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Fossil flora from Siwalik (Miocene) sediments of Kalagarh area in the Himalayan foot hills of Uttarakhand and its significance

Rajiv Ranjan[1], Ravi Krishna Mishra[1], Alok[2*], Sanjeev Kumar[3], Mahesh Prasad[4]
[1] Department of Botany, MLKPG College, Balrampur, Uttar Pradesh, India
[2] Department of Botany, SKBB Govt PG College, Harakh, Barabanki, Uttar Pradesh, India
[3] Center for Environmental Sciences, Central University of Jharkhand, Ranchi, Jharkhand, India
[4] Birbal Sahni Institute of Palaeosciences, 53 University Road, Lucknow, Uttar Pradesh, India

Abstract
Palaeobotanical study on the plant fossils (petrified woods and a leaf and) from Siwalik (Miocene) sediments of Kalagarh area, Uttarakhand has revealed the occurrence of 40 species belonging to 26 genera of 14 angiospermous families. The family Dipterocarpaceae (Sal family) represented by 12 species is the most dominant family in this Kalagarh fossil assemblage followed by Fabaceae (9 species). The evergreen elements dominate the fossil flora in Kalagarh area during Miocene in contrast to mixed deciduous elements at present. The predominance of evergreen elements in the Siwalik fossil assemblage indicates the prevalence of tropical warm humid climate with plenty of rainfall during the deposition of Siwalik sediments.
The analysis of present day distribution of all the species recovered from the Siwalik of Kalagarh area shows that they are mostly known to occur in South East Asia, North-East India and Indo –Malayan region wherever favorable climatic conditions exist. Only about 17% species of the total assemblage are found to grow presently in the Himalayan foothills and the remaining species are locally extinct which suggests a change in the climatic condition after Miocene.
The floral assemblage also indicates that tropical evergreen to moist deciduous plants were flourishing in Kalagarh and nearby area during Miocene in contrast to the mixed deciduous plants at present. The local extinction of most of the comparable extant species of the fossils indicates that a change in the climate must have taken place since Miocene most probably due to uplift of Himalaya. The Coexistence Approach (CoA) for palaeoclimate estimation suggests that the Kalagarh area was enjoyed with tropical climate during Upper Miocene having Mean Annual Precipitation (MAP) 2100-3100 mm and Mean Annual Temperature (MAT) 21.5-31.5°C). The presence of diffuse porous condition in all the fossil woods along with medium to large vessels and abundant parenchyma further suggest the prevalence of tropical humid climate in the region during Miocene.

Keywords: floristic analysis, Himalayan foot hills, Kalagarh area, miocene, palaeoclimate, Phytogeography

Introduction
The Siwalik period is unique for its highly diversified faunal and floral assemblages among the whole Tertiary events. The Siwalik flora based on both fossil woods and leaves, recovered mainly from the Miocene sediments exposed all along the Himalayan foot hills of India and Nepal is of great interest, particularly for the terrestrial vegetation useful for interpretation of plant diversity and climate during Siwalik period. The sediments of Siwalik were deposited continuously by various rivers in the Himalayan foreland since last 20 million years [1]. These sediments provide an excellent opportunity to study on the plant mega fossils including both carbonized and petrified woods and leaf, fruit and seed impressions entombed in alluvial sediments. The Siwalik sediments comprise mudstone, sandstone and coarsely bedded conglomerates laid down when the region was a vast basin during Middle Miocene to Upper Pleistocene. The Siwalik group has been sub divided into lower, middle, upper Siwalik [2]. The detailed lithology and stratigraphy of the Siwalik have been studied by few researchers [3-4]. Kalagarh (29°03'N78°46'E) is situated about 40 km East of Dampur in Pauri Garhwal District of Uttarakhand. The Siwaliks occur here as foot hills running in northeast direction. Geological study in this area was pioneered by Middlemiss [8], as part of his detailed work on the Garhwal Himalaya. The sedimentological aspects of Kalagarh siwaliks were investigated by Raju [9]. These sediments comprises of light red nodular shales and clays with grey soft sandstones. The Siwalik sediments of Kalagarh entombed with abundant fossils comprising mainly petrified woods. These woods were collected from different Sot like, Kuwan sot, Hathia sot, Kanandroo sot, Nungarh sot Dhara sot and Sukha sot etc. situated around Kalagarh within 20 km of the area (Figure 1).
A wealth of palaeobotanical work has been carried out from Kalagarh and nearby areas in order to build up the complete floristic. First of all, Prakash [10] reported some fossil woods of the genera, *Polyalthia*, *Dipterocarpus*, *Anisoptera*, *Cynometra*, *Cassia* and *Diospyros*. Later on, some authors have studied enormous amount of plant megafossils including petrified woods and leaves from Kalagarh and nearby area and revealed a variety of modern analogues mainly belonging to both monocot and dicot families of angiospermous [12-24]. The studies are imperative as they provide valuable database of Siwalik plant fossils and their modern analogues (Figure 2) for the interpretation of sequential changes in floral composition of the areas in term of the climate. On the basis of all the available data the

authors reconstructed the appropriate floristic and discussed in details the palaeoclimate and phytogeography/ plant diversity of the area during Miocene period.

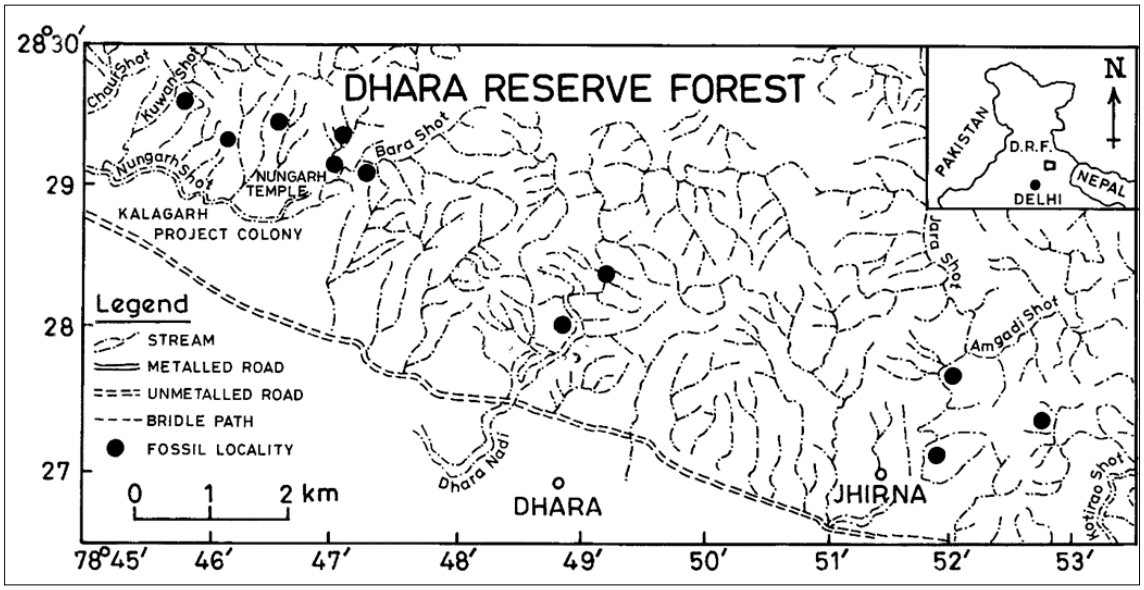

Fig 1: Map showing the different fossil localities in the study area (after Prasad 1993b).

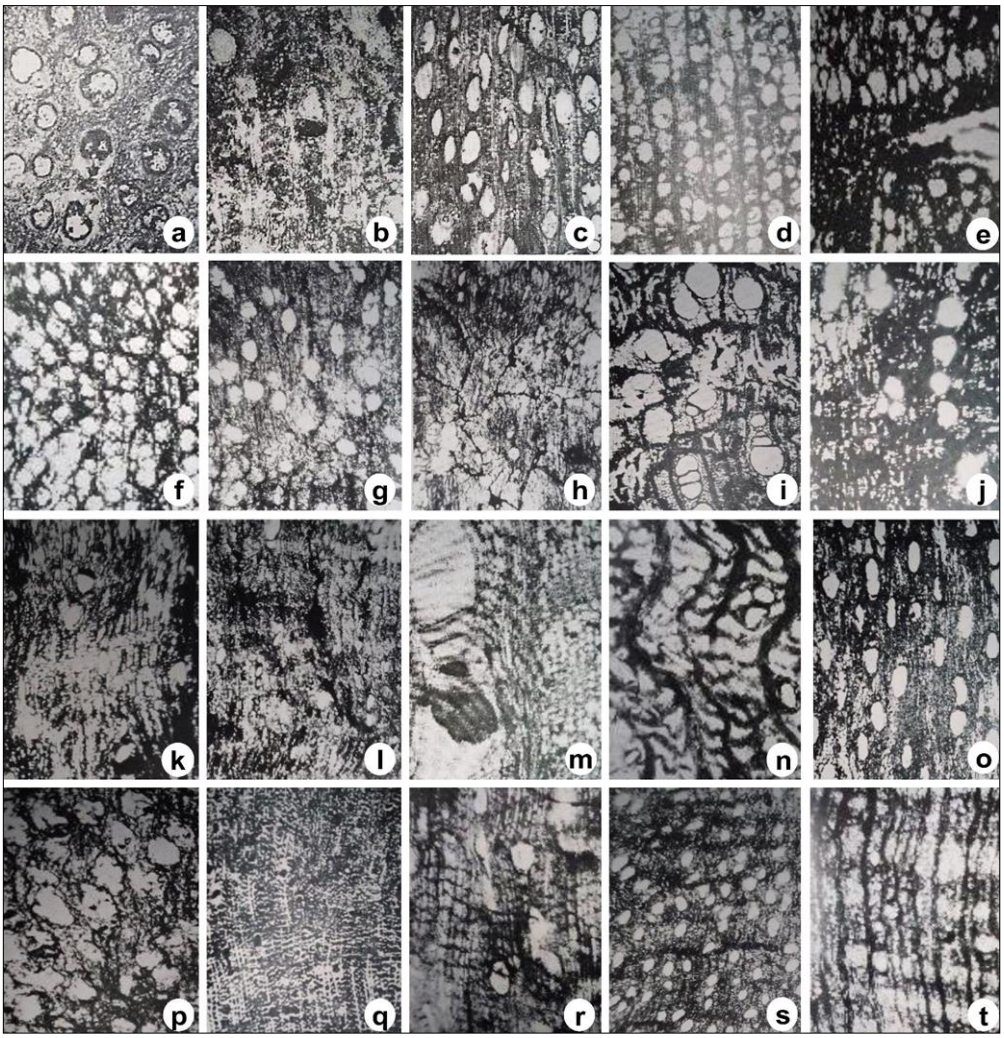

Fig 2: Fossil woods from Miocene sediments of Kalagarh area, Uttarakhand: a) Cocos sp., b) Polyalthia simiarum Benth. & H.f.T., c) Anisoptera glabra Kurz, d) Dipterocarpus tuberculatus Roxb., e) Shorea minor, f) Hopea nutans Ridl., g) Hopea wightiana Wall., h) Euphoria longana Ham.. i) Ormosia robusta Wight, j) Bauhinia malabarica Roxb., k) Dialium indum Linn., l) Millettia sp., m) Sterculia sp., n) Sterculia coccinia Roxb., o) Terminalia paniculata Roth., p) Duabanga maluccana Blume, q) Diospyros malabarica (Derr.) Kosten, r) Diospyros candoleana Wight, s) Artocarpus heterophylla Lam., t) Ficus bengalensis.
(Scale bar 1cm equal to 40µm for Figure 2a-o, q-t and 80 µm for Figure 2p).

Materials and methods

Presentstudy is based on the plant mega fossils comprising fossil woods and a leaf, collected from Lower and Middle Siwalik (Miocene) sediments of Kalagarh (29°03'N:78°46'E) and nearby area in the Pauri Garhwal District of Uttarakhand, India (Figure 1). The fossil were identified with their modern analogues. The structural features of fossil woods have also been used for deducing the climate of the area. The Climatic parameters *i.e* MAT and MAP of Kalagarh area as well as those the area where modern analogues of the fossils are flourished today, have been obtained from published literature [25]. Climatological table of Observation in India (1931-1960) and through internet (https//weather and climate.com /average monthly rain fall-temperature-sunshine-in Malaysia/-in Philippines; www.en.climate-data.org; www.sdwebx.worldbank.org; www.weatherspark.org etc.).

Results and discussion

Floral diversity/ Phytogeography

Palaeobotanical study on the plant fossils comprising mainly petrified fossil woods and a leaf from the Siwalik sediments exposed in Kalagarh and nearby area, Pauri Garhwal District, Uttarakhand revealed the occurrence of 40 species belonging to 26 genera and 14 families of Angiosperms (Table 1; Figure 2). The assemblage is overall dominated by woody plants/ trees (100%). The Dipterocarpaceous species show overall dominance consisting of 12 species in the assemblage (Table 1). The frequent occurrence of dipterocarps is also evident from other Siwalik fossil localities of both the India and Nepal during Miocene [22, 23, 26-40].

The Dipterocarpaceous species have not been authentically recorded from the Palaeocene sub-period of India and Nepal, which indicate that they might have entered later in the Indian sub-continent during Oligocene Period, after the establishment of land connections from where they were flourishing. The fossil assemblage of Kalagarh area comprises of exclusively tropical elements during the Siwalik times. The

Important tropical subdominant families are Dipterocarpaceae, Lythraceae, Sapindaceae, Combretaceae and Ebenaceae etc. They are mainly distributed in India, Nepal and South-East Asian regions. The present day distribution of the extant species of the fossils known from Kalagarh area indicates their wider distribution in different geographical regions all over India and other places (Table 1; Figure 3).

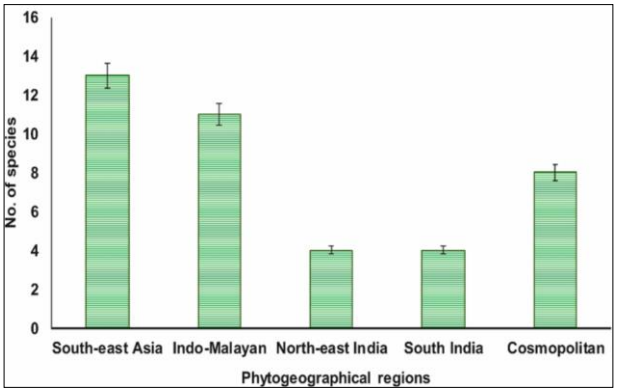

Fig 3: Showing the present day distribution of modern analogues of all the recovered species in different geographical regions.

Table 1: Fossil flora of Kalagarh area and their modern analogues, forest type, habitat and present day distribution

Fossil taxa	Modern analogues	Type of forest	Habitat	Present day distribution
Arecaceae				
Palmoxylon wadiaii Sahni; Prasad [20]	Cocos sp.	Evergreen	Tree	All along sea coast and on some Islands in India and abroad
Annonaceae				
Polyalthioxylon indicum Prakash [12]	Polyalthia simiarum Benth. & H.f.	Evergreen	Tree	North East India, Moist forest of Orissa and Mayurbhanj
Clusiaceae				
Kayea kalagarhensis Prasad [23]	Kayea floribunda Wall.	Evergreen	Tree	North East India, Myanmar
Dipterocarpaceae				
Anisopteroxylon kalagarhinsis Prakash [12]	Anisoptera glabra Kurz	Evergreen	Tree	South East Asia
Anisopteroxylon oblongoides [80]	Anisoptera oblonga Dyer	Semi evergreen to Moist deciduous	Tree	South East Asia
Dipterocarpoxylon siwalicus Prakash [12]	Dipterocarpus indicus Bedd.	Evergreen	Tree	South East Asia, South India, Andaman
D. parabaudii Prakash [12]	Dipterocarpus baudii Korth	Evergreen	Tree	South East Asia
D. kalagarhensis Yadav [80]	Dipterocarpus obtusifolia Teyam	Evergreen to Moist deciduous	Tree	South East Asia
D. surangei Prakash [13]	Dipterocarpus tuberculatus Roxb.	Evergreen to Moist deciduous	Tree	Myanmar, Cochin-China, Thailand, Bangladesh
D. arcotense Awasthi; Prasad [22]	Dipterocarpus tuberculatus Roxb.	Evergreen to Moist deciduous	tree	Myanmar, Cochin-China, Thailand, Bangladesh
D. nungarhensis Trivedi and Ahuja [16]	Dipterocarpus indicus Bedd., D. gracilis Blume, D. Obtusifolia Teyam	Evergreen	Tree	North East India, South India, Myanmar, Malaya
Shoreoxylon siwalicus Prasad and Prakash [24]	Shorea minor	Evergreen	Tree	Malaysian Archipelagoes
Hopenium prenutansoides Prasad and Prakash [24]	Hopea nutans Ridl.	Evergreen	Tree	Malaya
Hopenium kalagarhensis Prasad and Prakash [24]	Hopea sulcata Sym.	Evergreen	Tree	Malaya and Boeneo

Hopenium pondicherriense Awasthi; Prasad [22]	Hopea wightiana Wallich	Evergreen	Tree	Western Ghats, South India
Burseraceae				
Burseroxylon preserratum Prakash and Tripathi [26], Prasad [22]	Burserra serrata Wallich ex Coelebrook	Evergreen to Moist deciduous	Tree	North East India, Eastern Ghats, South India, Myanmar
Sapindaceae				
Euphorioxylon indicum Awasthi; Prasad [22]	Euphoria longana Lam.	Evergreen to Moist deciduous	Tree	Throughout Western Ghats, South East Asia
Fabaceae				
Ormosioxylon bengalensis Bande and Prakash [46]; Prasad [20]	Ormosia robusta Wight.	Evergreen	Tree	North East India, Myanmar
Hopeoxylon eosiamensis Prakash [13]	Sindora siamensis Teijsm ex Miq.	Evergreen to Moist deciduous	Tree	South East Asia
Bauhinium miocenicum Trivedi and Panjwani [17]	Bauhinia retusa Ham.	Mixed deciduous	Small to medium sized tree	Sub- Himalayan tract, South India, Central India
Bauhinium palaeomalabarica Prakash and Prasad [18]	Bauhinia malabarica Roxb.	Mixed deciduous	Medium sized tree	Sub- Himalayan tract, Central India, South India, Myanmar
Cynometroxylon sp. Cf C indicum (Chowdhary and Ghosh); Prakash [12]	Cynometra polyandra Roxb.	Evergreen	Tree	North East India, Malaya
Cynometroxylon siwalicus Trivedi and Panjwani [17]	Cynometra inaequalis A. Grey and C. cauliflora Linn.	Evergreen	Tree	South East Asia
Cassinium borooahii Prakash [12]	Cassia siamia Lam.	Mixed deciduous	Moderate sized tree	South India, Myanmar, Bangladesh, Sri Lanka
Dialiumoxylon palaeoindum Prasad [22]	Dialium indum Linn.	Evergreen	Tall tree	Malaya peninsula
Millettioxylon indicum Awasthi; Prasad [22]	Millettia prainii Dunn., M. pendula Benth. M. glabra Vent.	Evergreen to Moist deciduous	Tree	North East India, Myanmar, South India, Sub-Himalayan tract, Australia, Polynesia
Sterculiaceae				
Sterculioxylon kalagarhense Trivedi and Ahuja [14, 15]	Sterculia oblongata R.Br., S. rhinopetala K. Schun, S. urens Roxb.	Evergreen to Moist deciduous	Tree	South East Asia, Central South Africa, Sub-Himalayan tract, Myanmar, Sri Lanka
Sterculinium foetidense Prakash; Prasad [22]	Sterculia urens Roxb.	Mixed deciduous	Tree	Sub-Himalayan tract, Myanmar, Sri Lanka
Sterculinium kalagarhense (Trivedi and Ahuja) Guleria; Prasad [22]	Sterculia coccinea Roxb.	Mixed deciduous	Tree	Eastern Himalaya, Bhutan Assam, Myanmar
Anacardiaceae				
Dracantomelumoxylon mangiferumoides Prakash [13]	Dracantomelum mangiferum Blume	Evergreen to Moist deciduous	Tree	Andaman & Nicobar, Myanmar, Malaya peninsula
Glutoxylon kalagarhense Trivedi and Ahuja [14, 15]	Gluta renghas Linn.	Evergreen	Tree	Indo-Malayan region
Combretaceae				
Terminalioxylon palaeomanii Prakash [13]	Terminalia manii King	Evergreen to Moist deciduous	Tree	Andaman and Nicobar Islands
Terminalioxylon siwalicus Prasad 1989 [20]	Terminalia paniculata Roth.	Mixed deciduous	Tree	South India
Lythraceae				
Duabangoxylon indicum (Navale) Awasthi; Awasthi and Prasad [24]	Duabanga maluccana Blume	Evergreen to Moist deciduous	Tree	South East Asia
Ebenaceae				
Ebenoxylon miocenicum Prakash [12]	Diospyros kurzii Hiem	Evergreen	Tall tree	Andaman and Malaya peninsula
Ebenoxylon siwalicus Prakash [13]	Diospyros brandisiana Kurz	Evergreen	Tree	Tennasserim, Myanmar
Ebenoxylon kalagarhensis Prasad [20]	Diospyros malabarica (Derr.) Kosten	Evergreen	Tree	Malayan regions
Ebenoxylon palaeocandoleana Prasad [22]	Diospyros candoleana Wight	Evergreen	Small tree	South India
Lauraceae				
Laurinoxylon siwalicus Prasad [20]	Lauraceae	Evergreen	Tree	Throughout warmer part of world
Moraceae				
Artocarpoxylon deccanensis Mehrotra et al.; Prasad [22]	Artocarpus heterophylla Lam.	Evergreen to Moist deciduous	Tree	Western Ghats, Sri Lanka, Myanmar
Ficoxylon kalagarhensis Prasad [22]	Ficus bengalensis Linn.	Evergreen to Moist deciduous	Large tree	Indigenous, common in evergreen forest, deciduous forest of Central and South India

The whole flora consists of 3 major types of elements:

1. **Evergreen:** *Cocos* sp., *Polyalyhia simiarum* Benth. & H. f. & T., *Kayea floribunda* Wall., *Anisoptera glabra* Kurz, *Dipterocarpus indicus* Bedd., *D. baudii* Roth., *D. gracilis* Blume, *Shorea minor*,*Hopea nutans* Ridl., *H. sulcata* Sym., *H. wightiana* Wall. *Ormosia robusta*

Wight, *Cynometra polyandra* Roxb. *C. inaequalis* A. Grey and *C. caulifolia* Linn., *Dialium indum* Linn., *Gluta renghas* Linn., *Diospyros kurzii* Hiem, *D. brandisiana* Kurz, *D. malabarica* (Derr.) ex Kosten, and Lauraceae.

2. **Evergreen to Moist deciduous:** *Anisoptera oblonga* Dyer, *Dipterocarpus obtusifolia* Teyam., *D. tuberculatus* Roxb., *Bursera serrata* Wall. ex Coelebrook, *Euphorea longana* Lam., *Sindora siamensis* Teijsm. ex Miq., *Millettia* spp. *Sterculia* spp. *Dracantomelum mangiferum* Blume, *Terminalia manii* King, *Duabanga maluccana* Blume,*Artocarpus heterophylla* Lam. and *Ficus bengalensis* Linn, and
3. **Mixed deciduous:** *Bauhinia retusa* Ham., *B. malabarica* Roxb., *Cassia siamia*Lam., *Sterculia urens* Roxb., *S. coccinea* Roxb. and *Terminalia paniculata* Roth. (Table 1). Evergreen elements dominate the assemblage and obviously indicates that the tropical evergreen forests were growing around Kalagarh area during Miocene as compared to the present mixed deciduous forests in the region [41].It is further inferred that the evergreen species which were growing in the vicinity of Kalakarhhave got migrated to other phytogeographical regions (Table 1; Figure 3) due to unfavorable climatic conditions prevailed after Miocene Period most probably due to the uplift of Himalaya. In India, they are distributed mostly in North-East and southern regions.

About 11 species are found to grow both in India and Malaya peninsula. They are *Kayea floribunda* Wall., *Dipterocarpus indicus* Bedd., *D. gracilis* Blume, *Euphorea longana* Lam., *Cynometra polyandra* Roxb., *Cassia siamea* Lam., *Sterculia* spp., *Dracantomelum mangiferum* Blume, *Gluta renghas* Linn., *Diospyros kurzii* Hiem, and *Artocarpus heterophylla* Lam. which clearly indicate that there has been a fair exchange of floral elements between the two subcontinents after the land connections were established during the Miocene Period.

About 13 species in the present fossil assemblage have a restricted distribution in the South-East Asian region. These are *Anisoptera glabra* Kurz, *Anisoptera oblonga* Dyer, *D. baudii* Roth., *Dipterocarpus obtusifolia* Teyam., *D. tuberculatus* Roxb., *Shorea minor*, *Hopea nutans* Ridl., *H. sulcata* Sym., *Sindora siamensis* Teijsm ex Miq.,*Cynometra inaequalis* A. Grey,*Dialium indum* Linn., *Duabanga maluccana* Blume and *D. malabarica* (Derr.) ex Kosten. Whichobviously suggests that these species either migrated from South East Asia to India during Neogene and flourished around Kalagarh area at the time of deposition of Siwalik sediments or they disappeared from the area probably due to change in climatic conditions after Late Miocene and diversified towards South East Asian region.

Four species in the present assemblage still grow in North-East India, Bhutan, Bangladesh and Myanmar. These are *Polyalthia simiarum* Benth. H. f. & T., *Ormosia robusta* Wight, *Sterculia urens* Roxb. and *S. coccinea*Roxb. This suggests that these species were present during Miocene in the foot-hills near Kalagarharea but do not grow now a days there and thus they have migratedtoward East in Assam, Bengal, Sikkim, Meghalaya, Bangladesh and Myanmar because of better favorable conditions.

Some species i.e., *Hopea wightiana* Wallich, *Terminalia manii* King, *T. paniculata* Roth. and D*iospyos candoleana* Wight are found to grow in South Indian regions which indicates that these species were growing in Kalagarh area during Miocene and later on became disappeared due to prevailing ofunfavorable condition there. The floral analysis also indicates that there are only a few species, which are found to grow still at different altitudes in the Sub-Himalayan tract around Kalagarh and adjoining areas (Table 1). Which suggest that they have susceptibility to adopt in the new climatic conditions prevailing after Miocene mainly due to further rise of Himalaya. Dipterocarpaceae is one of the most phytogeographically important family comprising 12 species belonging to the four genera, *Dipterocarpus, Anisoptera, Shorea and Hopea.* The present and past distribution of this family indicates that it is pan tropical and specially belongs to tropical Asia. The fossil record suggests that Dipterocarpaceae originated during the early Middle Oligocene [42, 43]. Lakhanpal [34] envisaged that the family originated in western Malaysia, where about two third of all dipterocarps species occur today [35]. This region is also quite rich in the fossil record [34, 36]. From western Malaysia, dipterocarps spread eastward to Philippines and northward through Myanmar to India. The possible time of the southwest migration was Early Miocene when the land connections between Malaya, Myanmar and Eastern India were established. The abundance of dipterocarps such as *Dipterocarpus, Anisoptera, Isoptera, Shorea, Hopea, Dryobalanops* in Eastern India as well as in southern India during Miocene-Pliocene times indicates that they spread from Eastern India to south west to Sri Lanka via Himalayan foot-hills where they are still flourishing. The occurrence of dipterocarpaceous remains (fossil woods, leaves, fruits, and impressions; (Figure 2) in the Himalayan foot-hills [18,26,28,29,37] and the Tertiary beds of Africa, Bancroft [38] and Chiarugi [39] suggests that from Eastern India the dipterocarps also spread westward into Africa most probably via Arabia [40].

The one hypothesis suggests that the dipterocarps originated on the Eurasian plate possibly in the Malaysian region and migrated westward and towards south Asia/ India and Africa. This hypothesis is mainly based on assumption of high species diversity of dipterocarps. These originated there in the Late Mesozoic and migrated into India during Late Cenozoic Era. [41]. The other hypothesis suggested that the dipterocarps originated in Gondwana [42] and reach Asia by rafting on the Indian plate [43]. Moreover, the fossil resin chemistry and palynological data from 50 Ma old sediments suggest that the Asian dipterocarps migrated from India into Asia as the land connection between the Indian and the Asian plate was established at ca. 50 Myrs ago [44]. Conti *et al.* [45] also opined that many of the Angiosperms did not originate in the south-East Asian region but dispersed into the area from western Gondwana land. This view is strongly supported by the earliest record of fossil dipterocarps from Oligocene sediments (34-23 Ma) of Borneo, a centre of presently high diversity of dipterocarps with more than 280 species [46]. According to different workers, the dipterocarps originated within the Late Cretaceous rain forest of Africa or South America before they split. Like the rain forest, the family Dipterocarpaceae probably also experienced widespread expansion under the climatic optimum from the Paleocene to the Middle Eocene. The diversification of the dipterocarps in Africa and South America are rarely documented in the fossil record [42] perhaps due to the unfavorable depositional environment. The earliest fossil record of this family based on resin and pollen grain from early Eocene of western India. Dutta *et al.* [44] indicates the wide spread existence of the Asian sub family

Dipterocarpoideae in the early Eocene extremely equatorial climate of the Indian plate prior to the early Eocene collision of India with Asia [63]. Due to climatic change during the Late Eocene and Oligocene the diversification of dipterocarps decreases across the Indian sub-continent. The occurrence of fossil leaves of *Dipterocarpus* in the early Miocene sediments of North West India Guleria *et al*. [48] indicates the continuity of this family form Oligocene. In the Miocene climate became warmer and moister due to uplift of the Himalaya and made suitable for a drastic increase in their species diversity and became a dominant group in the forests of the Indian sub-continent as evidenced by geological distribution and diversification during Miocene period [30]. On increasing aridity and seasonality after Late Miocene and Pliocene the climatic conditions became unsuitable for the growth of dipterocarps and thus started towards their gradual disappearance along with the other moist loving species of Angiosperms form the most part of India. (Except South and North East India) [26, 29, 30,]. The record of the most of the species in the plant assemblage also supports this view.

Fabaceae is the largest and one of the other phytogeographically important family among the fossil floral assemblage comprising 9 fossil species and showing their close affinity with the genera, *Bauhinia, Sindora, Cassia, Dialium, Cynometra, Millettia* and *Ormosia*, (Figure 2). Most of them are distributed in evergreen forests of Borneo, Sumatra, Thailand, Peninsular Malaysia and north-East India. According to Schrine *et al*. [49] the family Fabaceae originally evolved in tropical regions along the Tethys seaway during Palaeogene period. The study on the plant megafossils from Tertiary sediments of Indian subcontinents indicates that the fabaceous genera are more common than the genera of other families [22, 26, 29, 30, 50]. The fabaceous genera have not been authentically reported from the Palaeogene period of Indian subcontinents which suggesting their later entry in the Indian subcontinents after the establishment of land connections with south east Asian region by the end of Oligocene/ early Miocene [51] and it was the appropriate times for entering the such south east Asian elements into the Indian sub continents through its north east corner during early Miocene [52]. Later on these species become abundant and growing luxuriantly during the Neogene throughout India [26, 29-30, 50].

Palaeoclimate

The studies on Tertiaryplants fossilsis One of the most important parameter for the palaeoclimate estimation because the tertiary plant fossils are supposed to be the reliable indicators of past climate especially those that are preferable to modern analogues. The accuracy of interpretations based on them is inversely proportional to the geological ages of the deposits from which the fossils are collected. As the plant fossils of the present assemblage have been collected from the Miocene sediments and the modern equivalents of the fossil still exist in the forests of different phytogeographical regions, it has, therefore become easier to deduce the palaeoclimate of the Kalagarharea in the Himalayan foot-hills of Uttrakhand during Miocene Period.The other parameters for deducing palaeoclimate are the structural features of plant fossils. The presence of mainly fossil woods in fossil assemblage plays a deciphering role in interpreting the palaeoclimate. Thus, on the basis of plant mega fossils the interpretation regarding palaeoclimate can be drawn by two methods:

The modern analogue community should be similar to the fossil assemblage in both species composition and their relative abundance. The plant fossils of Kalagarh area have been compared with their modern equivalents and it has been observed that all of them still exist in the different geographical area. Keeping in mind the few assumptions given by Utescher *et al*. [53], the quantitative climatic result for the present fossil flora can be constructed by Coexistence Approach (CoA) after consideration of the following four steps- (1). For each fossil species, the modern analogue / nearest living relatives (NLR) is determined (2).For each NLR the modern distribution area is compiled (3). For each distribution area the range of climate parameters (MAP, MAT) is determined separately (4). For each climate parameter analyzed, the climatic ranges in which maximum number of NLRs of fossil flora can coexist i.e. coexistence interval, is determined. The coexistence intervals of each climatic parameter such as, MAP as well as MAT of 22 modern speciesof fossil assemblage have been obtained from published literature [21] and Climatological tableof observation in India (1931-1960) as well as through internet (https// weather and climate.com/average monthly rain fall-temperature-sunshine-in Malaysia/-in Philippines;www.en.climate-data.org;www.sdwebx.worldbank.org; www. Weathers park.org etc.) and on its application it has been found that the value of Coexistence interval for MAP, MAT are21.5-31.5°C and 2100-3100 mm respectively under which all the fossil species once lived. Thus, it suggests that the Kalagarh area in the Himalayan foot hills of Uttarakhand enjoyed a tropical climate during the Miocene with the value of MAP 2100-3100 mm and MAT 21.5-31.4°C (Figure 4 a,b).

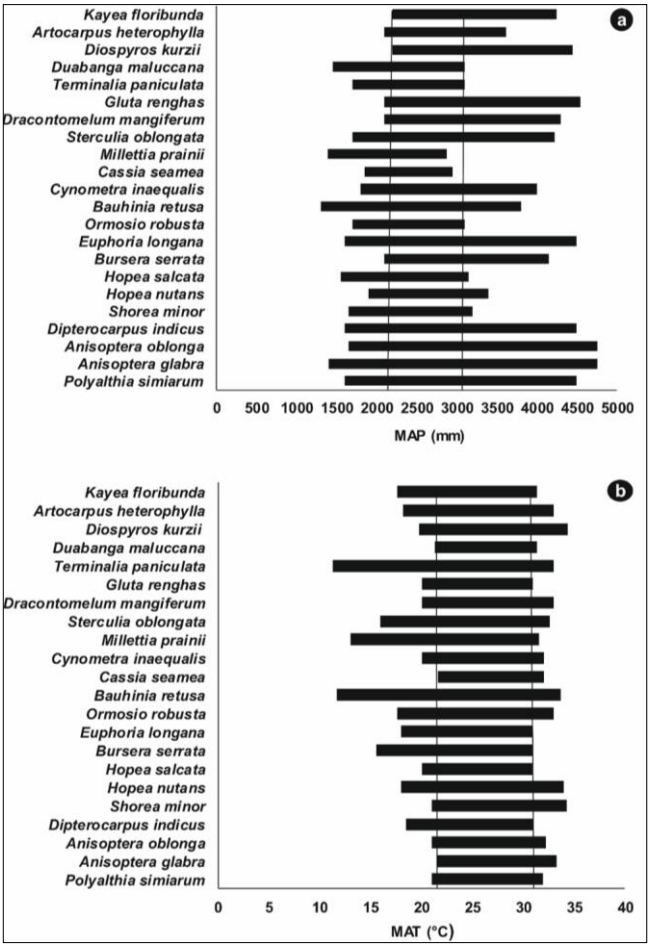

Fig 4: Showing the coexistence intervals of climatic parameter: a) Mean Annual Temperature (MAT) and b) Mean Annual Precipitation (MAP) of modern relatives of fossil species recorded from Kalagarh area, Uttarakhand. This mark (▬) indicate the intervals of coexistence and vertical line indicating the common range of MAT and MAP.

The fossil plants recovered so far from the Siwalik sediments of the Kalagarh area, Pauri Garhwal, comprise 41

fossil species and all of them were compared with modern equivalents (Table 1). The present habit and habitat of these equivalents show that they mostly occur in the tropical evergreen and moist deciduous forests of North-East India, Bangladesh, Myanmar and South-East Asian region (Malaya, Philippines, Java, Borneo etc.) where they receive higher rainfall [21, 35, 54-57] (Table 1). Thus it may be surmised that a warm and humid climate prevailed in Kalagarh area in the Himalayan foot hills during Miocene in contrast to the present relatively dry climate there. The predominance of evergreen elements in the assemblage further indicates the prevalence of tropical (warm humid) climate with plenty of rainfall. Most of the species in the fossil assemblage do not occur in the vicinity of Kalagarh or all along the whole Himalayan foot-hills of both India and Nepal (Table 1). This obviously indicates that changes in the climate must have taken place after the deposition of Siwalik sediments in this region. When this MAP value has been compared with the present MAP value of Kalagarh, Pauri Garhwal, Uttarakhand it has been seen that their average MAP value (1500 mm) is reduced by minimum of 600 mm and maximum by 1600 mm. This difference in MAP value of the present and past is much higher which can affect the climatic condition as well as the flora of the region.

The MAP value estimated from the fossil leaf assemblages of Kalagarh area has also been compared with the present MAP value of those regions (North-East India and South India) where now a day, most of the comparable species of the fossils are growing luxuriantly. It shows very less difference in the MAP value of North-East Indian (i.e. Assam 2740 mm, Kuchagaon3350 mm, Siliguri 2790 mm) and South India (Kerala 2780 mm and Karnataka 2810 mm). The structural features of the fossil woods recovered from Kalagarh area have been analysed in order to infer the climatic condition during Miocene period because the environmental factors influence the structure of secondary xylem of the woods due to which a quantitative changes in of the anatomical characters are taken due to variation in the climate. According to Dickison [58] the quantitative changes of fibres and vessels re related to environmental condition as they provide security and efficiency in the transport of water and other soluble material, Narrow and numerous vessel elements with simple perforation pate evolved in dry condition with low humidity however the solitary and more common vessel elements with greater lamina are evolved in wet and humid condition. In the fossil woods so far described here the quantitative changes in vessel element, its diameter, and length and the amount of parenchyma and fibres are very little. In all of them the vessels are mostly solitary and evenly distributed and having optimum size and greater Lumina. Thus, it may concluded that there was wet and humid condition with no any marked variation in the climate during the Miocene. Further, According to Carlquist [59] the plants that inhabit environments with defined seasonality and species that undergo period of stress (drought condition) have the sparseness of axial parenchyma i.e. storage system. Oppositely, the most of the species (except (Lauraceous species) in the present wood flora possess abundant axial parenchyma suggesting the undefined seasonality in environments and no drought condition in their inhabit environments. The other anatomical features that result from seasonal variation are diameter and density/ frequency of the vessels and can be used to infer the presence of tropical or temperate condition [60]. According to him the vessels of any wood occurring in the climate of little seasonality may be even ally distributed (diffuse porous) and of almost uniform size while the vessels in the woods of climate having marked seasonality may be larger with higher frequencyin early wood and smaller with lower frequency in late wood (ring porous). As all the fossil woods described in the present wood flora are diffuse porous in nature which indicate a tropical condition with little seasonality during the Miocene period.

Conclusion

- The xylotomical and morphotaxonomical study on the plant fossils (fossil woods and a leaf) from Miocene sediments of Kalagarh area, Pauri Garhwal, Uttarakhand revealed the occurrence of 41species of 26 genera belonging to 14 angiospermous families. The family Dipterocarpaceae represented by 12 species is the most dominant family in this fossil assemblage followed by Fabaceae (9 species), The Dipterocarpaceous species have not been authentically recorded from the Palaeocene sub-period of India and Nepal, which indicate that they might have entered later in the Indian sub-continent during Oligocene Period, after the establishment of land connections from where they were flourishing. The family Fabaceae which appeared in Upper Palaeocene became a major component of the evergreen forest during Miocene times all along the Himalayan foot hills.
- The evergreen elements (52%) dominate the fossil flora of Siwalik in Kalagarh area during Miocene followed by evergreen and moist deciduous species (32%) in contrast to mixed deciduous elements at present. The predominance of both evergreen and evergreen and moist deciduous elements in the Kalagarh fossil assemblage indicates the prevalence of tropical warm humid climate with plenty of rainfall there during the Siwalik sedimentations.
- The analysis of present day distribution of all the species recovered from the Siwalik of Kalagarharea shows that they are mostly known to occur in North-East India, Bangladesh, Myanmar and Malaysia wherever favorable climatic conditions exist. Only few of the species of the total assemblage are found to grow presently in the Himalayan foot hills and the remaining species are locally extinct, suggesting changes in the climatic condition.
- Modern analog Method suggests that the Kalagarh area in Himalayan foot-hills, Uttarakhand enjoyed a tropical climate (with MAT 21.5^0C-31.5^0C and MAP 2100-3100mm) along with plenty of rainfall during the Miocene Times. This is, however, contrary to the present day climate of the area with reduced precipitation

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Conflict of interest statement

The authors declare that they have no conflicts of interest.

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