PREFACE

Palaeobotany is the study of past vegetation involving many aspects of both botany and geology. It has application in the understanding of floristics, palaeoclimates, palaeoecology, phytogeography and stratigraphy. The palaeobotanist investigates plant fossils from the distant to the immediate past to understand their form and function and build up floristic patterns through nearly 3500 million years of life records. Palaeobotanical investigations also help in charting the history of modern vegetation and the origins and development of agriculture and plant utilization.

The Siwalik flora of India has been subjected to numerous changes. Many genera which are recorded in India during Mio-Pliocene either migrated or faced extinction. Evolution of the Siwalik floras in the northern region has largely been influenced the Himalayan orogeny. The Middle-Miocene orogeny of the Himalaya led to the proliferation of several gymnospermic groups and appearance of several subtropical angiospermic taxa. The problems associated with the Pliocene floras are of regionalism, endemism and migration/extinction in response to physical and climatic factors which need to be worked out in detail to unravel the history of the modern flora of India.

This exercise will enhance its academic and applied utility of palaeobotanical study for those engaged in evolutionary botany, forestry, environmental interpretation, climatology and exploration of fossil fuels. Based on the authentic and refined palaeobotanical knowledge/data so far available, the reconstruction of vegetation scenarios of Himalayan foot hills through Mio-Pliocene time has been done, and also discussed on problems related to provincialism, endemism, phytogeography and migratory pathways of mainly angiospermous plants.
Under present thesis entitled, "INVESTIGATION ON PLANT FOSSILS FROM SIWALIK FORELAND BASIN OF TANAKPUR, UTTARAKHAND, INDIA" an investigation has been carried out to explore and workout systematically the plant megafossils (leaf and fruit impressions) from the Siwalik sediments exposed in Tanakpur area in the Himalayan foot-hills of Uttarakhand and on the basis of available data the reconstruction of the Palaeofloristics, palaeoclimate/ palaeoecology and phytogeography of the area have been interpreted.

The whole thesis is divided into four parts.

The first part consists of General Introduction in which physiography of the area, geology of the Siwalik, geological set up of the study area, modern flora of the Himalayan foot hills, climate, previous work in the Siwalik of Himalayan foot hills, aims and objectives of the study and material and method have been dealt with illustrations and photographs.

In the second part, Systematic of fossil assemblage, the detail description of leaf and fruit impressions of the Siwalik sediments of Tanakpur area, Uttarakhand, their modern affinity, fossil records and comparison and the present day distribution of their modern equivalents have been given. The fossil assemblage comprises 57 species belonging to 51 genera of 25 families which are listed below:

MARANTACEAE

Donax ovatus (AWASTHI & PRASAD) n. comb.

ANONACEAE

Anona miocenica sp. nov.
Popowia siwalica sp. nov.
Saccopetalum pretomentosum PRASAD et al., 2004
Meiogyne purniyagiriensis sp. nov.
Kingstonia palaeonervosa sp. nov.

POLYGALACEAE
Securidaca precorymbosa sp. nov.

XANTHOPHYLLACEAE
Xanthophyllum mioglaucum sp. nov.

CLUSIACEAE
Kayea kalagarhensis PRASAD, 1993
Calophyllum suraikholensis AWASTHI & PRASAD, 1990

DIPTEROCARPACEAE
Dipterocarpus suraikholensis PRASAD & PANDEY, 2008
Parashorea mioplicata sp. nov.
Hopea kathgodamensis PRASAD, 1994c

RUTACEAE
Toddalia purniyagiriensis sp. nov.
Atlantic siwalica sp. nov.
Clausena miocenica sp. nov.

ZYGOPHYLLACEAE
Balanites siwalica sp. nov.

MELIACEAE
Aglaia purniyagiriensis sp. nov.

ICACINACEAE
Gomphandra palaeocoriacea sp. nov.

RHAMNACEAE
Ventilago miocalyculata sp. nov.

SAPINDACEAE
Sapindus eotrichfoliatus sp. nov.
Lepisanthes miocenica sp. nov.
Lepisanthes tanakpurensis sp. nov.
Harpullia siwalica PRASAD & AWASTHI, 1996
Filicium koilabasensis PRASAD, 1994e

ANACARDIACEAE
Drimycarpus siwalicus sp. nov.
Boeua premicrophylla ANTAL AND AWASTHI, 1993

SABIACEAE
Sabia eopaniculata PRASAD, 1994e

CONNARACEAE
Gnestis purniyagiriensis sp. nov.

FABACEAE
Bauhinia nepalensis AWASTHI & PRASAD, 1990
B. purniyagiriensis sp. nov.
Millettia mioinermis sp. nov
M. siwalica PRASAD, 1990a
Humboldtia miocenica sp. nov.
Wagatia miopticata sp. nov.
Dalbergia tanakpurensis sp. nov.
Derris prakashii PRASAD et al., 2004
D. mio scandens sp. nov.
Pongamia siwalika AWASTHI & LAKHANPAL, 1990
Cynometra palaeoiripa PRASAD et al., 1999

COMBRETACEAE
Terminalia bhairauensis sp. nov.
Combretum purniyagiriensis sp. nov.

MELASTOMACEAE
Medinilla siwalica sp. nov.

LYTHRACEAE
Lagerstroemia prakashii sp. nov.
Lagerstroemia mioparviflora DWIVEDI et al., 2006

Rubiaceae
Ixora purniyagiriensis sp. nov
Randia tanakpurensis sp. nov.

Sapotaceae
Plaquium palaeograndis sp. nov.
Chrysophyllum bairauvensis sp. nov.

Lauraceae
Cinnamomum palaeotamala LAKHANPAL & AWASTHI, 1984

Myristicaceae
Myristica siwalica sp. nov.

Euphorbiaceae
Mallotus prejaponicus sp. nov.
M. kalimpongensis ANTAL & AWASTHI, 1993
Baccaurea miocenica sp. nov.
Bridelia hanumanchattensis sp. nov.

Urticaceae
Ficus precunea LAKHANPAL, 1968
Sarcochlamys miopulcherima sp. nov.

The Third part is Discussion and Conclusion in which the results of the present study on plant megafossils have been discussed under three chapters i.e. Floristic composition and analysis, palaeoclimate/palaeoenvironment and plant diversity/phytogeography. Besides, the comparison of fossil flora of Tanakpur area has been made with other equivalent flora of India, Nepal and Bhutan.

The morphotaxonomical study on fossil assemblage including leaf and fruit impressions reveals the occurrence of 57 species of 25 angiospermous families. Of these, 39 species have been recorded new to the fossil flora of
Himalayan foot hills and remaining 18 species are reported already from different Siwalik fossil localities in the Himalayan foot hills of India, Nepal and Bhutan.

The family Fabaceae (Legume family) represented by 15 species is the most dominant family in this Siwalik fossil assemblage followed by Anonaceae (8 species), Sapindaceae (5 species), Lauraceae and Euphorbiaceae (4 species) and Dipterocarpaceae and Rutaceae (3 species). The family Fabaceae which appeared in Upper Palaeocene became a major component of the evergreen forest during Mio-Pliocene times all along the Himalayan foot hills.

The evergreen elements (54%) dominate the fossil flora of Siwalik in Tanakpur area during Mio-Pliocene 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 rain fall during the deposition of Siwalik sediments.

The analysis of present day distribution of all the species recovered from the Siwalik foreland basins shows that they are mostly known to occur in North-east India, Bangladesh, Myanmar and Malaysia wherever favourable climatic conditions exist. Only about 14% taxa of the total assemblage are found to grow presently in the Himalayan foot hills and the remaining 86% taxa are locally extinct, suggesting changes in the climatic condition.

The palaeoclimate/palaeoecology has been drawn by two methods:

1. **Coexistence method**, i.e., from comparison of the leaf-impression with the extant taxa.

2. **Foliar physiognomy method**, i.e., from study of the structural features of leaf-impressions.
Coexistence method

This deals with the interpretation of past climate by using the climatic preferences of modern plants. Climate reconstruction using fossil assemblage requires three bits of information: (1) a living relative for each fossil species (2) the autoecology of the living relatives of each fossil species and (3) a modern association of species similar to the fossil flora. In the real sense, the modern analogue community should be similar to the fossil assemblage in both species composition and relative abundance of taxa. The plant fossils collected from Tanakpur area have been compared with their modern equivalents and it has been observed that a few of them still exist in the area. Therefore it is easier to infer the palaeoclimate of the region during the past.

The fossil plants recovered so far from the Siwalik sediments of the Tanakpur area comprise 71 fossil taxa and mostly all of them were compared with modern taxa. The present habit and habitat of these taxa 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 (GAMBLE, 1972; HOOKER, 1982, 1882, 1885; CHAMPION & SETH, 1968; DESCH, 1957;). Thus it may be surmised that a warm and humid climate prevailed in Tanakpur area in the Himalayan foot hills during Mio-Pliocene 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 taxa in the fossil assemblage do not occur in the vicinity of Tanakpur or all along the whole himalayan foot-hills of both India and Nepal. This obviously indicates that changes in the climate must have taken place after the deposition of Siwalik sediments in this region.
Foliar physiognomy method

Physiognomic features of the fossil angiospermous leaves such as shape, size, venation, density, texture, margin, and tip, etc. has a great relationship with climate and thus provides more reliable results (Table 3). As this method is independent of the systematic relationship of the species, the errors in the interpretation of palaeoclimate are minimized as compared to the above Coexistence method. The detailed physiognomic study of the fossil leaves recovered from the Siwalik sediments of Tanakpur area in the Himalayan foothills of Uttarakhand provides some significant data for the estimation of on climatic conditions prevailing in the foot hills during Siwalik period.

One of the best indicators of climate appears to be the leaf margin, viz., entire versus non-entire. The approach, Leaf margin analysis (LMA) for the reconstruction of climate is based on the work of BAILY AND SINNOT (1916), who had found a direct relation between the margin and climate. According to him the typical entire margined leaves of woody families like Anonaceae, Lauraceae, Ebenaceae, Clusiaceae, Sapotaceae, Dipterocarpaceae and Apocynaceae, etc. are practically absent from mesophytic cold temperate regions. On the contrary, non-entire leaved families as Betulaceae, Aceraceae, Platanaceae, etc. are absent from low land tropical areas. Nevertheless, the families like Malvaceae, Rosaceae, Ulmaceae, Fagaceae, Tiliaceae, Flacourtiaeae, Anacardiaceae and Fabaceae possess both types of leaf margins, i.e., entire and non-entire. According to BAILEY AND SINNOTT (1916) the woody plants of tropical low lands possess entire margins, while in temperate they possess non-entire margins. Similarly, WOLFE (1969) concluded that the tropical rain forests have the highest percentage of entire margined species. This percentage decreases with decreasing temperature either with increasing altitude to the submontane and montane rain forests or with increasing latitude
to the warm temperate forest. The leaf margin analysis of the fossil leaf assemblage of Tanakpur area, revealed that all the species except three taxa, i.e., Bauhinia nepalensis, Mallotus prejaponicus, and Sarcochlamys miopulcherima, have entire margin indicating a warm tropical climate (Table -3). The remaining taxa (95.5%) in the assemblages are with entire margin. WOLFE (1971) presented a comparison of mean annual temperature (MAT) and percentage of species with entire margined leaves for 19 modern floras which increase from 10-86% of entire margined species corresponding to an increase from $40^0 - 28^0$C in temperature. Similar models were derived from the plot of MAT and percentage of entire margined species by WOLFE, 1979 for the species of eastern Asia, GREENWOOD (1992) for the species of Australia and WILF (1977) for the species of America. Converting the plots into linear equations they have given regression models as follows.

$$\text{MAT} = 1.4 + 0.306 \times (\% \text{ entire}) \text{ by WOLFE, 1979; WING AND GREENWOOD, 1993)}$$

(In this equation ($\% \text{ entire}$) is the percentage of leaves in the assemblage that have entire margins).

When this equation is applied to the present floral assemblage it has been found that the MAT value is $30.6^0$C. This suggests that the MAT (Mean annual temperature) during Mio-Pliocene time all along the Himalayan foot hills was $30.6^0$C which was reduced by $6.2^0$C at present day (the present day MAT of the Himalayan foot hill zone is $24.40^0$C. (data of 20 year obtained from Indian Metrological Department and Champion & Seth, 1968).

The present estimated MAT ($30.6^0$C) is very significant as it corresponds to the present day MAT value of North east India ($29.04^0$C) where Maximum
(more than 28%) comparable taxa of the fossils of Tanakpur area are found. (Tables 2; Fig.9). Similarly more than 17% comparable taxa of the fossil assemblages are growing now-a-days in the south Indian region where MAT value varies from $25^0$ to $27^0$C and is responsible for the existence of evergreen forest (CHAMPION & SETH, 1968).

There a strong relation between the Mean Annual Precipitation (MAP) and average leaf area. WILF et al. (1998) has formulated an equation to estimate the MAP by using the proportion of large size leaves in the assemblage of any region. This equation is as follows.

$$MAP = 47.5 + 6.18X \times (% \text{ Large leaves})$$

(% Large leaves) is the percentage of leaves in an assemblage of mesophyll size or larger in area mesophyll or larger ($\geq 33 \hspace{1cm} \text{cm}^2$).

In order to estimate the Mean Annual Precipitation (MAP) of Himalayan foot hills in Tanakpur area during Mio-Pliocene time the above equation is applied to the Tanakpur leaf assemblages and found that the MAP value is 397mm. When this MAP value has been compared with the present MAP value of different places in the Himalayan foot hills (ie Jammu 89 mm., Kathgodam and Tanakpur 167 mm., Hardwar 180 mm, Surai Khola and Koilabas 106 mm and Siliguri 279) it has been seen that their average MAP value (164 m) is reduced by 233 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 Tanakpur area has also been compared with the present MAP value of those regions (North east India and South India) where now-a days, 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 274 mm, Kuchagaon 335 mm, Siliguri 279 mm) and South India (Kerala 278 mm and Karnataka 281 mm.)

Thus, from the foregoing discussion it may be concluded that the Tanakpur area in Himalayan foot-hills, Uttarakhand enjoyed a tropical climate (with MAT 30.6°C and MAP 397mm) along with plenty of rainfall during the Mio-Pliocene Times. This is, however, contrary to the present day climate of the area with reduced precipitation.

The dominance of entire margined species (95.5%) in the fossil assemblage indicates the presence of tropical climate during the Siwalik sedimentation. The other physiognomic features like drip tips, leaf size, leaf texture, nature of petiole and venation density etc. collectively further suggest tropical climate during the deposition of Siwalik sediments.

Dipterocarpaceous taxa in the present floral assemblage are very significant from the phytogeographical point of view which appears frequently during Mio-Pliocene times. The present and past distribution of the family Dipterocarpaceae indicates that it is pan tropical and specially distributed in tropical Asia. The fossil record suggests that the family Dipterocarpaceae originated in western Malaysia during 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 dipterocarpaceous fossils (LAKHANPAL, 1974; BANDE & PRAKASH, 1986). Thus, it is evident that the dipterocarps spread from western Malaysia eastward to Philippines and northward to eastern India through Myanmar, and then spread throughout Himalayan foot hills and flourished luxuriantly there during middle Miocene to Middle Pliocene. The possible time for their migration was early Miocene when
the land connection between Malaya, Myanmar and eastern India were established.

The floral assemblage also comprises a good amount of taxa which have been found common to Malaya, Myanmar and India indicating a fair floral exchange after establishing the land connection between these sub-continents.

In the Fourth part, References, the references of authors cited in the text have been enumerated.

Thus, the present study has updated the knowledge of the Siwalik flora of India, Nepal and Bhutan and provided sufficient contributions of palaeobotanical interest.