mean annual temperature is cooler than that of today (~27°C) and the modern mean annual range of temperature (2.8°C) is smaller (Shukla *et al.*, 2014b). The Paleobotanical evidence points towards a near-coastal tropical flora of evergreen trees subject to frequent wildfires under a strongly seasonal precipitation (monsoon) regime (Kumar *et al.*, 2016; Spicer *et al.*, 2017). The analysis of Spicer *et al.* (2017) showed that, at the time of deposition of the Gurha mine sediments, this part of the Indian continent was subject to a seasonal climate. Inter-tropical Convergence Zone-influenced Indonesia-Australia Monsoon, rather than the Himalaya-influenced South Asia Monsoon experienced in the region today.

Biogeography: In the leaf fossils collected from the Gurha mine, their recent counterparts are found in the tropical and subtropical environments of the following places; the genus *Kleinhovia*, Family Malvaceae native to Africa, Asia, Australia (Mabberley, 1997; Shu, 2007) and *Grewia* (India); Family Moraceae, genus *Ficus* (Asia: Bangladesh, Bhutan, China, Nepal, Pakistan, Thailand; Vietnam and in Africa is a native of Chad, Egypt and Madagascar); Family Myrtaceae, genus *Eucalyptus* (Australia, Argentina and Gondwana distribution, New Zealand); Family Rhamnaceae, genus *Ziziphus* (southwestern Asia, Mediterranean, western Africa to India, USA); Family Rutaceae, genus *Clausena* (South East Asia, Africa) and Family Anacardiaceae, genus *Mangifera* (India, Malaysia, Burma).

Based on our findings, we support the view that the dispersal of angiosperm plants into Asia was facilitated by the rafting Indian plate. The floral and faunal exchange between Africa and India during the Cretaceous and late Neogene time has been recognized (Mehrotra, 2003; Shukla et al., 2013) via Greater Somalia and Arabia, respectively. Shukla and Mehrotra; 2014 suggested that the genus *Uvaria* Linn., reported from the same locality is thought to have originated in Africa, and the present finding gives an idea about its geologic distribution in Asia and Australasia. The genus *Uvaria* Linn. originated in Africa–Madagascar and subsequently dispersed into Asia. Doyle and Le Thomas 1996, 1997; Doyle *et al.*, 2004; Briggs (1989) also suggested a more or less continuous floral and faunal exchange between India and Africa.

The study on amber from the nearby Cambay Basin indicates the presence of family Dipterocarpaceae, a family of moist tropical forest with its current center of biodiversity in Borneo, and once thought to have reached India in the Miocene from there. However, the Cambay amber, together with other fossil evidence, indicates a more likely origin for the family in Africa, with the Indian continent transporting the forests to Asia, followed by their subsequent later Cenozoic radiation (Ghazoul, 2016).). The insect assemblage (Figs 10 a-f) also justifies the tropical and humid climate. The presence of mayflies and ants indicate a cleaner environment, ants serving as decomposers in the ecosystem, while mayflies are absolutely intolerant to pollution. Presence of lowland Dipterocarp forests may also be ascertained since they provide suitable habitats for Ephemeroptera nymphs and adults. Terrestrial ants highlights the existence of an ideal social colony comprising of castes from queens, the immature to the workers, defined by their function in the society.

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