Plant Archives Vol. 21, No. 2, 2021 pp. 447–458 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2021.v21.no2.070

PLANT DIVERSITY AND CLIMATE DURING MIDDLE MIOCENE PERIOD AROUND KATHGODAM IN THE HIMALAYAN FOOT HILLS OF UTTARAKHAND, INDIA

Rajiv Ranjan[1], Shivdatt Tiwari[1], Alok[2*], Pawan Kumar Singh[3] and Mahesh Prasad[3]
[1]M.L.K. P.G. College, Balrampur, U.P, India
[2]S.K.B.B. Govt. P.G. College, Harakh, Barabanki, U.P, India
[3]Birbal Sahni Institute of palaeosciences, 53, University Road, Lucknow-226007 India
*Corresponding Author Email: alok.sharma13@gmail.com

(Date of Receiving : 08-05-2021; Date of Acceptance : 14-07-2021)

ABSTRACT

Morphotaxonomical study on the plant fossils recovered from Lower Siwalik (Middle Miocene) sediments of the Kathgodam area, Uttarakhand has revealed the occurrence of 66 species belonging to 28 families of angiosperm and a pteridophyte. The family Fabaceae is the most dominant family represented by 12 species in this assemblage followed by Euphorbiaceae (5 species), Meliaceae, and Ebenaceae (4 species), and Anonaceae, Cluciaceae and Dipterocarpaceae (3 species). The family Fabaceae that appeared in Upper Palaeocene became a major constituent of the evergreen forest during Miocene times all along the Himalayan foothills. The predominance of evergreen and moist deciduous taxa in this fossil assemblage indicates the prevalence of tropical warm humid climate with plenty of rainfall during the Middle Miocene.

The present day distribution of comparable modern species of all the fossils recovered from the Kathgodam area indicate that they are mostly known to occur in South east Asia, Indo-Malayan and North-east Indian regions, wherever favorable climatic conditions exist. Only about 12% taxa of the fossil assemblage are found to grow presently in the Himalayan foothills and the remaining taxa are locally extinct most probably due to change in climate after Miocene. Study of the structural features of fossil leaf-impressions suggests that the Kathgodam area in the Himalayan foothills of Uttarakhand enjoyed a tropical climate along with plenty of rainfall during the Middle Miocene times. Coexistence /Nearest Living Relative (NLR) method further suggests that the area enjoyed a tropical climate with the Mean Annual Temperature (MAT)MAT 21-29^{0}C and Mean Annual Precipitation (MAP) 2000 -3200 mm during the Middle Miocene.

Keywords: Floristic analysis, Kathgodam area, Himalayan foot hills, Uttarakhand, Palaeoclimate, Plant diversity, Middle Miocene.

INTRODUCTION

The Siwalik formation attains an average thickness of 6000m and is exposed all along the Himalayan foot-hills covering a distance of 2400Km. in length. The Siwalik sediments are made up of rock materials resulting from denudation of slopes of the Himalayan mountains and deposited on the flood plains of the foreland basins over a span of time (-20 Ma). These are exposed at several places along the northern boundary of the Indian subcontinents. The Siwalik sediment is characterized by the alternate presence of sandstone and mudstone facies, the later very often containing abundant plant fossils belonging to both Monocotyledonous and Dicotyledonous families.

Kathgodam is one of the important Siwalik localities in the Himalayan foot-hills of Uttarakhand, India. This is located in the district of Nainital, about 306 km northeast of New Delhi on Haldwani–Nainital road bounded by Siwalik Hills in North and Terai Plain towards the south (Fig. 1). The Siwalik beds in the Kathgodam area are found running in a north-east direction and are well exposed along Kathgodam-Nainital Road, Kathgodam-Bhimtal Road near Ranibag Bridge, and on both sides of Gola and Balia rivers. A geological study of the Siwalik sequence of the Kathgodam-Rainbag-Amritpur sector of Kumaun sub-Himalaya has been made by Shukla (1984). This sequence consists of several alternations of sandstone and mudstone varying in thickness from 4m-54m. A Middle Miocene age has been assigned to these Siwalik beds based on lithology and vertebrate fauna (Ranga Rao *et al*., 1979).

In the last two decades, a rich and diversified assemblage of plant fossils was collected from the Siwalik sediments of the Kathgodam and nearby areas. The study on these fossils, especially leaf impressions revealed the occurrence of 66 species of mostly dicotyledonous families (Prasad, 1991, 1994c, d; Prasad *et al*., 2004). They provide a valuable database of Siwalik flora for the interpretation of sequential changes in the floral composition of the areas in terms of the climate. On the basis of all the available data, the authors reconstructed the appropriate floristic and discussed in detail the palaeoclimate and phytogeography/plant diversity of the area during the Miocene period.

MATERIALS AND METHODS

The present study is based on the plant mega fossils comprising mainly fossil leaves, and some fruits collected from Lower (Middle Miocene) sediments of the Kathgodam (29°16'12": 79°31'48.'') and nearby area in Nainital District of Uttarakhand, India (Fig. 1). The fossil leaves and fruits (Fig.2 A-V) were identified with their modern analogues at the Herbarium of Central National Herbarium, Sibpur, Howrah, West Bengal. The structural features of fossil leaves such as leaf margin, nature of apex and base, and shape, and size have been analyzed for deducing the climate of the area. The Climatic parameters i.e. Mean annual Temperature (MAT) and Mean Annual Precipitation (MAP) of the Kathgodam area as well as those the area where modern analogues of the fossils are found today, have been obtained from published literature (Champian and Seth,1968), Climatological table of Observation in India (1931-1960) and through the internet (http://weather and Climate.com/average monthly rain fall-temperature-sunshine-in Malaysia/-in Philippines. Foliar physiognomic method and Nearest Living Relatives (NLR) method have been used for the estimation of palaeoclimate.

RESULT AND DISCUSSION

During the uplift of Himalaya the Siwalik (Middle Miocene) has been considered as the most important as several significant changes took place in physiography and environment which ultimately changed the floral composition of foothills regions. The older forms, which could not adjust themselves to the new environment, gradually became disappeared and in their place, new plants came into existence and flourished there. Most of the taxa migrated from South-East Asia to Indian sub-continent via Myanmar and vice versa after the establishment of land connection between India and South East Asia (Smith & Briden, 1979). As the result many taxa, especially members of Dipterocarpaceae that were present during the Palaeogne in South East Asia appeared in the Indian sub-continent during Neogene. The most important aspects of studying the fossil plants from Siwalik of the Kathgodam area are to reconstruct the Siwalik floristic and to throw light on the climatic changes during Lower Siwalik succession (Middle Miocene). The extensive study on plant megafossils especially leaf impression provides reliable data for inferring the above aspect more precisely.

PLANT DIVERSITY/FLORISTIC ANALYSIS

The fossil leaves so far, recovered from different Siwalik localities in the Kathgodam and the nearby areas have been identified with the modern taxa up to a specific level. From the present day distribution of these comparable species, it is evident that most of the species of the fossil assemblage are not found at present in the foot-hills and became extinct due to the prevalence of unfavourable climatic conditions after Mio-Pliocene times The Siwalik assemblage is dominated by evergreen constituents like dipterocarps, legumes and other associated taxa like, Uvaria, Mesua, Calophyllum, , Diospyros, Phyllanthus, Sterculia, Hydrocarpus, Michilus and Ficus etc. during Miocene times in contrast to the mixed deciduous constituent of the present day floral assemblage of the regions. This is most probably due to the post-Pliocene orogeny of the Himalaya, which brought changes in the topography, and climate that adversely affected the vegetation scenarios of the Himalaya foothills.

The fossil leaf assemblages (Table-1) indicated that in the foothills of the Kathgodam area, a tropical forest flourished luxuriantly with a variety of angiospermous taxa during Middle Miocene. The fossil leaves so far recovered from Siwalik sediments of the Kathgodam area comprise 66 species belonging to 28 families of both monocotyledon and dicotyledon and a pteridophyte. A single family Thelmyptridaceae represents the latter and the monocot is represented by only two families viz. Marantaceae and Poaceae. The rest are of dicotyledonous families. Among them, the most common and widely distributed genera are, Calophyllum, Dipterocarpus, Shorea, Hopea, Sterculia, Gynocardia, Hydnocarpus, Grewia, Toona, Zizyphus, Euphorea, Millettia, Cynometra, Pongamia, Ormosia, Terminalia, Lagerstroemia, Diospyros, Phyllanthus, and Ficus etc.. The present fossil leaf assemblage is overall dominated by fabaceous taxa representing 12 species of 10 genera. The next dominant family is Euphorbiaceae constituted by 5 species and the families like Meliaceae and Ebenaceae come on the third position in the diversification of the overall present assemblage.

The analysis of the present-day distribution of modern comparable species of fossil leaf assemblages from Siwalik of the Kathgodam area revealed that they presently grow in different geographical regions (Table, 1; Fig.3). They are distributed mostly in Southeast-Asian and Indo-Malayan regions wherever favorable climatic conditions are found now a day. In the present fossil assemblages about 78% of comparable taxa growing in the evergreen to moist deciduous forests of different geographical regions which suggest that the taxa which were present in the Himalayan foothills around the Kathgodam area during the Middle Miocene period do not grow now a day there. They have migrated towards the east in the Assam, Sikkim, Meghalaya, Bangladesh, and Myanmar and further southeast as well as southwards because of getting better climatic conditions.

In the fossil leaf assemblages of the Siwalik foreland basin there are a good amount of comparable taxa which grow presently in Southeast Asia (Table 1; Fig.3) They are *Alpinia buteocarpa* Poepp., *Bambusa tulda* Roxb., *Calophyllum polyanthum*, *Hydnocarpus kurzii* (King) Wrab., *Capparis micrantha* DC., *Dipterocarpus tuberulatus* Roxb., *Hopea micrantha* Hook. f., *Shorea buchananii*, *Grewia laurifolia* Hook., *Euphoria didyma* Blanco. *Dialium indum* Linn., *Millettia atropurpurea* Bemth., *Diospyros eriantha* (Champ.) Benth., *Mallotus repandus* Muell. Arg., *Phyllanthus gracilis* Muell., *Glochidion chlorophaes* Baill. Which is revealing that these taxa had migrated from the South-east Asian region to the Indian sub-continent during Miocene and flourished all along the Himalayan foothills at the time of deposition of Siwalik sediments but later on they disappeared from Kathgodam area after prevailing unfavorable condition most probably due to further uplift of the Himalaya. About 20 taxa of the fossil assemblages are distributed in both India and Malaya region (Table-1). These are *Cananga odorata* H.f.T., *Saccopetalum tomentosum* H.f.T., *Mesua ferrea* Linn.., *Albizia lebbek* Benth., *Millettia racemosa* Benth., *Millettia ovalifolia* King, *Cynometra iripa* Kotel, *Derris trifoliatus* Lour, *Pongamia glabra* Vent., *Terminatia belerica* Roxb., *Lagerstroemia flos-reginae* Retz., *Lagerstroemia speciosa* Pers., *Morinda tinctoria* Roxb., *Diospyros chloroxylon* Roxb., *Michilus oddoratissima* Nees, *Mallotus cochinchinensis* Laur, *Phyllanthus reticulatus* Poir., *Homonoia riparia* Lour, *Ficus benjamina* Linn. and *Wrightia tinctoria* Roxb. which are indicating that there has been a fair exchange of plant taxa between the two subcontinents after the land connections were established during the early Miocene period.The comparable taxa like, *Bambusa tulda* Roxb., *Gynocardia odorata* R. Br., *Sterculia coccinea* Jack., *Chukrassia tabularis* Adr, Juss., *Ormosia robusta* Wight, *Ardisia simplicifolia*Walp., *Sarcosperma arboretum* Benth. and *Diospyros cacharensis* (Das & Kanjilal) H.B. Naithani is restricted to the northeastern Indian regions. A good amount of comparable taxa (10 species) of the Kathgodam fossil assemblage have their wide distribution mostly in tropical regions of South Africa, South America, and Australia which revealing that these taxa are of Gondwana origin. They came to Indian subcontinents during the split of Gondwanaland masses and flourished in the sub-himalayan tract up to the Miocene period and later on became disappeared due to changes in the climate.Only some of the comparable taxa of the fossil leaves recovered from the Kathgodam area are found to grow still at different altitudes all along the Himalayan foot-hills.These are *Clinogyne grandis* Benth. & Hook., *Toona ciliata* Roxb., *Zizyphus xylopyrus* Wills., *Z. jujuba* Lam., *Holarrhena antidysentrica* Wall., *Ficus cunea* Ham, *Bixa orelleana* Linn. and *Cassia tora* Linn., This suggests that such taxa have susceptibility to adapt to the new climatic conditions prevailing after Middle Miocene.

Moreover, based on Habit and Habitat of comparable taxa of fossil leaves it has been concluded that there were 3 major types of constituents in the forest during the sedimentation of Siwalik sediments(Fig.4). (1) Evergreen (2) Evergreen and moist deciduous (3) Mixed deciduous. The assemblage contains 53% evergreen taxa viz., *Cyclosorus prolifera* Persl., *Uvaria hamiltonii* Hook. f. & Th. *Cananga odorata* Hook. f. & Th, *Capparis micrantha* DC. ,*Mesua ferea* Linn., *Garcinia combogia* Roxb., *Gynocardia odorata* Linn., *Calophylluum polyanthum* Wall, *Hopea micrantha*, Hooker. f .*Shorea assamica* Dyre, *S. buchananic*, *Pachira malabarica*, *Dysoxylum kalanderi* E Muell, *Euphorea didyma* Blanco, *Cupania Jackiana* Heirn., *Dialium indum* Linn., *Samanea saman* Merrill, *Milliettia ovalifolia* Knirz, *M. atropurpurea* Benth, *Ormosia robusta* wight., *Parinari excelsa* Sabine,*Morinda tinctoria* Roxb., *Gardenia jasminoides* Rdz., *Sarcosperma arboreum* Benth., *Diospyros cholroxylon*,Roxb,. *D. eriantha*,Champ ex. Benth, *Mallotus cochinchinensis* Lour., *M. repandus* Muell Arg., *Phyllanthus reticulatus* Poir, *Homonoia riparia* Lour., *Glochidion chlorophaes* Baill and the evergreen to Moist deciduous are 25% of the total assemblage. These are*Dipterocarpus tuberculatus* Roxb. *Acronychia baueri* Schott. *Toona ciliata* Roxb.,*Chukrassia tabularis* Adr. Juss., *Zizyphus jujuba* Lam., *Albizia lebbek* Benth., *Pongamia glabra* Vent., *P. pinnata* Vent. *Terminalia belerica* Roxb., *Lagerstroemia flosreginae* Retz, *Ardisia simplicifolia* Walp, *Diospyros ebenum* Kurz., *Michilus odoratissima* Nees., *Ficus cunea*, Ham and *F. benjamina*. Linn. However, the Mixed deciduous taxa are 22% represented by *Clinogyne grandis* Benth & Hooker, *Alpinia bueteocarpa* Poeppe, *Bambusa tulda* Roxb. *Saccopetalum tomentosum* Hook. f. & TH.,*Bixa orellana* Linn., *Uncobia* (Stuartiat) *spinosa*, Forsk., *Trichelia glabra* Vell., *Zizyphus xylopyrus*, *Holarrhena antidysentrica* Wall., *Cassia tora* Linn., *Millettia racemosa* Benth., *Cynometra iripa* Kotel.,*Derris trifoliatus* Lour., *Lagerstroemia speciosa* Pers., *Wrightia tinctoria* R. Br. This distribution pattern of modern comparable taxa of the fossils revealed that a tropical evergreen forest was in existence during the Middle Miocene time in the Kathgodam area as compared to the mixed deciduous type of forest at present there.

The fabaceous taxa which dominate the fossil assemblage were not recorded earlier from Paleocene-Eocene sediments Indian sub-continents, suggesting a late entry of such taxa into the Indian sub-continent, probably prior to the Miocene, only after the development of land connections that allowed free movement of elements from regions where they were flourishing (Smith & Briden 1979, Smith *et al*., 1994). Perhaps, this was the appropriate time for South-east Asian elements to enter into the Indian sub-continent, through its northeast corner during the early Miocene (Agarwal *et al*., 2006). Later on, these taxa became abundant and were growing luxuriantly during the Neogene throughout India (Guleria, 1992b, Prasad, 2008). Another cause of luxuriant growth and richness of family Fabaceae at the end of the Oligocene was global warming which was at its peak in the middle Miocene (Zachos *et al*., 2001; Punyasena *et al*., 2008). Phylogenetic evidence suggests that the family Fabaceae evolved in tropical/sub-tropical regions along the Tethys seaway during the Palaeogene period (Schrine *et al*., 2005). Other fabaceous taxa were also authentically not recorded from the Palaeogene sub-period of India, Nepal and Bhutan, which indicated that the Asian elements might have entered later, in the Indian sub-continent during the Miocene Period, only after the establishment of land connections with South-east Asia.

The family Sapindaceae is represented by two taxa, *Euphoria didyma* Blanco. and *Cupaniajackiana* Hiern. This is primarily tropical or sub-tropical in distribution, showing centre of diversity in the south Asian regions, with some forms extending into the temperate regions of Asia and North America (Klassen, 1999). Harrington (2008) opined that the family originated during the Pliocene–Miocene, rather than in the Paleocene. In India, the oldest record of Sapindaceae is from the Late Cretaceous of Deccan Intertrappean beds (Dayal, 1965; Mehrotra, 1987).

The family Annonaceae represented by three taxa viz. *Uvaria hamiltonii* Hook. f., *Cananga odorata* Hook. f. & Th., and *saccopetalum tomentosum* hook f. & Th. in the assemblage, is a mainly pantropical family occurring mainly in rainforests, with a few occurrences in the temperate regions (Richardson *et al.,* 2004).

Family Combretaceae represented by only one taxon, *Terminalia belerica* Roxb. in the Kathgodam fossil assemblage occurred throughout the tropical and sub-tropical regions with limited spread into warm temperate zones. The oldest confirmed remains of Combretaceae (*Terminalia*) are from the Late Cretaceous of Portugal (Friis *et al.,* 1992; Stace, 2007). In India, fossils of Combretaceae have been reported from the Late Cretaceous and Paleocene to Eocene deposits of western India (Mahabale & Deshpande 1965, Prakash & Dayal 1968, Singh *et al.,* 2010, 2011).

Lythraceae is represented by three species of *Lagerstroemia* L., which known to occur in the Mio-Pliocene of different localities of India and Nepal (Prasad, 2008). The family comprises mainly of woody plants that have worldwide distribution mostly in tropical to the sub-tropical region, (Dahlgren & Thorne 1984). They occur primarily in moist to wet habitats including mangroves, rainforests and marshes. The family has an extensive fossil record that includes both extant and extinct genera (Tiffney, 1981). In India, the oldest records of *Lagerstroemia* Linn. are from the Late Cretaceous (Intertrappean beds) from where both leaves and silicified fruits (Mehrotra *et al.,* 2007) were recorded.

Three taxa viz., *Gynocardia odorata* R. Br., *Hydnocarpus kurzii* (King) Wrab. and *Uncobia spinosa* Forsk. are representing the family Achariaceae (Flacourtiaceae) in the present assemblage. *Hydnocarpus* is an Indo-Malaysian genus according to Mabberley (1997). The fossil record suggests that it was common in India during the Mio-Pliocene times (Prasad 2008).

The genus *Diospyros* L., another constituent of the Kathgodam plant assemblage, is one of the most common genera of the family Ebenaceae. It is native to the tropical and sub-tropical regions and shows the greatest diversity of species in the Indo- Malayan region.

Dipterocarpaceae is the most phytogeographically important family among the fossil assemblage. It is pantropical family and especially distributed in tropical regions of South-east Asian countries. The fossil record suggests that the family Dipterocarpaceae originated in western Malaysia during the early Middle Oligocene (Merrill 1923; Muller, 1970; Lakhanpal, 1974). About two-third of the members of Dipterocarpaceae are found to grow today in the Malaysian region (Desch, 1957). This region is also quite rich in Dipterocarpaceae fossils (Lakhanpal, 1974; Bande & Prakash, 1986). Thus, it is evident that the dipterocarps spread from western Malaysia eastward to the Philippines and northward to eastern India through Myanmar, and then spread through at Himalayan foot-hills and flourished luxuriantly there during the middle Miocene to Middle Pliocene. The possible time for their migration was the early Miocene when the land connections between Malaya, Myanmar and eastern India were established.

PALAEOCLIMATE RECONSTRUCTION

The palaeoclimatic reconstruction from fossil plants is the most important contribution of the palaeobotanical study. The conservative approach to the study of palaeoclimate of a particular region is to compare fossil flora recovered from there with the modern vegetation. This Study becomes more accurate as we go from Paleocene upward until the Pleistocene because the modern equivalents of the fossil forms still exist in the present day for their comparison and identification. In this case, all the plant fossils have been collected from Mio-Pliocene sediments of Himalayan foreland basins and their modern comparable taxa still exist in the forests of different geographical regions and thus it has become easier to deduce the palaeoclimate of the area.

Based on fossil leaf impressions the reconstruction of palaeoclimate may be drawn by two methods: (1) Co-existence method and (2) foliar physiognomic method. In the Co-existence method, the climatic preferences of modern comparable plants of the fossil are used to interpret the past climate. It requires three bits of information (1) a living relative i.e. modern comparable species of the fossils (ii) autecology of the living relatives of each fossil taxa (iii) The plant association of both modern and fossil taxa.

Keeping in mind the few assumptions given by Utescher *et al*. (2014), 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 taxon, the modern analogues / 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 (MAT, MAP) is determined separately (4). For each climate parameter analyzed, the climatic ranges in which the maximum number of NLRs of fossil flora can coexist i.e coexistence interval is determined. Accordingly, the coexistence intervals of climatic parameter, MAT (Mean Annual Temperature), and MAP (Mean Annual Precipitation) of 28 modern taxa of fossil assemblage have been obtained from published literature (Champion & Seth, 1968) and Climatological table of observation in India (1931-1960) as well as through internet and on its application it has been found that the value of Coexistence interval for MAT, MAP are 21^0C-$29.^0$C, and 2000-3200 mm respectively under which all the fossil taxa once lived(Fig.5 a & b). Thus, It suggests that Kathgodam area in the Himalayan foot hills of Uttarakhand enjoyed a tropical climate having the value of MAT 21°-29.°C and MAP 2000-3200 mm during the Middle Miocene.

The fossil plants so for recorded from the Siwalik of Kathgodam area comprise 66 fossil taxa which were compared with the modern species. The present habit and habitat of the modern comparable taxa of the fossils shows that they mostly occur in the evergreen and moist deciduous forest of different phytogeographical regions, (Table 1, Fig. 2) where found suitable climatic condition most probably similar to Middle Miocene time. The occurrence of an abundant evergreen taxa (up to 53%) in the present assemblage indicate that a warm and humid climate with plenty of rainfall prevailed in all along the Himalayan foot hills of Kathgodam area during Middle Miocene in contrast to relatively dry climate there at present. The analysis of present day distribution of the modern comparable species revealed that about 88% comparable species do not grow in Kathgodam and nearby area but they have migrated to different suitable geographical regions (Fig. 3). This obviously indicates that changes in climate must have taken place Middle Miocene onwards.

Physiognomic Method, the other widely accepted parameter for the reconstruction of palaeoclimate in which the fossil leaves of any fossil assemblage play an important role in estimating the palaeoclimate of the region in the case of any geological ages. This parameter does not depend on any systematic relationship of the modern species and therefore, it is likely that the errors in interpretation are minimum. Only few leaf features such as leaf margin size, drip tips, petiole, texture, apex and base, organization and venation density of the angiospermous fossil leaves of Siwalik foreland basin have been analysed for reconstruction of the palaeoclimate.

Leaf margin analysis (LMA) is a frequently used quantitative technique of palaeoclimate reconstruction that applies present day correlation between the proportions of woody dicot species with entire leaves and mean annual temperature to estimate palaeotemperature from the fossil leaf assemblage. Baily and Sinnot (1915, 1916) were the first who observed that the percentage of woody species with entire margined leaves is higher in tropical flora than the temperate flora. Moreover, the entire margined leaf families like,Anonaceae, Lauraceae, Ebenaceae, Clusiaceae, Sapotaceae, Dipterocarpaceae are particulary absent from cold/temperate regions. On the other hand the families having non-entire leaves like, Betulaceae, Aceraceae, Plantanaceae etc are absent from low land tropical regions. Wolf (1969, 1971, 1979) further analysed this convolution between leaf margin types of flora and climate and concluded that the tropical rainforests have the highest percentage of entire margined species and the percentage decreases with decreasing temperature either with increasing altitude to the submontane and montane rain forests or with increasing latitude to the warm temperate forests. Application of the above criterion to the leaf assemblages of Kathgodam area, in which most of the fossil leaves (about 98%) possess entire margin (Fig. 2) indicating a warm tropical climate. The attenuate apex (Drip tips) is also important physiognomic feature of angiospermous leaves, which is seen in wet tropical forest elements (Dorf, 1969). This is useful for hastening the runoff of water from the leaf. Richard (1952) pointed that it facilitates them to retard the growth of epiphytes and the deciduous leaves generally lack drip tip because of their short life span. The analysis of the leaf apex (tip) of all the leaves of present fossil assemblages it has been seen that a majority of taxa possess conspicuous drip tips. However, in some specimen the tips got either broken or indistinct due to bad preservation. Thus it also shows the prevalence of tropical humid climate in the Kathgodam and nearby area during the Middle Miocene times. The other leaf characters that have been used for determining the palaeoclimate are leaf size drip tips, organization of leaf, venation density, leaf texture and leaf base shape. The leaf size distribution in any forest type is correlated with under story plant of humid evergreen forests and decreases with low temperature and precipitation. Dilcher, (1973) opined that the leaf size decreases with decreasing rainfall. Givnish 1976 postulated that optimal size should be greatest in the tropics.Wilf *et al.* (1998) found a strong relation between the mean annual precipitation (MAP) and average leaf area. Simple organization of leaf and close venation density in the leaf assemblages are also related with available moisture or precipitation and thus indicating higher precipitation in the region as compared to present day with reduced precipitation.

CONCLUSION

The evergreen elements (53%) dominate the fossil flora of the Kathgodam area in the Himalayan foot-hills of Uttarakhand during Middle Miocene in contrast to mixed deciduous elements occurring at present which indicates the prevalence of tropical warm humid climate with plenty of rainfall during the deposition of Siwalik sediments.

The family Fabaceae (Legume family) represented by 10 genera and 12 species is the most dominant family in the Siwalik fossil assemblage followed by Euphorbiaceae (5 species), Meliaceae and Ebenaceae (4 species) and Dipterocarpaceae, Anonaceae and Clusiaceae (3 species). The family Fabaceae which appear in Upper Palaeocene became a major component of the evergreen forest flourishing during Mio-Pliocene all along the Himalayan foot-hills.

The analysis of present day distribution of all the 66 species recovered from the Siwalik of Kathgodam area shows that they are mostly known to occur in South-east Asia, North-east India, Bangladesh, Myanmar and Malayan regions wherever favorable climatic conditions prevailed.

Only about 9 taxa of total assemblage found to grow presently in the Himalayan foot-hills of Kathgodam area The remaining taxa are locally extinct. This indicates that the climatic changes must have been taken place thereafter Miocene.

The dominance of entire margined leaves (about 98%) in the fossil assemblage of the Kathgodam area is indicating the presence of tropical climate. The other feature like Drip tips, leaf size, leaf texture, nature of petiole and venation density etc. collectively also suggested tropical during Middle Miocene times around the Kathgodam and nearby areas.

The coexistence approach for palaeoclimate reconstructions suggest that the Kathgodam area in the Himalayan foot-hills of Uttarakhand enjoyed a tropical climate during the Middle Miocene with the value of MAT 21°-29.°C and MAP 2000-3200 mm.

Fig. 1 : Google map showing the different fossil localities in the study area.

☆ **Fossil collection sites**

Figs 2a-v. Fossil leaves from Middle Miocene sediments of Kathgodam area, Uttarakhand:

a.*Bambusa tulda* Roxb.**b.** &**v**.*Alpinia buteocarpa* Poepp.**c**.*Holarrena antidysentrica* Wall.**d.***Gynocardia odorata* Linn.**e.** Dicot leaf **f.**&**h**. *Bixa orelleana* Linn. **g**. & **n**. *Pachira malabarica* Aubl.**i.** *Cupania jackiana Hiern*.**j.** *Ormosia robusta* Wight **k**. *Millettia atropurpurea* Benth. **l.** *Sarcosperma arboretum* Benth..***m***. *Lagerstroemia speciosa* Persl.**o.** *Capparis micrantha* DC. **p.** *Grewia laurifolia Hook.***q**. *Cyclosorus prolifera* Persl.**r**. *Diospyros chloroxylon* Roxb.**s.** *Diospyros eriantha* Champ. **t.** *Cynometra eripa* Kotel **u**. *Ficus bengalensis*

(Scale bar 1cm).

Table 1: Present day distribution and forest types of modern comparable species of Kathgodam assemblage, Uttaranchal

Fossil taxa	Modern comparable species	Forest types	Distribution
PTERIDOPHYTES			
Cyclosorus eoprolifera Prasad 1991	*C. prolifera* persl	Evergreen	North east India, Nilgiris
MONOCOTYLEDON			
Marantaceae			
Alpinia siwalica Prasad *et al.,* 2004	*A. buteocarpa* Poepp.	Evergreen	Philippinse
Clinogyne ovatus Awasthi & Prasad, 1990	*C.grandis* Benth. & Hooker	Moist deciduous	Sub-Himalayan tracts
Poaceae			
Bambusa siwalika Awasthi & Prasad, 1990	*B. tulda* Roxb	Moist deciduous	NE- India, Bangladesh, Myanmar
DICOTYLEDONS			
Anonaceae			
Uvaria siwalika Prasad,1994 c	*U. hamiltonii*, Hook. f.	Evergreen to moist deciduous	sub-Himalayan tract, Assam, Sikkim, Khasi Hills, Chhota Nagpur, East Bengal, Andaman Island and Burma.
Cananga tertiara Prasad,1994 c	*C. odorata*, Hook.f. & Thoms.	Evergreen	Martaban and Tenasserim, MalayanPeninsula and Archipelago
Saccopetalum pretomentosum Prasad *et al.,* 2004	*S.tomentosum*, Hook f. & Thoms	Moist deciduous	Bihar, Orissa, western Ghat and throughout the Peninsula Arawali Hills
Capparidaceae			
Capparis palaeomicrantha Prasad *et al.,* 2004	*C. micrantha* DC	Evergreen	MalayaPeninsula, Pegu, Tenasserim
Bixaceae			
Bixa kathgodamensis Prasad *et al.,* 2004	*B. orellana*, Linn.	Evergreen	Tropical India&America, India
Flacourtiaceae			
Gynocardia mioodorata Prasad et al 1999	*G. odorata*, R. Br.	Evergreen	Sikkim, khasi Hills, Burma, NE –India
Hydnocarpus palaeokurzii Prasad 1994 c	*H. kurzii* (King) Wrab.	Evergreen	Martaban, eastern and Southern slopes of Peguyoma
Uncobia palaeospinosa Prasad 1994 c	*U. (Stuartia) spinosa* Forsk	Mixed Deciduous	Tropical Arabia & Egypt
Clusiaceae			
Mesua tertiara (Lakhanpal) Prasad, 1994c	*M. ferea* Linn.	Evergreen	Chittagong, Upper MyanmarAndaman Islands, Malaysia, S. Lanka, South India
Garcinia eocambogia Prasad 1994 c	*G. Cambogia* Roxb	Evergreen	western peninsula from Konkan to Travancore and Sri lanka. forest of India,
Calophyllum suraikholaensis (Awasthi & Prasad,1990) Prasad *et al.,* 2004	*C. polyanthum*, Wall.	Evergreen	Bangladesh, Myanmar and Malaya.
Dipterocarpaceae			
Dipterocarpus siwalicus (Lakhanpal & Guleria) Prasad, 1994c	*D. tuberculatus* Roxb.	Evergreen to Moist deciduous	Myanmar, Cochin China and Thailand.
Hopea Kathgodamensis Prasad, 1994d	*H. micrantha* Hook.f.	Evergreen	Malacca, Myanmar and Borneo.
Shorea. miocenica (Antal & Prasad, 1996b) Prasad *et al.,* 2004	*S. buchananii*, Fischer	Evergreen	Myanmar.
Bombacaceae			
Pachira palaeomalabarica Prasad *et al.,* 2004	*P. malabarica (sesoilis)* Aubl.	Evergreen	Tropical America, Mexico, West Indies.
Sterculiaceae			
Sterculia Kathgodamense Prasad, 1994 c	*S. coccinea*, Jack	Evergreen	Sikkim, Assam, Khasi hills, Bhutan and Myanmar.
Tiliaceae			
Grewia kathgodamensis Prasad *et al.,* 2004	*G. laurifolia* Hook.	Evergreen	Malacca & Penang, Maingay, Borneo.
Rutaceae			
Geijera siwalica Prasad, 1994d	*G. pariviflora* Lindl.	Evergreen	Tropical Australia
Acronychia siwalica Prasad, 1994d	*A. baueri* Schott.	Evergreen to Moist deciduous	Australia (Queensland Macleay and Clarence rivers)
Meliaceae			
Trichilia miocenica Prasad, 1994c	*T. glabra* Vell	Moist deciduous	Tropical Africa
Toona siwalica (Awasthi & Lakhanpal) Prasad, 1994 c	*T. ciliata* Roxb	Evergreen to Mixed deciduous	Sub-Himalayan tract from Indus eastwards, western Ghats and hills of western peninsula
Chukrasia miocenica Prasad, 1994d	*C. tubularis* Adr. Juss.	Moist dediduous	North east India, Myanmar Chittagong, throughout South India.
Dysoxylum mioklanderi Prasad, 1994d	*D. kalanderi* F. Muell.	Evergreen	Australian land masses
Rhamnaceae			
Zizyphus miocenicus Prasad, 1994c	*Z. jujuba* lam.	Mixed deciduous	Throughout India & Myanmar

Z. kathgodamensis Prasad, 1994 c	*Z.xylopyrus* Wild.	Mixed deciduous	Northwestern Himalayan foot hills, Central India and western Peninsula.
Sapindaceae			
Euphorea siwalica Prasad 1994c	*E. didyma* Blanco.	Evergreen	Malayan Archipelago
Cupania miocenica Prasad *et al.,* 2004	*C. Jackiana* Heirn.	Evergreen	Nicobar Islands.
Anacardiaceae			
Holarrhena nainitalensis Prasad *et al.,* 2004	*H. antidysentrica* Wall.	Mixed deciduous	Sub-himalayan tract, India, Western peninsula, Myanmar.
Fabaceae			
Acacia eosericata Prasad,1994 c	*A. sericata* A. cun ex Benth.	Mixed deciduous	Northern Australia
Albizia siwalica (Prasad) Prasad, 1994 c	*A. lebbek* Benth	Evergreen to Moist deciduous	Sub-Himalayan tract, Both Peninsulas and Myanmar
Dialium palaeoindum Prasad, 1994 c	*D. indum* Linn.	Evergreen	Malayan Peninsula
Cassia siwalica Prasad, 1994c	*C. tora* Linn	Mixed deciduous	Central Himalaya, Madhya Pradesh, cosmopolitan
Samanea siwalica Prasad, 1994 c	*S. saman* Merrill	Evergreen	Tropical America
Millettia palaeoracemosa (Awasthi & Prasad) Prasad, 1994 c	*M. racemosa* Benth.	Moist deciduous	Konkan, North Kanara, Coastal Andhra Pradesh, South Deccan, Burma, Pegu and Tennaserim.
M. siwalica Prasad, 1994d	*M. ovalifolia* Kurz	Moist deciduous	Sub-himalayan region, Myanmar
M. kathgodamensis sp. nov.	*M. atropurpurea* Benth.	Evergreen	Pegu yoma Hills, Martaban and Tenasserim
Cynometra palaeoiripa (Prasad *et al,* 1999)	*C. iripa* kotel	Moist deciduous	Indo-Malayan region
Ormosia robustoides (Prasad, 1990b)	*O. robusta*, Wight	Evergreen	Arunachal Pradesh, Assam, Bangladesh, Myanmar
Derris prakashii Prasad *et al.,* 2004	*D. trifoliata* Lour	Evergreen	China, N. Australia, Polynesia, Eastern Himalaya, western Peninsula and Ceyon.
Pongamia kathgodamensis (Prasad, 1994 d)	*P. glabra* Vent.	Evergreen to moist deciduous	Oudh forests and sub - Himalayan tract, Sri Lanka, Malaya Tropical Australia
Rosaceae			
Parinari Kathgodamensis (Prasad, 1994c)	*P. excelsa* Sabine	Evergreen	Tropical Africa Sierra leon, Don and BagrooRivers
Combretaceae			
Terminalia miobelerica Prasad, 1994 c	*T. belerica* Roxb.	Evergreen to Moist deciduous	Sub-Himalayan tract, common throughout India and Myanmar except the arid region of Sindh, western Rajasthan and Southern Punjab and Malaysia.
Lythraceae			
Lagerstroemia patelii (Lakhanpal & Gularia) Prasad1994. C	*L..florsregnae* Retz.	Evergreen to moist deciduous	Assam, Chittagong, Lower Myanmar, Western Ghats, Sri Lanka, & Malayan peninsula
	L. speciosa, Pers.	Moist deciduous	Myanmar, Bangladesh, Ceylon, Malaya peninsula, Assam & Western Ghats.
Lagerstroemia jamraniensiss Prasad *et al.,* 2004		Moist deciduous	Myanmar, Bangladesh, Ceylon, Malaya peninsula, Assam & Western Ghats.
Rubiaceae			
Morinda palaeotinctoria Prasad, 1994c	*M. tinctoria* Roxb.	Evergreen	Central Provinces, Bihar, Myanmar, Malaysia peninsula.
Gardenia nainitalensis Prasad*,* 1994c	*G. jasminoides* Retz. = *(G. scandense)*	Evergreen	Taiwan to Japan
Myrsinaceae			
Ardisia palaeosimplicifolia Prasad, 1994c	*A. simplicifolia* Walp.	Evergreen to Moist deciduous	Tennasserim, Bengal and Assam
Saptaceae			
Sarcosperma mioarboratum Prasad *et al.,* 2004	*S. arboreum* Benth*.*	Evergreen	Sub- Himalayan tract and outer hills, Eastern India, Upper Myanmar and Yunnan.
Ebenaceae			
Diospyros kathgodamensis Prasad, 1994 c	*D. cacharensis* (Das & Kanjilal) H.B. Naithani.	Evergreen	Cachar & Lakhimpur in Assam, Khasi Hills in Meghalaya, Siang District, Arunanchal Predesh.
D. palaeoebenum Prasad, 1994 d	*D. ebenum* Kurz.	Evergreen	Ceded Distt. especially Kurnool and Cuddapoh, Sri Lanka
Diospyras nainitalensis Prasad *et al.,* 2004	*D. chloroxylon,* Roxb.	Moist deciduous	Western peninsula, and North & Eastern part of India
D. palaeoeriantha sp. nov.	*D. eriantha* (Champ.) Benth.	Evergreen to Moist deciduous	Philippiines
Apocyanaceae			
Wrightia siwalica Prasad, 1994 c	*W. tinctoria* R. Br.	Moist deciduous	Rajputana, Central Provinces, Western peninsula
Lauraceae			
Michilus miocenica (Prasad , 1994 d	*M. odoratissima* Nees	Evergreen to moist deciduous	Outer Himalayan ranges from Indus eastwards, Khasi Hills of Martaban and upper Myanmar.
Euphorbiaceae			
Mallotus venkatachalai Prasad,1994 c	*M. cochinchinensis,* Lour. *M. rependus* Muell. Arg.	Evergreen	Assam, Bengal, Bangladesh, Burma, Sri Lanka&Malaysia.
Phyllanthus siwalica Prasad, 1994d	*P. gracilips* Muell	Evergreen to Moist deciduous	Shady forests of Java
P. mioreticulatus (Prasad, *et al* 1999)	*P. reticulatus,* Poir.	Mmoist deciduous	India, Myanmar, Sri Lanka
Homonoia mioriparia (Antal & Prasad, 1997) Prasad *et al.,* 2004	*H. riparia,* Lour	Evergreen	Myanmar, Sri Lanka., Malaya peninsula, China, India except in the North- West
Glochidion miocenica (Prasad1994 c)	*G. chlorophaes* Baill.	Evergreen	Malaysia.
Moraceae			

Ficus precunea Lakhanpal 1969	*F. cunea* Ham.	Mixed deciduous	Sub- Himalayan tract & Outer Hill from the Chenab eastward, Manipur, Khasi hills, Myanmar
Ficus oodlabariensis (Antal& Awasthi, 1993)	*F. benjamina* Linn	Evergreen	Eastern Himalaya, Assam, Chittangong, Andamans, Pegu, Martaban.

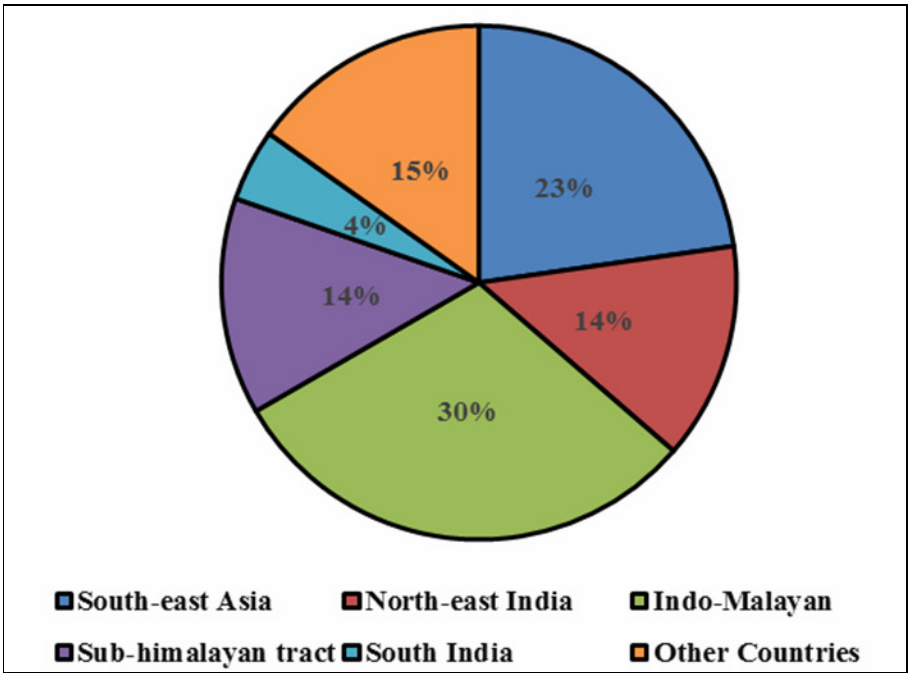

Fig. 3. Showing the present day distribution of modern analogues of all the recovered fossil species in different geographical regions.

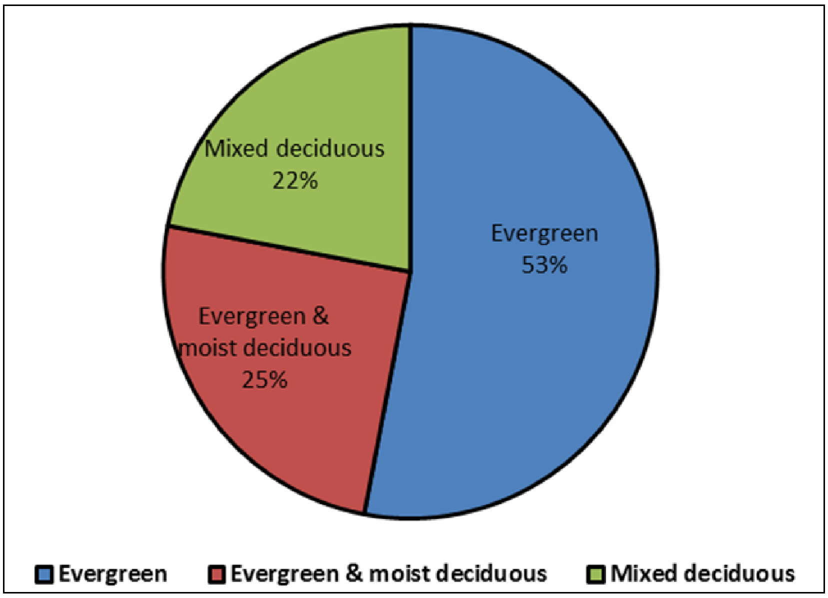

Fig. 4 : Diagrammatic representation of different types of forest elements in the fossil assemblage of the Kathgodam area.

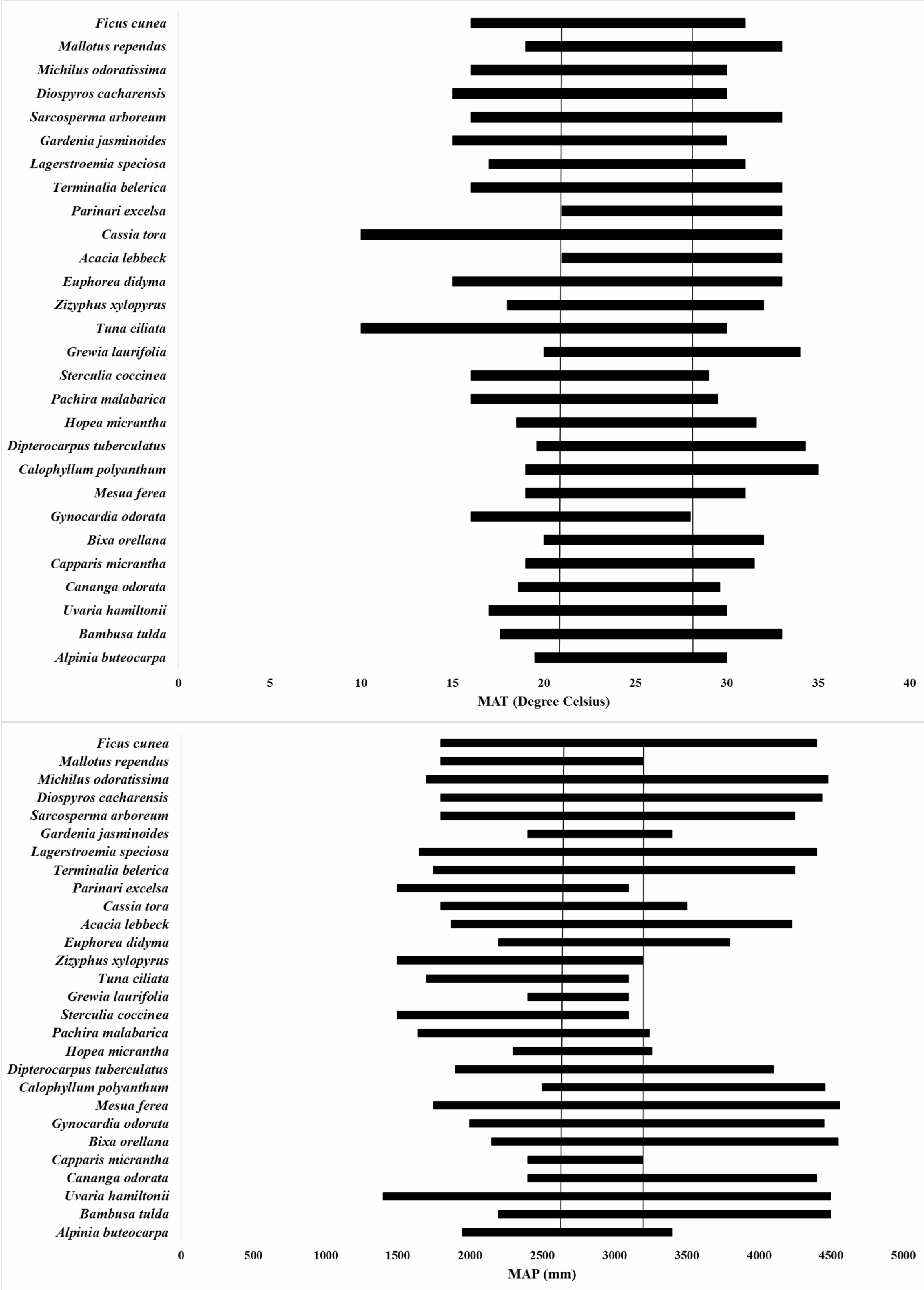

Fig. 5 : Showing the coexistence intervals of climatic parameter. (a) Mean Annual Temperature (MAT) and (b) Mean Annual Precipitation (MAP) of modern relatives of fossil species recorded from Kathgodam area, Uttarakhand. (▬) indicate the intervals of coexistence) and vertical line indicating the common range of MAT and MAP

ACKNOWLEDGEMENT

We express our gratitude to the Director, Birbal Sahni Institute of Palaeosciences, Lucknow for providing necessary facilities during the consultation of the institute's library.We are thankful to the authorities of Central National Herbarium, Sibpur, Howrah,West Bengal for permitting to consult their Herbarium for the Identification of the fossils.

REFERENCES

Agarwal, A.; Prasad, M. and Mandaokar, B.D. (2006). Leguminous fossil woods from the Lower Miocene sediments of Tuipang area, Mizoram, India. *Journal of Applied bioscience,* 32(2): 168-173.

Bailey, I.W. and Sinnott, E.W. (1916). The climatic distribution of certain type of angiosperm leaves. *American Journal of Botany,* 3: 24-39.

Bande, M.B. and Prakash, U. (1986). The Tertiary flora of Southeast Asia with remarks on its palaeoenvironment and phytogeography of the Indo-Malayan region. *Review of Palaeobotany Palynology,* 49: 203-233.

Champion, H.G. and Seth, S.K. (1968). *A revised survey of the forest types in India*. Manager of Publication, Delhi.

Dahlgren, R.R. and Thorne, F. (1984). The order Myrtales: circumscription, variation, and relationships. *Annals of the Missouri Botanical Garden,* 71: 633-699.

Dayal, (1965). *Sapindoxylon schleicheroides* sp. nov, a fossil dicotyledonous woods from the Deccan Intertrappean beds of Madhya Pradesh. *Palaeobotanist*13: 163–167.

Desch, H.F. (1957). Manual of Malayan timbers. *Journal of Malayan Forest Record,* 15: 1-328.

Dilcher, D.L. (1974). Approaches to identification of angiospermous leaf remains. *Botanical Review,* 40: 1-157.

Dorf, E. (1969). Palaeobotanical evidence of Mesozoic and Cenozoic climatic changes. *Proceedings of the North American palaeontological Convention*: 323-346.

Friis, E.H., Pedersen, K.R. and Crane, P.R. (1992). *Esgueiria* gen. nov. fossil flowers with combretaceous features from the Late Cretaceous of Portugal. *Biologiska Skrifter K. Danske Videnskabernes Selskab,* 41: 1–45.

Givinish, T.I. (1976). Leaf form in relation to environment: A theoretical study. *Unpublished Ph.D. Thesis; Princeton University*. 467pp; Princeton.

Guleria, J.S. (1992). Neogene vegetation of Peninsular India. *Palaeobotanist,* 40: 285-311.

Harrington, G.H. (2008). Phylogeny and evolutionary history of Sapindaceae and *Dodonaea. Ph.D. Thesis. James Cook University, Queensland, Australia*, 185 pp.

Karunakaran, C. and Rangarao, A. (1979). Status of exploration of hydrocarbon in the Himalayan region. Contribution to stratigraphy and structure. *Geological Survey of India Miscallneous Publication,* 41(v): 1-66.

Klassan, R.K. (1999). Wood anatomy of the Sapindaceae. *IAWA (International Association of Wood Anatomists) Journal Suppement,* 2: 895-908.

Lakhanpal, R.N. (1970). Tertiary flora of India and their bearing on the historical geology of the region. *Taxon,* 19(5): 675-694.

Lakhanpal, R.N. (1974). Geological history of the Dipterocarpaceae. *Symp. Origin Phytogeogr. Angiosperms, B.S.I.P. Publication,* 1: 3039.

Mabberley, D.J. (1997). *The Plant Book*. Cambridge.

Mahabale, T.S. and Deshpande, S.R. (1965). *Terminalioxylon tomentosum* sp. nov. a fossil wood from Ghala (Gujarat State) belonging to the family Combretaceae. *Bulletin Botanical Survey, India*. 7: 267–275.

Mehrotra, R.C. (1987). A new fossil dicot wood from the Deccan Intertrappean beds of Mandla District, Madhya Pradesh. *Geophytology,* 17(2): 204–208.

Mehrotra, R.C.; Paul, A.K. and Verma, S.K. (2007). Plant remains from the Disang Group of Wokha District, Nagaland, *India. Current Science,* 92: 597-598.

Merrill, E.D. (1923). Distribution of the Dipterocarpaceae. *Philippines Journal of Science,* 23: 1-32.

Muller, J. (1970). Palynological evidences on early differentiation of angiosperms. *Biological Review,* 45: 415-450. Cambridge.

Prakash, U. and Dayal, R. (1968). Fossil wood of *Terminalia* from Kutch. *Current Science*8:

Prasad, M. (1991). Fossil fern *Goniopteris prolifera* Persl. From the Siwalik Sediments near Nainital, U. P. India. *Current Science,* 60(11): 665-666.

Prasad, M. (1994a). Siwalik (Middle-Miocene) leaf impressions from the foot-hills of the Prasad, Himalaya, India. *Tertiary Research,* 15(2): 53-90.

Prasad, M. (1994b). Morphotaxonomical study on angiospermous plant remains from the foot- hills of Kathgodam, North India. *Phytomorphology* 44(1 & 2): 115-126.

Prasad, M. (2008). Angiospermous fossil leaves from the Siwalik Foreland Basins and its palaeoclimatic implications. *Palaeobotanist*57: 177-215.

Prasad, M.; Ghosh, R. and Tripathi, P.P. (2004). Floristics and climate during the Siwalik (Middle Miocene) near Kathgodam in the himalayan foot hills of Uttaranchal, India. *Journal Palaeontological Society, India,* 49: 35-93.

Punyasena, S.; Eshel, W.G. and McElwain, J.C. (2008). The influence of climate on the spatial patterning of Neotropical plant families. *Journal of Biogeography,* 35: 117–130.

Ranga Rao, A.; Khan, N.N.; Venkatachala, B.S. and Sastri, V.V. (1979). Neogene Quaternary Boundary and the Siwalik. *Field Conference NIQ Boundary, India Proceeding,* 1981: 131-142.

Richards, P.W. (1952). *The tropical rain forest: an ecological study*. Cambridge University Press, Cambridge.

Richardson, J.E.; Chatrou, L.W.; Mols, J.B.; Erkens, R.H.J. and Piri, M.D. (2004). Historical biogeography of two cosmopolitan families of flowering plants: Annonaceae and Rhamnaceae. *Philosophical Transactions of the Royal Society of London* B, 359: 1495-1508.

Schrine, B.D.; Lewis G.P. and Lavin, N.M. (2005). Biogeography of the Leguminosae. In Lewis *et.al.* Legume of the world, Kew, England: 21-54.

Shukla, A. (1984). Palaeopedology of the overbank intervals of the Lower Siwalik sub group (Kathgodam-Amritpur section of Kumaun Himalaya, India. *Unpublished M.Sc. Dissertation, University of Delhi, New Delhi*.

Singh, H.; Prasad, M.; Kumar, K.; Rana, R.S. and Singh, S. (2010). Fossil fruits from Early Eocene Vastan Lignite, Gujarat, India: taphonomic and phytogeographic implications. *Current Science,* 98(12): 1625-1652.

Singh, H.; Prasad, M.; Kumar, K. and Singh, S.K. (2011). Palaeobotanical remains from the Palaeocene – Lower Eocene Vagadkhol formation, Gujarat, western India and their palaeoclimatic and phytogeographuic implications. *Palaeo world.* 20: 332-356.

Smith, A.G. and Briden, J.C. (1979). *Mesozoic and Cenozoic palaeocontinental maps*: Cambridge University Press, Cambridge.

Smith, A.G.; Smith, D.G. and Funnel, M. (1994). *Atlas of Mesozoic and Cenozoic coastline*: Cambridge University Press, Cambridge.

Stace, C.A. (2007). Combretaceae, The families and genera of vascular plants. *In Eudicots (ed. Kubitzki, K.), Springer-Verlag, Berlin- Heidelberg.* 67–82.

Tiffney, B.H. (1981). Fruits and seeds of the Brandon lignite. IV. *Microdiptera* (Lythraceae). *Journal of the Arnold Arboretum,* 62: 487-516.

Utescher, T.; Bruch, A.A.; Erdei, B.; Francois, L.; Ivanova, D.; Jacques, F.M.B.; Kern, A.K.; Liu, Y.S.; Mosbrugger, V. and Spicer, R.A. (2014). The Coexistence Approach- Theoretical background and practical consideration of using plant fossils for climatic quantification. *Palaeogeography, Palaeoclimatilogy, Palaeoecology,* 410: 58-73.

Wilf, P.; Wing, S.L.; Greenwood, G.R. and Greenwood, C.L. (1998). Using fossil leaves as palaeoprecipitation indicators: an Eocene example. *Geology,* 26: 203-206.

Wolf, J.A. (1969). Palaeogene flora from the Gulf of Alaska region United State Geological Survey Open file report: 114.

Wolfe, J.A. (1971). Tertiary climatic fluctuation and method of analysis of Tertiary floras. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 9: 27-57.

Wolf, J.A. (1979). Temperature parameter of humid to mesic forest of eastern Asia and relation to forests of other regions of the northern hemisphere and Australasia. *United State Geological Survey Professional Paper,* 1106.

Zachos, J.C.; Pagani, M.; Sloan, L.; Thomas, E. and Billups, K. (2001). Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science* 292: 686–693.