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SOME ASPECTS OF BIOCLIMATOLOGY AND VEGETATION OF PENINSULAR INDIA

BY

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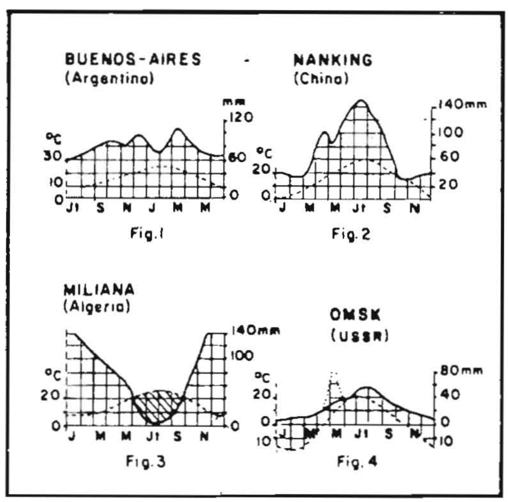
Mr Chairman Prof. Mahabale, Madam Sahni, Prof. K. N. Kaul, Prof. K. R. Surange, Prof. T. N. Khoshoo, Prof. R. C Misra and distinguished members of this gathering, I consider it a great honour having been invited to deliver the 27th Sir Albert Charles Seward Memorial Lecture this year. At the very outset I would like to seek your indulgence by admitting that mine will not be a learned lecture like those of my predecessors who were all eminent botanists and geologists.

CLIMATE AND BIOCLIMATE

The purpose of a climatic classification is to characterise the climatic regions in terms of meteorological elements like precipitation and temperature which are the most decisive in determining the landscapes of the earth. In physical classification of climates, in general, importance is given to the annual averages. Thus Buenos Aires (Argentina), Nanking (China), and Miliana (Algeria) have almost the same mean annual temperature of 16°C and the same total of annual precipitation, 950 mm. However, from point of view of natural vegetation, Buenos Aires possesses a savanna, Nanking a temperate forest and Miliana a mediterranean type of sclerophyllous forest. If we examine the climate-diagrams of these three stations (Figs. 1-3), we find the differences in the rhythm of temperature and rainfall in the course of the year at these stations, which enable us to explain the diverse types of vegetation met with.

One more example which illustrates the defect of the use of the annual averages is provided by the station of Omsk in U.S.S.R. The mean annual temperature is under 1°C and total of precipitation is 280 mm. These figures convey the idea of a climate that is arid and unfavourable to the vegetation. A study of the seasonal march of phenomena indicates that it is not so. The climate diagram of Omsk (Fig. 4) shows that after a cold period of almost six months lasting from November to April, the growth of the vegetation is facilitated by an abrupt rise of temperature and by the water made available from the spring thaw. With the result there are four months of conditions conducive to plant growth and consequently Omsk possesses a coniferous forest.



Figs 1-4 — Ombrothermic diagrams.

Therefore, a climatic classification which is based mostly on the mean annuals is not absolutely satisfactory in the domain of plant-geography. A classification based on the rhythms of temperature and precipitation is much more reasonable. It should take into consideration the conditions favourable or unfavourable to the life, i.e. the wet and dry period or the warm and cold period. One may, therefore, define a bioclimate as the climate in relation to life.

Climatic Factors

The climatic factors of prime importance are:

— mean temperature of the coldest month of the year,

— annual precipitation,

— the length of the dry season expressed by a number of dry months. The definition of a dry month is a controversial topic, the precipitation limit varying from 25 mm to 100 mm according to the authors and countries. For those inhabiting deserts even 20 mm of rains suffice to call it a wet month but for those used to the torrential rains of equatorial and tropical humid belts anything less than 100 mm would be classified as a dry month. Bagnouls and Gaussen (1957) have defined a month as dry when its precipitation in mm is less than twice the mean temperature in °C. This definition though empirical has given good results for India (Meher-Homji, 1965).

— the period of frost. A month with mean temperature less than −2°C is considered as a month of frost.

Bioclimatic Map of the Indian Sub-continent

All these climatic factors are brought out on a graph called an ombrothermic diagram (Bagnouls & Gaussen, 1957). Etymologically the term ombrothermic is derived from the words of Greek origin: Ombros = rainfall and thermos meaning temperature. On the abscissa are marked the months of the year, on the ordinates, to the left the scale of temperature in °C, and to the right the scale of rainfall in mm. The rainfall curve is shown in full line, the temperature curve is dotted. In order to bring out the length of the dry season on the graph, the scale of temperature is taken as double that of the rainfall. Dryness prevails when the temperature curve goes above the rainfall curve.

The winter of the northern hemisphere corresponds to the summer of the southern hemisphere and vice-versa. In order to render the diagrams comparable between the two hemispheres, January is taken as the first month on the abscissa in the northern hemisphere and July in the southern. Thus the middle of the graph represents in both the cases, the period where the days are longest and the temperatures highest.

These diagrams can be used to compare the climates of the world and bring out the analogous stations. Some examples are given in Figs 5-12. The diagram of Jacobabad (Pakistan) resembles that of Attar in Mauritania. The graphs of Bombay, and Ziguinchor (Senegal) are identical, New Delhi resembles Leon (Mexico), and Cochin and Phnom-Penh (Cambodia) are comparable.

Based on the ombrothermic diagrams, detailed bioclimatic maps of India and South-east Asia have been prepared at the French Institute, Pondicherry.

The alternation of rainy season and dry season, a phenomenon so typical of the tropical climate, is shown on the map by means of two bands, one corresponding to the rainy season, the other to the dry, their width being proportional to the relative lengths of the rainy and the dry seasons.

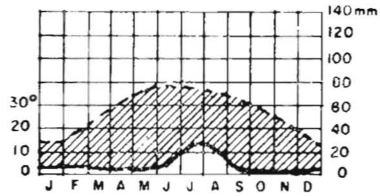


Fig.5. JACOBABAD
28°17'N. 68°27'E 56m

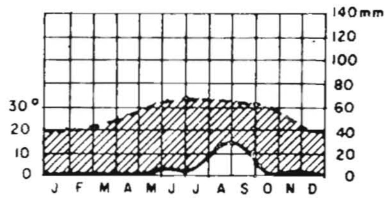


Fig.6. ATTAR, Mauritania
21°31'N. 13°04'W. 225m.

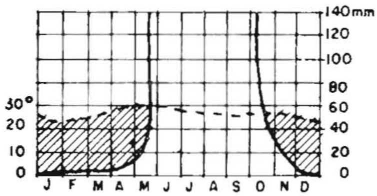


Fig.7. BOMBAY
18°54'N. 72°49'E. 11m.

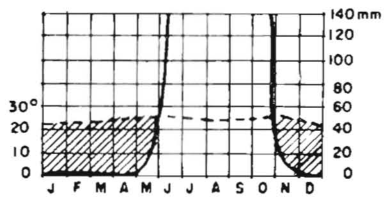


Fig.8. ZIGUINCHOR, Senegal
12° 35'N. 16°16'W. 10m.

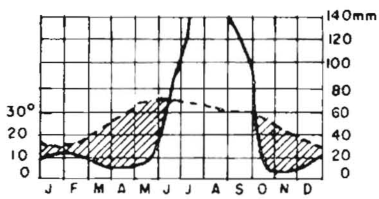


Fig.9 NEW-DELHI
28°35'N. 77°12'E. 217m.

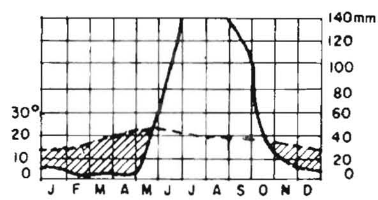


Fig.10. LEON, Mexico
21°7'N. 101°41'W. 1809m.

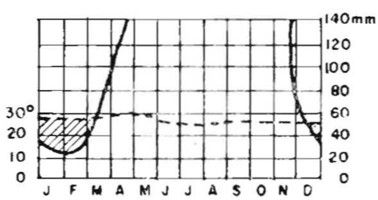


Fig.11. COCHIN
9°58'N. 76°14'E 3m.

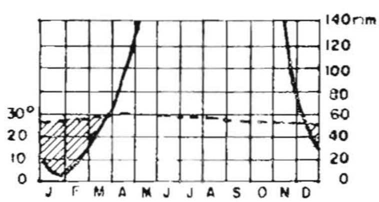


Fig.12. PHNOM-PENH, Cambodia
11°33'N. 104°51'E 10m.

FIGS 5-12 — Ombrothermic diagrams.

Colour Scheme

The main principle is the logical use of the colours of the spectrum to represent the ecological conditions. High rainfall (> 2000 mm) is represented in blue, the colour of water bodies, and very poor rainfall (< 100 mm) of the deserts in red, the colour of heat and burning. In between these extreme classes of rainfall, the intermediate colours of spectrum ranging from light blue to yellow and orange represent the intermediate classes of rainfall.

Similarly high temperature, mean of the coldest month (t) > 20°C is shown in reddish colour; orange is used if it is between 15 and 20 C and yellow if the temperature is yet milder: 10-15°C.

By superimposing the colours of rainfall and temperature, the resultant colour of the ecological complex is obtained. Thus for the equatorial and tropical humid regions, blue will be used for high rainfall and red for high temperature. Superimposition of blue and red will result in violet colour. For the arid zones red will be used; for the tropical mountains, the final colour will be green: blue for rainfall and yellow for temperature.

This resultant colour of the ecological complex is used for the band of rainy season on the map; for the band of dry season, the colour of the temperature class is used. For Kerala, the dry season is very short and hence the band of dry season represented in red is very narrow. Dryness increases as we proceed northwards or eastwards and correspondingly the width of the red coloured band also widens.

Equatorial climate and tropical montane climate without any dry season are shown in full violet and full green respectively without any band of dry season. At the other extreme, the Thar desert is presented in full red without any band of violet coloured rainy season.

Thus the bioclimatic map shows the large variety of climates existing in the sub-continent. Along the base of the Himalayas prevails the bixeric climate with two dry seasons; one of the peaks of rainfall is during the winter due to the western disturbances, another peak is during the summer due to the influence of the south-west monsoon. Parts of Pakistan and Afghanistan are under the average mediterranean regime with winter-spring precipitation and summer dryness.

The bioclimates are referred to in terms of values of climatic factors and the use of controversial terms like subtropical or temperate is avoided especially for the tropical mountains. I will come back to the question of subtropical climate a little later.

Xerothermic Index

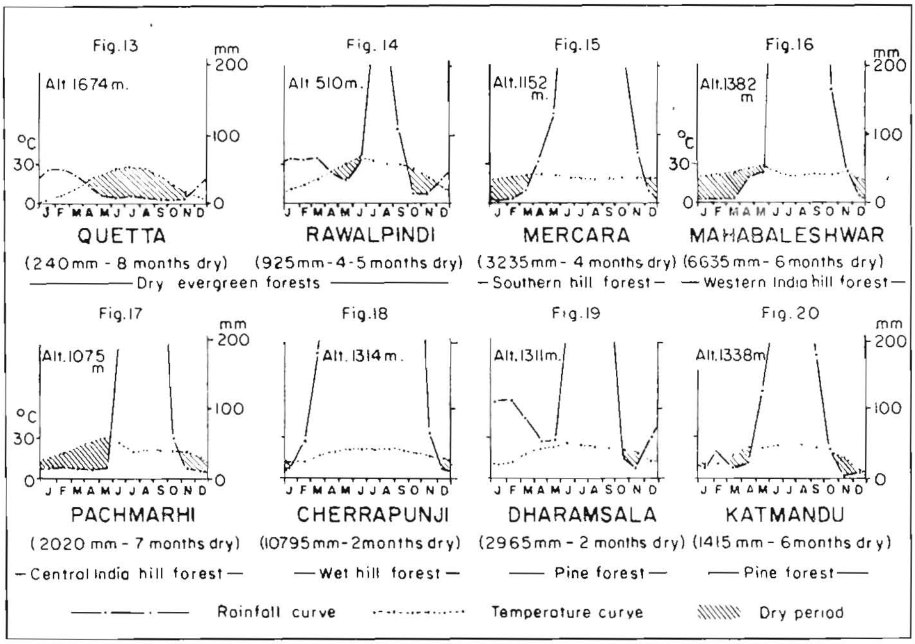
Above we defined empirically a month as physically dry when the relationship was precipitation less than twice the mean temperature. Within this framework, further precision could be added to the degree of dryness by considering secondary factors that reduce the severity of drought.

Xerothermic index of Bagnouls and Gaussen (1953) evaluates the number of biologically dry days. From the total number of days in a dry month are subtracted the number of rainy days and half the number of foggy and misty days. If relative humidity is more than 90%, the figure given by the above formula is multiplied by 5/10, if humidity is 80-90%, then the figure is multiplied by 6/10 . . . . if humidity is between 40-60% than by 9/10 and for values lower the 40% by 10/10. The true dry days of all the dry months represent the xerothermic index. Dewy days are also of considerable importance and they too should be incorporated in the formula.

SUBTROPICAL CLIMATE: FACTS AND FALLACIES

The term subtropical has been interpreted geographically as a latitudinal belt comprising the area between the tropic of Cancer and 40° latitude North or between the tropic of Capricorn and 40° latitude South, climatically as involving temperatures and precipitation lower than in the tropics or having season of rains inverse to that of the tropics, and vegetationally as either corresponding to the deserts, mediterranean areas or moderate elevation of tropical mountains. Large variations in climatic patterns (Figs 13-20) and floristic diversity further complicate the issue of subtropicality.

Champion and Seth (1968) created the subtropical forest category as a transitional step from the tropical to the temperate type. The limit is based on temperature: mean annual value 17-24°C, January mean 10-18°C. Thus hill tracts of moderate altitude of India have been classified



Figs. 13-20 Ombrothermic diagrams of stations having subtropical forests according to Champion (1936).

as subtropical but what could be subtropical geographically, for example parts of Rajasthan and Madhya Pradesh, have been excluded from this category because the temperatures fall short of the stipulated limits by very narrow margin.

Contrary to the axiom 'altitude compensates for the latitude', the montane areas of lower latitudes differ considerably from the subtropics in the diurnal and, seasonal features of photoperiod and temperature. Whereas seasonal variations are well marked in higher latitudes, diurnal fluctuations play an important role in the tropical hills.

As the deserts of the world are generally concentrated in the subtropical latitudes, there is a tendency to associate the subtropical climate with the arid zones. Evidently, the statement is not wholly true as Hyderabad (Sind) and Cherrapunji both located on the 25th parallel witness extremes of precipitation.

Yet another trend is to equate the subtropical climate with the mediterranean one wherein the rains are concentrated in winter-spring-autumn. The rainfall rhythm is thus diametrically opposite of the tropical zone where the rainy season corresponds to the summer with high temperatures and long days. The dry "mediterranean" type of vegetation of north-west Pakistan is thus classified as subtropical dry evergreen forest by Champion (1936).

Figures 13-14, ombrothermic diagrams present the climatic features of Quetta and Rawalpindi. However, as mentioned earlier, the hilly areas of the tropics experiencing typical south-west monsoon regime are also brought within the framework of subtropics by Champion (1936) entirely on the stength of temperature factor. Hill stations like Mercara, Mahabaleshwar and Pachmarhi illustrate in Figs 15-17 the tropical regime with summer concentration of rains.

What perhaps could pass off as subtropical vegetation in India purely on account of its extra-tropical location is the *Anogeissus pendula* Edgew. forest of eastern

Rajasthan and Bundelkhand; it does not extend much in altitude in the Aravallis. The type is assigned '*tropical deciduous edaphic*' status by Champion (1936). The edaphic appendage is questioned by Verma (1972). The tropical title may be defended by the temperature figures of the meteorological stations within the *A. pendula* tract. Probably, the data monitored by thermographs at the forest sites would reveal a picture different from that obtained by the observatories located in towns. Anyway, the important point to bear in mind is that in spite of its restricted occurrence to subtropical latitude, almost all the species associated with *A. pendula* occur further southwards in the deciduous forests of Peninsula.

Another probable candidate for latitudinal subtropicality is the 'northern tropical desert thorn forest' of Champion but once again its main constituents like *Prosopis cineraria* (L.) Druce, *Capparis decidua* (Forsk.) Pax and *Ziziphus* spp. among others also occur on the Deccan plateau. Thus the Tropic of Cancer does not strictly bring about any major change in the vegetation Sal (*Shorea robusta* Gaertn. f.) forests occur on either side of this parallel, teak (*Tectona grandis* L.) extends but little north of it in Rajasthan and Madhya Pradesh. It may be said that the vegetation types of Peninsular India are oriented meridionally rather than latitudinally, following the rainfall gradients generated by the north-south running Western Ghats and Eastern Ghats.

As regards the term subtropical and temperate for the Himalayas which first and foremost convey the idea of montane ecosystems, the altitudinal limits demarcating various vegetation types and floristic boundaries are more meaningful than the vague comparisons with the latitudinal belts, tropical, subtropical, temperate. The terms alpine and subalpine have been coined to depict the high montane environments and to avoid confusion with the latitudinal notions arctic and subarctic; in spite of the presence of snow-cover at both very high altitudes and latitudes, the fundamental differences of day length and temperature rhythms necessitate their separation into distinct alpine and arctic categories. The same principles demand that in a lofty mountain range like the Himalayas, the ecological zonations are marked out with reference to elevation rather than latitudinal implications.

From floristic point of view, only a few genera like *Acer*, *Celtis*, *Styrax*, *Pinus*, *Quercus* are of widespread occurrence in the geographical subtropical zone, though not exclusively. There are species of pines and oaks confined to the middle latitudes but their distribution is too disjunct to characterise a uniform, global subtropical phytogeographic belt as envisaged by the geographers.

MACRO- MESO- AND MICRO-CLIMATES

So far we have dealt with climatic factors in terms of averages but in quite some cases, the climatic means conceal facts of practical importance. The interyearly fluctuations in rainfall are well-known. Pondicherry may receive only about 650 mm per annum when the frequency of depressions is low. In other years with good development of depressions in the Bay of Bengal, the amount received may be four times higher. The mean rainfall of 1300 mm has not much bioclimatic significance. In other cases, the length of dry season may be involved. For example, at Kodaikanal the majority of individual years experience dryness of 1 to 4 months, yet on the basis of averages, the drought period does not come out because the dry spells occur in different months in different years. At Murree, the average length of dry season is 1 month but in actual years it may vary from 0 to 5 months. Rawalpindi with 5 months of dryness on an average basis presents the range of 2 to 8 dry months.

New Delhi with a range of 5 to 11 months dryness presents average of 9.

For certain stations of Kashmir and north-west Pakistan, the average rainfall regime turns out to be of mediterranean type but in reality the south-west summer monsoon is quite important some years, the importance of which is masked by the mean data.

Figures 21 and 22 show the variations in the regimes at Peshawar and Srinagar respectively during the period 1927 to 1942. They also reveal the interyearly variability in precipitation amount and the length of the dry season. Figure 23 reveals the variations in the climatic factors of seven dry zone stations for a series of 17 to 24 years. The station Dera Ismail Khan presents the full gamut of regime range from tropical to bixeric, irregular and mediterranean types. Such frequent changes in the regime from year to year are to be considered amongst adverse agroclimatological factors. Had such adverse changes any role to play in the abandonment of the Indus Valley culture sites ?

Three degrees of mediterranean climate have been recognised for the north-west part of the Indo-Pakistan sub-continent (Meher-Homji, 1973):

— Under the pure degree of mediterraneity, exemplified by the station Nokkundi, aver-

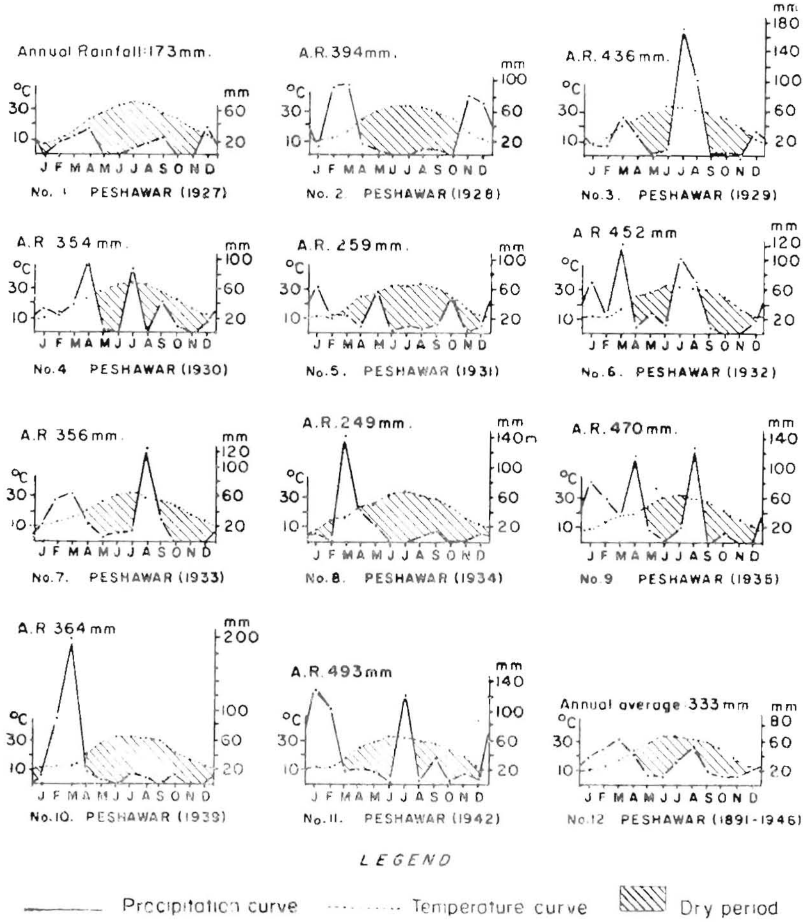


FIG. 21 — Ombrothermic diagrams of Peshawar.

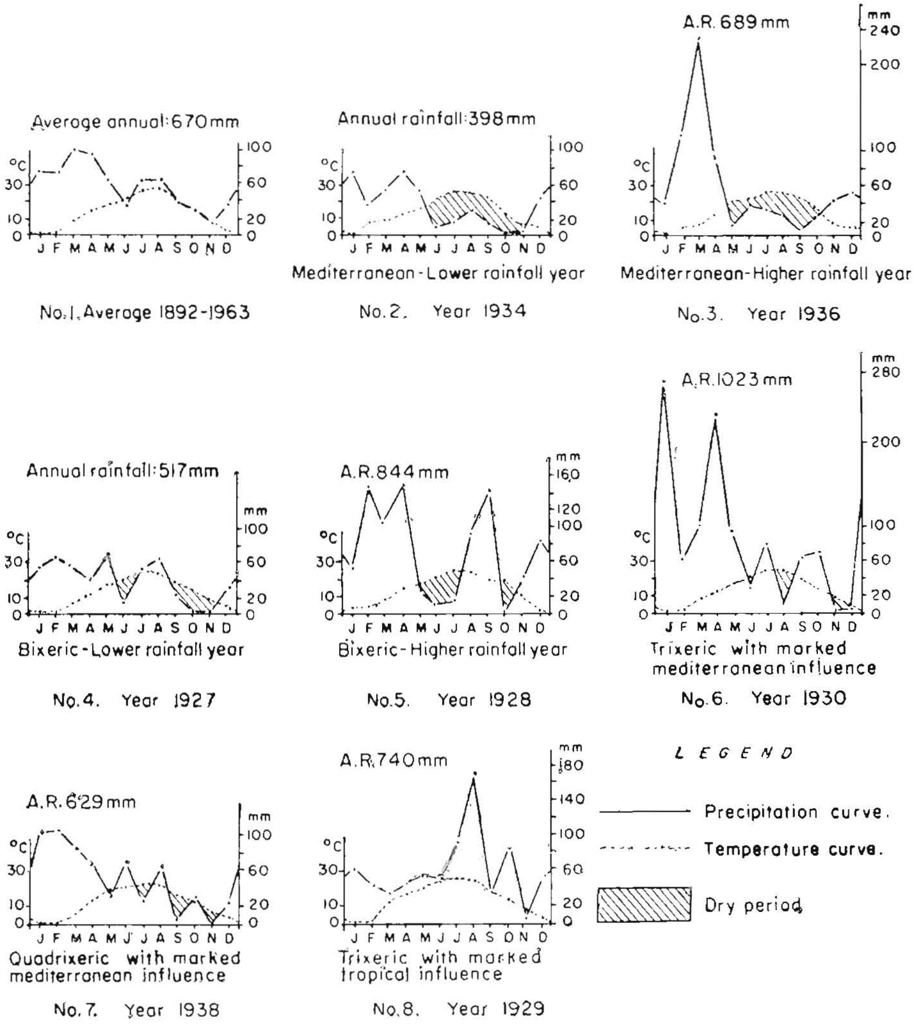


FIG. 22 — Ombrothermic diagrams of Srinagar

age summer rainfall and number of rainy days expressed as percentage of the total rainfall and total rainy days is zero, and all the individual years have mediterranean climatic regime.

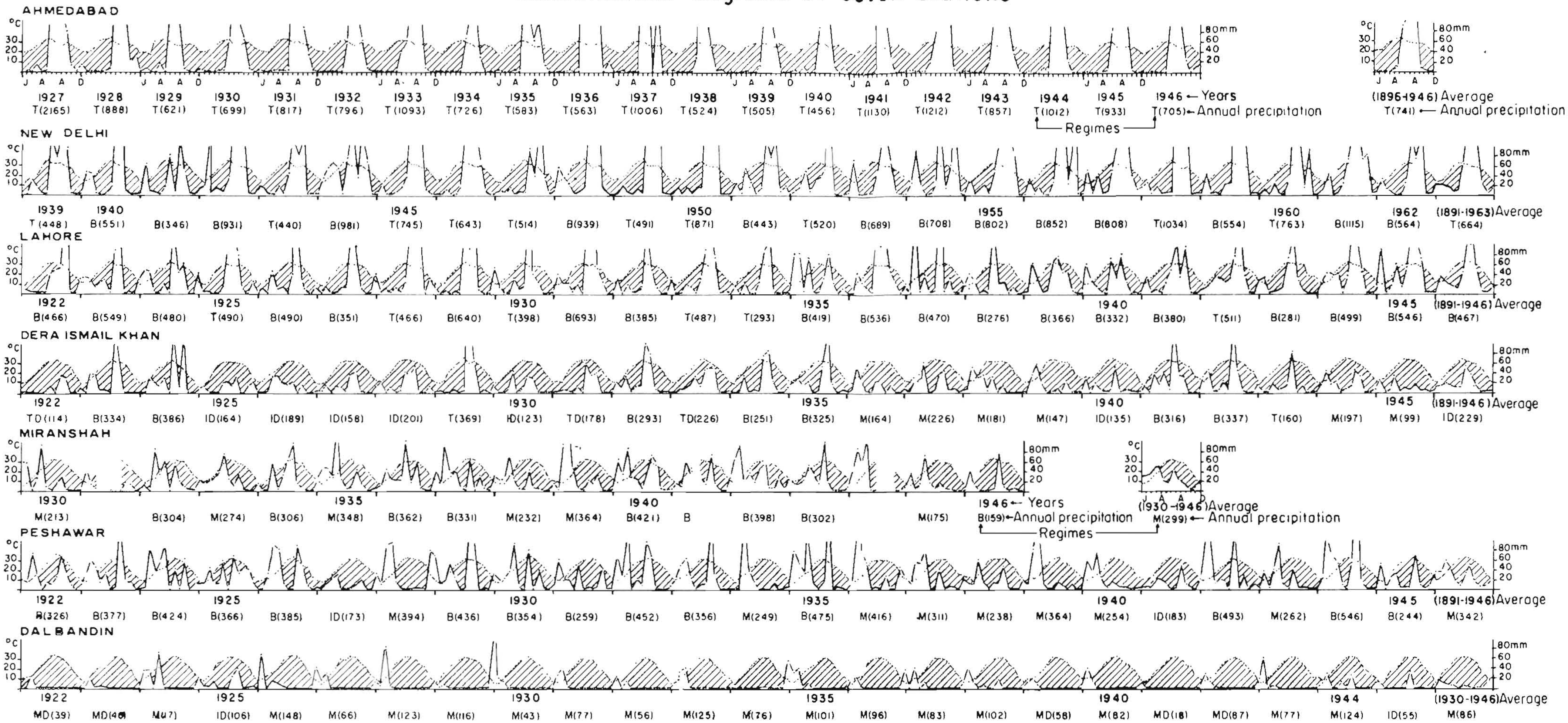
— Under the moderate degree of mediterraneity, average summer rainfall and number of rainy days expressed as percentage of the total is less than 43. At least 33 per cent years have mediterranean climatic regime.

— Under the attenuated degree of mediterraneity, average summer rainfall is 43 to 60 per cent of the total rainfall, and the average number of rainy days in summer is 43 to 55 per cent of the total. Eighteen to 33% years have mediterranean climatic regime.

Figure 24 shows these degrees of mediterraneity. Interesting relationship is obtained between the conditions of aridity, temperature and degrees of mediterraneity represented in the area covered in Fig. 25 and the floristic elements.

In areas experiencing tropical climate like Delhi Union Territory (Maheshwari, 1963), Indus Delta (Blatter *et al.*, 1929),

Ombrothermic diagrams of seven stations



Precipitation curve   Temperature curve   Dry period

Precipitation regimes: T=Tropical, M=Mediterranean ; B=Bixeric , I=Irregular , D=Desertic (12 months dry).

Value of annual precipitation is given in brackets.

FIG. 23.

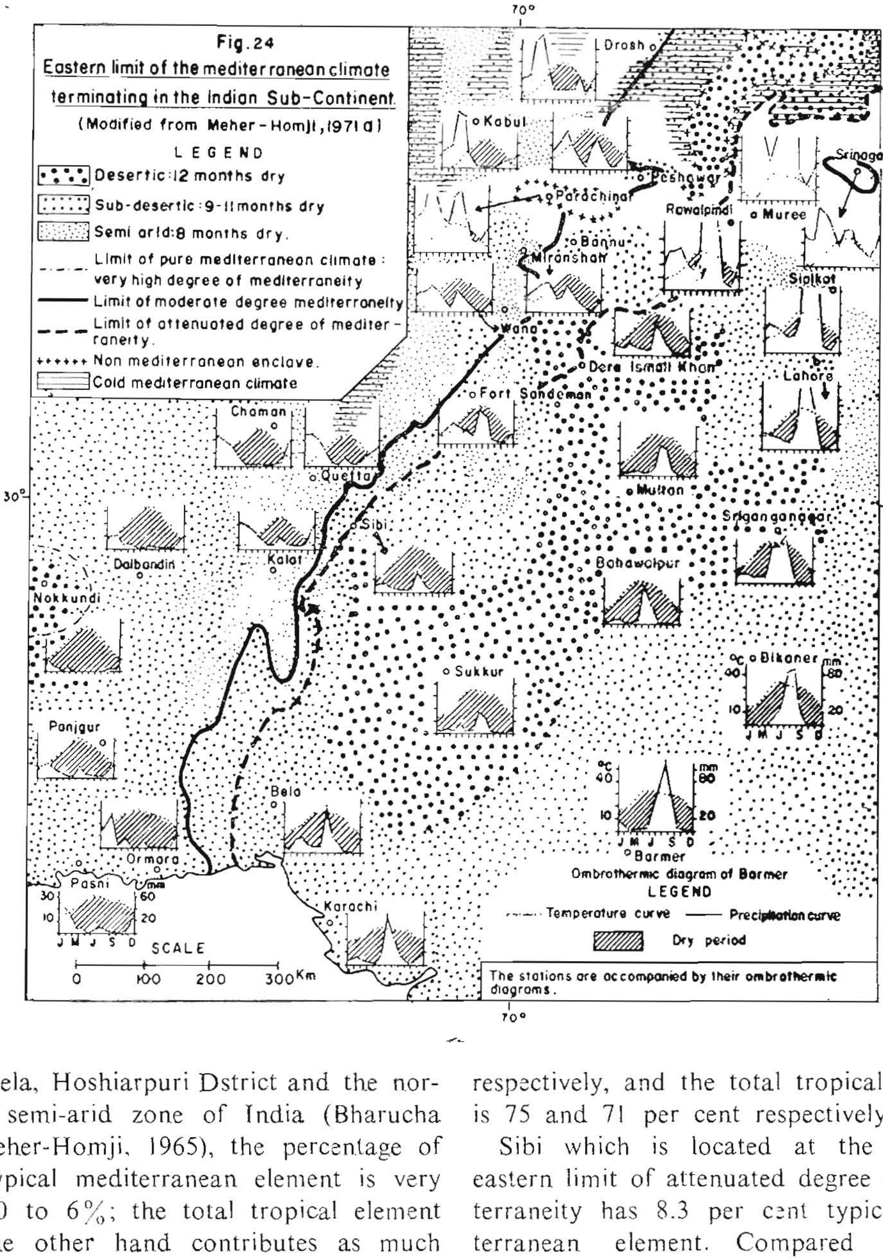


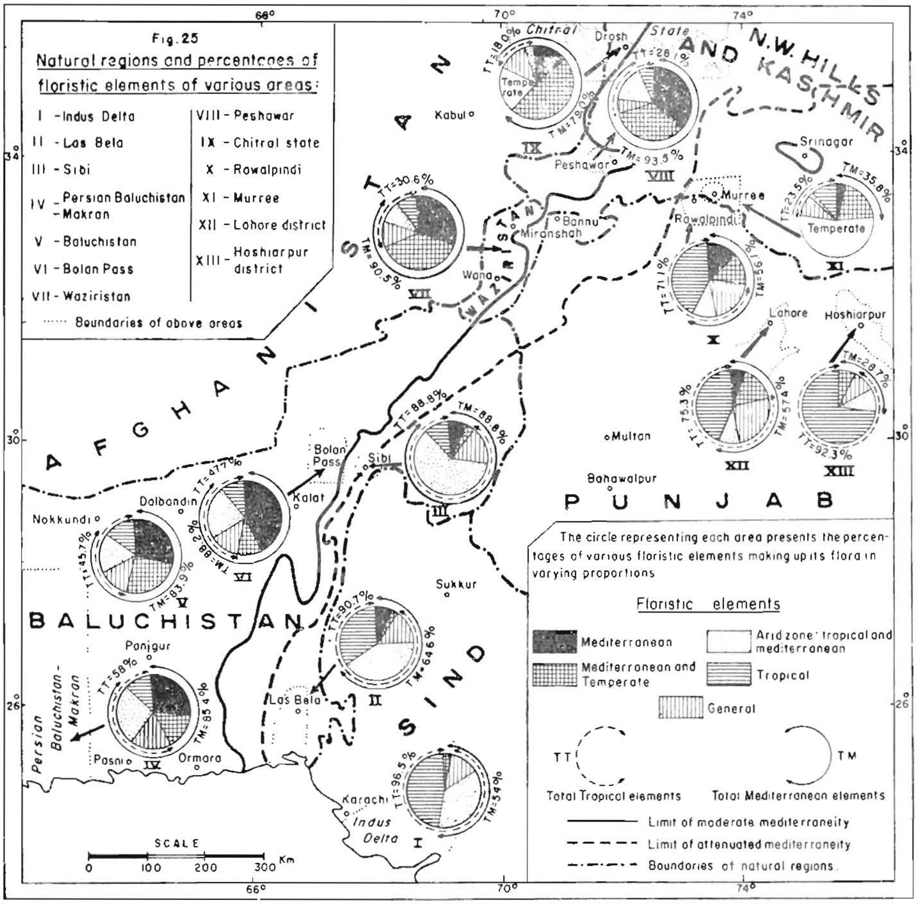
Fig. 24
Eastern limit of the mediterranean climate terminating in the Indian Sub-Continent.
(Modified from Meher-Homji, 1971 a)

Las Bela, Hoshiarpuri Dstrict and the northern semi-arid zone of India (Bharucha & Meher-Homji, 1965), the percentage of the typical mediterranean element is very low, 0 to 6%; the total tropical element on the other hand contributes as much as 89 to 96.5 per cent. The winter rains which occur occasionally in this tract may account for this slight percentage of the mediterranean floristic element (Fig. 25).

For the areas of bixeric climate like Lahore District and Rawalpindi (with winter-spring and summer rains), the typical mediterranean element is 7 and 13.7 per cent respectively, and the total tropical element is 75 and 71 per cent respectively.

Sibi which is located at the extreme eastern limit of attenuated degree of mediterraneity has 8.3 per cent typical mediterranean element. Compared to the tropical and bixeric areas, the typical tropical element falls considerably at Sibi, from 35-83 per cent to 11 per cent.

For the regions having moderate degree of mediterraneity like the Persian Baluchistan and Makran, Bolan Pass, Waziristan and Peshawar, the typical mediterranean element is 26·5 to 40·5 per cent.



Given the variability of the climate, one of our aims is to distinguish between the stable and the unstable climates, the stable climates being those where the annual average pattern repeats itself with reasonable fidelity year after year. In case of wide interyearly fluctuations which characterise the unstable climes, the concept of a probable year reflecting the range of rainfall, length of dry seaon is more meaningful rather than the notion of average year.

The concept of probable year may be approached in two ways: (i) the pattern of majority of individual years, say 65 to 75 per cent years, would define the range of each climatic factor, (ii) a probable year may be considered as one wherein the figures of precipitation, number of rainy days and dry months correspond to mean values plus or minus the standard deviation, and the regime is of the most common type or types. Each year has to have the value of each factor within the range set by mean ± standard deviation to qualify as a probable year.

Percentage number of years corresponding to the pattern of probable year define the degree of stability or unstability of the climate.

Microclimatic studies involve monitoring the environment at the exact site of investigation. The temperature recorded at the Kodaikanal observatory is never below zero °C but when thermographs were installed at different sites it was observed that in the grassy blanks during the winter nights temperature drops as low as −9°C but at the same time under the shola (montane forest) canopy, it is above zero °C (Legris & Blasco, 1969).

Again, during the dry spells of 1 to 4 months mentioned earlier, the relative humidity in the grasslands drops to about 30 per cent but remains quite high under the forest.

These facts reveal fundamental eco-climatic differences existing between the forests and savannas of the South Indian hill-tops and explain why the *Shola* species fail to germinate in the grassy blanks and colonise them. The dry spells also account for the fires which are regular features sweeping through the grasslands and plantations of wattles (*Acacia* spp.) and *Eucalyptus*.

ON THE RECENT CLIMATIC CHANGES

Linked to the variability and stability of the climate is the problem of ascertaining whether the rain in India is on the wane. This has been a debated subject; the publications appearing till 1963 on the Indian arid zone argued in favour of no climatic change (Pramanik *et al.*, 1952; Rao, 1958). However, recently Winstanley (1973) has come out with the theory that since the late 1920s, the summer rainfall in the Sahel zone (South of the Sahara) and in north-western India has been showing a declining trend with a corresponding increase in the winter-spring precipitation of the Middle East and of the regions to the north of the Sahara along the Mediterranean coast.

One striking point in Winstanley's (1973) analysis is that he combines the data of different stations, sometimes having totally different regimes; for example, Marrakech, Tunis, Tripoli, Jerusalem, Beirut, Mosul, Shiraz are Mediterranean having a bulk of the rains in winter-spring, but Attar, Bikaner and Jodhpur are tropical, with rains concentrated in summer.

Trends in the total and seasonal rainfall and rainy days of 13 Indian stations analysed by means of 20-year running averages revealed no out and out decreasing tendency (Legris & Meher-Homji, 1976). Figure 26 shows the increasing tendency of total rainfall at Bombay.

As to the effect of large scale deforestation on the precipitation pattern, some evidence of declining trend is presented by the stations of western Karnataka. Wherever the deforestation exceeds 15 per cent of the area within a radius of 16 km, 7 to 11 criteria out of a total of 12 of rainfall and rainy days show decreasing tendency. An exception to the rule are the coastal stations, where the humidity from the sea seems to compensate the loss of forest mantle (Meher-Homji, 1980).

To revert to the main topic of bioclimates and mapping, it may be said that given the variability of the climatic factors, another logical approach would be to delimit the bioclimatic zones on the basis of natural vegetation. The plant-cover is a good reflector of the environmental conditions and also integrates the variability aspect of the climate.

MAPS OF VEGETATION

Using the principles advocated by Gaussen (1959), twelve sheets have been published so far covering India south of 28° latitude north, in collaboration with the Indian Council of Agricultural Research. Each sheet is accompanied by an explanatory booklet. Around the main map of natural vegetaion at 1:1,000,000 showing the various forest types and the stages of their degradation, six insets on hyposometry, geology-lithology, soil types, bioclimates, potential vegetation types and agricultural regions at 1:5,000,000 are presented.

In the main vegetation map, a clear-cut difference is maintained between the cul-

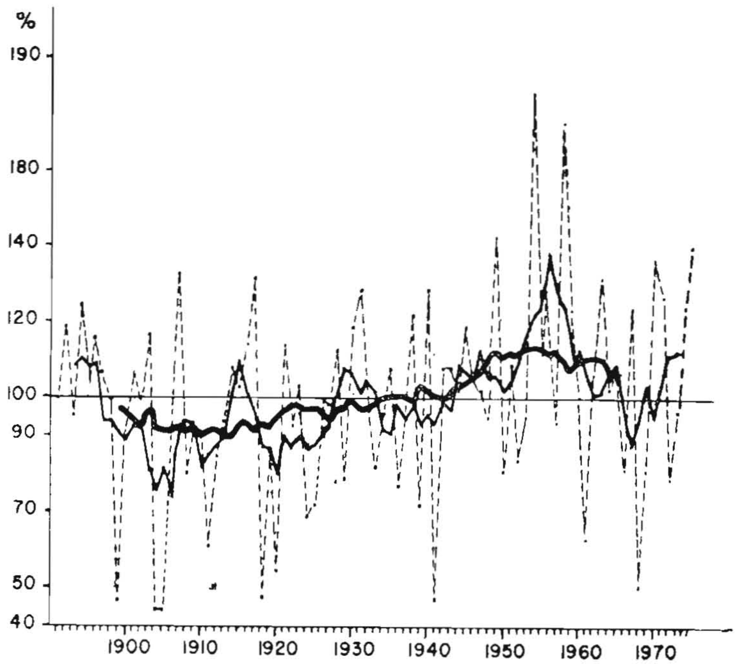


Fig. 26. BOMBAY - (Total) Rainfall

------- Yearly
——— 5 years running means centred on year given
━━━ 20 years running means centred on year given

tivated areas and the uncultivated ones. The cultivated areas are left in white so their location and importance can easily be made out as they contrast shraply with the coloured background of the natural vegetational areas. This convention also adds to the clarity of the map in that the symbols of the cultivated crops come out distinctly over the white background. Some of the symbols carry a statistical value, each sign representing an area of 10,000 ha.

The horizontal lines on the map indicate human action in the landscape. For example, the plantations are shown by horizontal lines, and the practice of shifting cultivation by leaving white horizontal blanks in the coloured area of the vegetation. The irrigation canals are depicted in fine blue lines and the projects under construction by blue dashes. The hedge-lined landscape is represented by red squares. Whereas the horizontal bands indicate the landscapes created by man, the vertical bands indicate the proportions: proportions of the crops of first importance, second importance and third importance of every agricultural region in the inset of Agriculture.

Land use of every district is shown by letters C.F.P.U. where C stands for cultivation, F for forests, P for fallows and U for unculturable wastes. Typography of these letters shows percentages of forests, cultivated, cultivable and uncultivable areas. Whereas the agricultural landscape is presented in white, the uncultivated areas are shown in colours. These represent either the forests or the different stages of their degradation like scrub-woodland, thicket, savanna-woodland, tree-savanna, shrub-savanna and scattered shrubs. Man has clear-felled forests, ploughed fields, left areas in fallows and managed pastures for the live-stock. Thus he has created a series of landscapes ranging between forest and barren land.

If a piece of waste land containing only some scattered shrubs is left free from human activity and grazing, it gradually gets covered with more and more vegetation; passing through successive stages of grasses, shrubs, thickets, it may eventually reach the forest stage. The different physiognomic stages of vegetation encountered in a region leading to a same forest type go to form what Gaussen (1959) calls a series of vegetation. The final, maximum stage of the series is called plesioclimax. Theoretically, it is defined as the stage a given plot of vegetation would reach in a sufficiently long time, without human interference. In practice it is recognised as the most developed formation met with in an ecological region. Each of the series is named after two to four species chosen from the plesioclimax stage, some for their dominance-abundance, some for their value as characteristics and some for their economic importance. Each of the phyisognomic stage is represented by a definite pattern. For example, the grasslands are indicated by a fine network of small dots. If shrubs are scattered amidst the grasses, they are indicated by big dots, thickets are shown by crosses and the forest type, i.e. the plesioclimax, in full tone colour. Thus more advanced the stage of degradation, lesser is the intensity of colour.

Each series is given a definite colour according to the ecological conditions of the area of its occurrence. Colour given by the rainfall-temperature complex is used. This may be suitably modified by the length of the dry season or the edaphic factor. If there are two types of soils in a region, one more water retentive than the other, a bluish shade may be added for the former or a reddish tint for the latter. In the southern Deccan we encounter alternation of black clayey soils with red ferruginous sandy loam. The former bears *Acacia* spp. and the latter *Albizia amara* which avoids calcimorph black soils. The latter type is presented in a deeper shade of orange.

The crops of dry ecology like millets, cotton, pulses, and palmyra palm (*Borassus*) are presented in red and orange colours, those of wetter ecology like paddy, sugarcane and coconut in blue and violet. Combined together with the colours assigned to the natural vegetation, they bring out the strong climatic contrast existing between the western and eastern halves of southern India in the sheet entitled "Cape Comorin".

Whereas the main map shows the actual state of vegetation, the inset of vegetation types depicts the potential area under each series. As every series is determined by a definite set of climatic and edaphic factors, the potential area of the series is derived from the ecological conditions besides the remnants, if any, of the characteristic species of the plesioclimax. Thus the cultivated lands have also been classified according to the potential area of the series. A comparison between the main map and the inset gives an idea of degree of degradation brought about by man. Knowing the potential area of the series helps in selection of suitable species for plantation in wastelands and other degraded areas.

As to the uses of the vegetation maps, they are the inventories of the plant resources showing their distribution in the landscape and thereby the extent of what is valuable and what deserves attention. Secondly, through proper interpretation of the data mapped, it is possible to make suggestions regarding the optimal land-use. Thirdly, as the same standards are used throughout the world in preparation of these types of International Vegetation

Maps as regards both the representation of physiognomy by definite patterns and the climatic analogies by colours, the work of comparing any two countries is facilitated. The five countries mapped so far at the French Institute, Pondicherry, are besides Peninsular India, Sri Lanka, Malagasy Republic, Cambodia and Mexico. The floristic composition naturally varies between India and Madagascar in view of the geological history, yet similarity in the climate and physiognomy provide valuable guidelines for the interexchange of economic species. Violet colour indicates tropical humid environment and evergreen forest on the west coast of India. The same colour is seen on the east coast of Madagascar indicating homologous vegetation and bioclimate. Yellowish colour band is indicative of the teak belt in India. As this important species does not occur naturally into Madagascar or Africa it can be introduced in the zones of similar colour. Thus the mapping provides scientific basis for introduction of useful species which so far has been a matter of trial and error.

The Karnataka and Kerala Forest departments are interested in introducing the clove tree (*Eugenia caryophyllata*), the oil palm (*Elaeis guinensis*) and other valuable timber species in their States. An ecological project is in progress in collaboration with the French Institute and seven maps have been planned at the scale of 1:250,000 scale.

Past History of Vegetation and Palaeo-ecology

Examples from tropical dry evergreen and deciduous forests — What is said above pertains to the present-day vegetation. The wet evergreen vegetation in Peninsular India is confined only to the west coast of southern India. As against this, the fossil record reveals widespread occurrence of wet evergreen species throughout the Peninsula in Palaeogene-Neogene times. The Pondicherry-Cuddalore-Neyveli area is presently clothed with thickets or the so-called tropical dry evergreen forests (sensu Champion, 1936). However, the Cuddalore Sandstone Series have yielded macro-fossils of certain rain-forest genera like *Anisopteroxylon* (Navale, 1962a), *Cynometroxylon* (Navale, 1958; Ramanujam & Raghurama Rao, 1966), *Dipterocarpoxylon* (Navale, 1962a; Awasthi, 1975), *Dryobalanoxylon* (Awasthi, 1969), *Glutoxylon* (Awasthi, 1965), *Hopeoxylon* (Navale, 1962a), *Mesuoxylon* (Lakhanpal & Awasthi, 1963), *Milletioxylon* (Awasthi, 1967, 1973), *Parinarioxylon* (Awasthi, 1968), *Shoreoxylon* (Ramanujam, 1953b). Combined together with fossils of deciduous forest species, they seem to represent a semi-evergreen type of forest.

Amongst the genera indicative of cool, humid climate, fossil pollen grains of *Viburnum*, *Swertia*, *Ranunculus* or *Anemone* (Navale, 1961), *Haloragis*, *Engelhardtia*, *Pterocarya*, *Ligustrum*, *Symplocos* and *Wikstroemia* (Ramanujam, 1966) have been reported from the Neyveli lignite. *Nothofagus* has also been cited among this assemblage but Lakhanpal (1970) has commented upon sporodermal differences observed in the true *Nothofagus* pollen and the specimens from India.

The presence of these "temperate" genera could be explained by long-distance transport from the neighbouring hills of the Eastern Ghats. Rao (1955), Navale (1971) and Ramanujam (1966) are of the opinion that the climate then was warm and humid as suggested by the wide distribution of Microthyriaceae, Schizaeaceae, Polypodiaceae, Palmae and the rarity of gymnosperms.

The only area around Pondicherry where dominates fossil gymnosperm is Tiruvakkarai. Huge petrified podocarpaceous woods makes this area one of the best, preserved Miocene sites in India (Lakhanpal, 1973; Ramanujam, 1968). The only extant conifer in South India is incidentally also a *Podocarpus*, *P. wallichianus* Presl. confined to the Western Ghats south of the Nilgiris at 900-1500 m elevation. In the past it could have extended along the Biligirirangan-Shevaroy-Kalrayen-Javadi axis, and further northwards along the Eastern Ghats to form a continuous range with *P. neriifolia* of Assam-Burma. Species of fossil podocarps (*Mesembrioxylon*) have also been recently reported from the Rajahmundry area (Mahabale & Satyanarayana, 1978a; Mahabale & Rao, 1973). *Podocarpus* as a genus generally plays a conspicuous role in the montane vegetation of Borneo, Philippines and Africa and so we may envisage a similar landscape with local profusion of podocarps in the Gingee Hills and Javadis not far from Tiruvakkarai in mid-Tertiary. One of the probabilities is the chance tranport of one of such colonies of *Podocarpus* to Tiruvakkarai which is located on the eastern bank of he Varahanadi that flows through Gingee. This hypothesis is not free of criticism. Why should all the podocarp fossils collect at one Tertiary site and not even a single megafossil should turn up at any other Tertiary site in South India (except Rajahmundry) ? The transported nature of the silicified woods of Tiruvakkarai is not very certain. Firstly, the woods show buttresses and traces of of roots indicating their local forigin. Secondly, in the case of water-transported fossils, such huge logs as encountered at Tiruvakkarai are unlikely. Does it suggest a local gregarious edaphic facies of this conifer in Tiruvakkarai (and also near Rajahmundry) not unlike the present-day *Taxodium distichum* (L.) Rich. community of the swamps of eastern and southern United States ? Should we then conclude a two fold origin of the fossil Tertiary flora of Pondicherry-Tiruvakkarai-Neyveli area: one of local origin mainly podocarpaceous in Tiruvakkarai, and the other angiospermous transported from the nearby hills ?

Three other gymnosperms have been recorded from Rajahmundry area: *Ginkgo* from the Deccan Intertrappean beds of Eocene age (Rao, 1969) and also from the Rajahmundry Sandstone (Cuddalore) series of Mid-Tertiary age from Pangidi (Mahabale & Satyanarayana, 1978b), *Taxaceoxylon* from Kateru (Mahabale & Satyanarayana, 1977), *Dadoxylon* along with *Mesembryoxylon* from Pangidi and Rajahmundry (Mahabale & Satyanarayana, 1978a; Mahabale & Rao, 1973). Their presence has been interpreted as indication of cool climate in the region prior to the uplift of the Himalayas but these fossils could well be the denizens of the nearby Eastern Ghats, higher in elevation then compared to present, transported by the Godavari. It may be noted that these fossil sites are located on both the eastern and western banks of the Godavari.

Among the fossil angiosperms recovered from the Deccan Intertrappean sites of the Chhindwara and Nagpur districts, once again there are genera indicator of a more humid climate during the Eocene, the age generally assigned to the Deccan Intertrappean Series. Lakhanpal (1973) and Chitaley (1974) have argued in favour of somewhat older age — Upper Cretaceous to Palaeocene — for this series.

Among these humid zone taxa may be mentioned *Ailanthoxylon* (Prakash, 1958; Shallom, 1959), *Anacardioxylon* (Prakash & Dayal, 1964; Patil, 1971), *Barringtonioxylon* (Prakash & Dayal, 1964), *Canarioxylon* (Chitaley & Shallom, 1967), *Elaeocarpoxylon* (Prakash & Dayal, 1963), *Glochidioxylon* (Prakash, 1958; Lakhanpal, 1973), *Indocarpa* (Jain, 1964; Nambudiri, 1969), *Lagerstroemia indica* (Trivedi, 1954), *Mallotoxylon* (Lakhanpal & Dayal, 1962), *Musa* and *Musocaulon* (Jain, 1963a, 1963b), *Oleoxylon* (Paradkar & Joshi, 1971), *Perrotetioxylon* (Chitaley, Patil & Hunnargikar, 1971), *Shoreoxylon* (Paradkar, 1972), *Simarubaceoxylon* (Prakash, 1960; Shallom, 1960) and *Tetrameleoxylon* (Lakhanpal & Verma, 1965).

The following are known from the Deccan Intertrappean of the Mandla District: *Bischofinium* (Bande, 1974), *Homalioxylon* (Bande, 1974), *Machilusoxylon* (Bande, 1972; Ingle. 1974), *Polyalthioxylon* (Bande, 1973), *Vitexoxylon* (Ingle, 1972).

Sparganium (Mahabale, 1953) and other species of temperate origin like Rosaceae (Pers. Comm. Professor T. S. Mahabale) could be orophytic element inhabiting the Satpura Range. Chhindwara itself lies at 600 m elevation and the hill station Pachmarhi is located only about 70 km to its north-west.

Fossils of angiosperms like *Nypa*, *Rhizophora*, *Sonneratia* and of algae *Halimeda*, *Dissocladella*, *Terquenella* and *Holosporella* indicate estuarine environment. A branch of Tethys extended up the Narmada valley to Jubbalpur in the Cretaceous (Krishnan, 1952) but in the Eocene this branch had retreated westwards and almost the present-day coastal configuration was achieved. This is perhaps one more reason in favour of Upper Cretaceous or Palaeocene age of the series. Maritime location and sites along creeks could account for the fossils of mangroves and halophytes. The find of dinoflagellates would confirm the coast-line habitat and also throw further light on the age.

Fossils of wet evergreen forest species such as *Calophyllum*, *Garcinia* and *Mesua* (Lakhanpal & Bose, 1951; Lakhanpal, 1970: Lakhanpal & Singh, 1975) and *Cocos* (Kaul, 1951) have been known from the Eocene Fuller's earth in the Barmer District; lignite (Lower Eocene) too occurs at Palana near Bikaner. The above evidence coupled with the discovery of *Dipterocarpoxylon* (Ghosh & Ghosh, 1959) from Kutch is an indication of not only a wetter but also uniformly warm and humid climate in the Peninsula including the now arid Kutch, Barmer, Bikaner districts, till about mid-Tertiary. Recent geological studies of Chatterji (1977) confirm this general situation in Rajasthan.

Lukose (1977) from the palynological evidence obtained from the Jaisalmer basin suggests a warm and wet climate of the basin during the Lower Cretaceous which later became less humid due to the uplift of the land, regression of the sea and the consequent changes in the distribution of land and sea. The gradual deterioration of climate continued till arid conditions set in during the sub-Recent times.

The palynological record from the Warkalli deposits and Quilon beds indicate that the climate of Kerala had been tropical humid in the Neogene just as at present (Rao & Ramanujam, 1975; Ramanujam 1977).

CAUSES OF CLIMATIC CHANGE

What then are the probable causes that brought about a climatic change towards drier conditions in the Peninsular India ?

First of all may be considered the location of the Peninsula in the late Cretaceous or early Tertiary. India occupied a more southerly position astride the equator in the Eocene (Frakes & Kemp, 1972). Palaeomagnetic studies of the Traps reveal the position of Nagpur as late as in Miocene at 7°N (Deutsch *et al.*, 1959; Verma & Narain, in press). The decline in the rainfall pattern may also be attributed to the uplift of the Himalayas in the wake of the northward drift of the Indian landmass, introducing the monsoon regime. The Himalayas were elevated in four stages, the last one being in the late Pliocene to early Pleistocene, establishing the present trend of precipitation in the Peninsula.

Some authors (Powell & Conaghan, 1973) have expressed the view that India had reached its present position by Upper Eocene. In support of this is cited the work of Ranga Rao (1971); the fossil mammalian genus *Indohyus* collected from the Murree group of Jammu and Kashmir States presents certain resemblance with *Gobihyus* from the Eocene of Mongolia. However, Ranga Rao (1971) himself has cast doubts on the affinity and the age of the fossils. Hsü (1976) also agrees that the contact of the Indian and the Eurasian plates took place after early Eocene because Cretaceous-early Eocene floras of Tibet are different from those of the Deccan Intertrappeans.

The subsequent northern drift, probably accompanied by a slight southern shift of the equator (Aubreville, 1969), the uplift of the Himalayas and the maximum rise of the Western Ghats in the Pliocene (Krishnan, 1968; Vaidyanathan, 1977) contributed towards drier conditions on the Coromandel coast and a change from the wet evergreen forest to a deciduous and ultimately to a dry evergreen type of thicket (Meher-Homji, 1974). The rate of drift of India during the Tertiary has been estimated at about 6 cm per year (Meher-Homji, 1976).

Whereas the major portion of the Indian subcontinent experienced a climatic change in the Tertiary, the south-east Asia has retained a more or less uniformly humid climate. The pollen stratigraphy suggests that in this central part of the Indo-Malaysian region, plant evolution has continued unperturbed by any major climatic shift since the Cretaceous (Muller, 1970). Aubreville (1969) proposed that the Tertiary equator was not far from the present-day equator in south-east Asia and so the vegetation did not experience much change compared to Africa. Melville (1966, 1967) ascribes the climatic change in India to its rapid and exactly south-north drift. This eliminated most of the Cretaceous gymnosperms (Florin, 1961) and accounted for small contribution of India to its modern flora in spite of its size, compared to south-east Asia and Africa.

GONDWANIAN VS. MALESIAN ORIGIN OF THE DIPTEROCARPACEAE

The present-day distribution of the Dipterocarpaceae covers south-east Asia, India, Sri Lanka and Africa. About two-thirds of the species are confined to Malay-Peninsula, Indonesia, Phillipines. Sarawak (West Borneo) tops the list with 247 species (Ashton, 1969a); it has been geologically stable for longer period than south-east and South Borneo. Malaya and Sabah (North Borneo) each have 150 species, (Symington, 1943; Wood & Meijer, 1964). Brunei has 153 species (Ashton, 1964). The oldest fossil records too, Oligocene in age, are known from Borneo only (Muller, 1964, 1970). Therefore, Borneo may rightly claim the title of being the cradle of the family (Meijer, 1974).

Of the 16 genera, *Dipterocarpus*, *Hopea*, *Shorea*, *Vateria* and *Vatica* are represented in India. Sri Lanka has in addition three more genera, *Cotylelobium*, *Doona* and *Stemonoporus*, the latter two being endemic. *Vateria* is the only genus of the subcontinent that does not extend to south-east Asia; it is common to India and Sri Lanka but one species *V. seychellarum* occurs in the Seychelles Island. Remaining Indian genera extend from Sri Lanka to Malaysia. *Monotes* and *Marquesia* are the two African endemic genera belonging to the sub-division Monotoides as opposed to Dipterocarpoideae which accommodate the remaining genera. *Pakaraimaea* of Guyana (South America) is placed under a third subfamily Pakaraimoideae by Maguire and Ashton (1977) but Kostermans (1978) considers the genus to belong to Tiliaceae. Of the 45 dipterocarp species in Sri Lanka, all but one are endemic. Figure 27 shows the world distribution of Dipterocarpaceae.

The Afro-Asian distribution, both present and past, immediately suggests Gondwanian origin of the family (Bancroft, 1933; Croizat, 1952; Lakhanpal, 1974; Ashton *in* Jacobs, 1978). Melville (1967) and Ridd (1971)

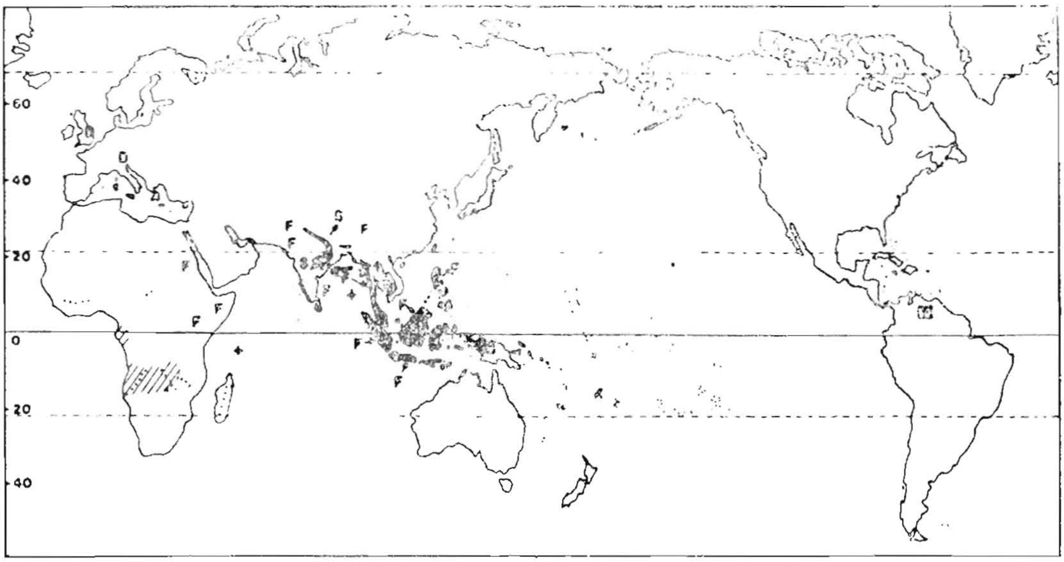


Fig 27 Distribution of Dipterocarpaceae

Asian sub-division Dipterocarpoideae		S. American Pakaraimaea	
Their presence in Seychelles and Andaman	. +	Shorea robusta	S
African { Marquesia		Fossils	F
African { Monotes	. ..	Doubtful fossils	D

regarded Malaya-Indonesia as a part and parcel of the drifting Indian Peninsula that later got separated along the line of Ninety-East fault and moved to the north-east. Such an interpretation would very much favour the genesis of the dipterocarps in the Gondwanaland. However, the recent palaeomagnetic findings of McElhinny *et al.* (1974) and Haile *et al.* (1977) reveal that Malesia was not a part of the drifting South Asian plate and hence of Gondwanaland. Even the Andaman-Nicobar Islands are regarded as not a part of drifting India but belonging to the Asian landmass (Balakrishnan, 1978). Thorne (1978) points out that the separation of Africa and India was a mid-Cretaceous event that took place around 100 million years ago (Raven & Axelrod, 1974) when the very existence of the extant genera and species and even families of flowering plants in Gondwana was doubtful.

With its exuberance of dipterocarps, Malesia is indicated as the region of origin (Ashton, 1969b; Lakhanpal, 1970) from where migration took place westwards to India and later to Africa. Land connections favourable for their entry were probably established by mid-Eocene when the north-east part of the drifting Indian plate came in contact with the Asian landmass. Figure 28 shows the positions of India relative to Eurasia towards the end of Cretaceous, end of Palaeocene and Pliocene.

The gross migration rate estimated by Meijer (1974) at about 5,000 years to cover a radius of 100 km gives enough time to the dipterocarps to spread from Malesia over the length and breadth of India, from Burma-Bengal to Kutch (and even beyond to East Africa) and down south to Sri Lanka by Miocene. Certain humid taxa like *Dipterocarpus*, *Dryobalanops*, *Hopea* and *Shorea*

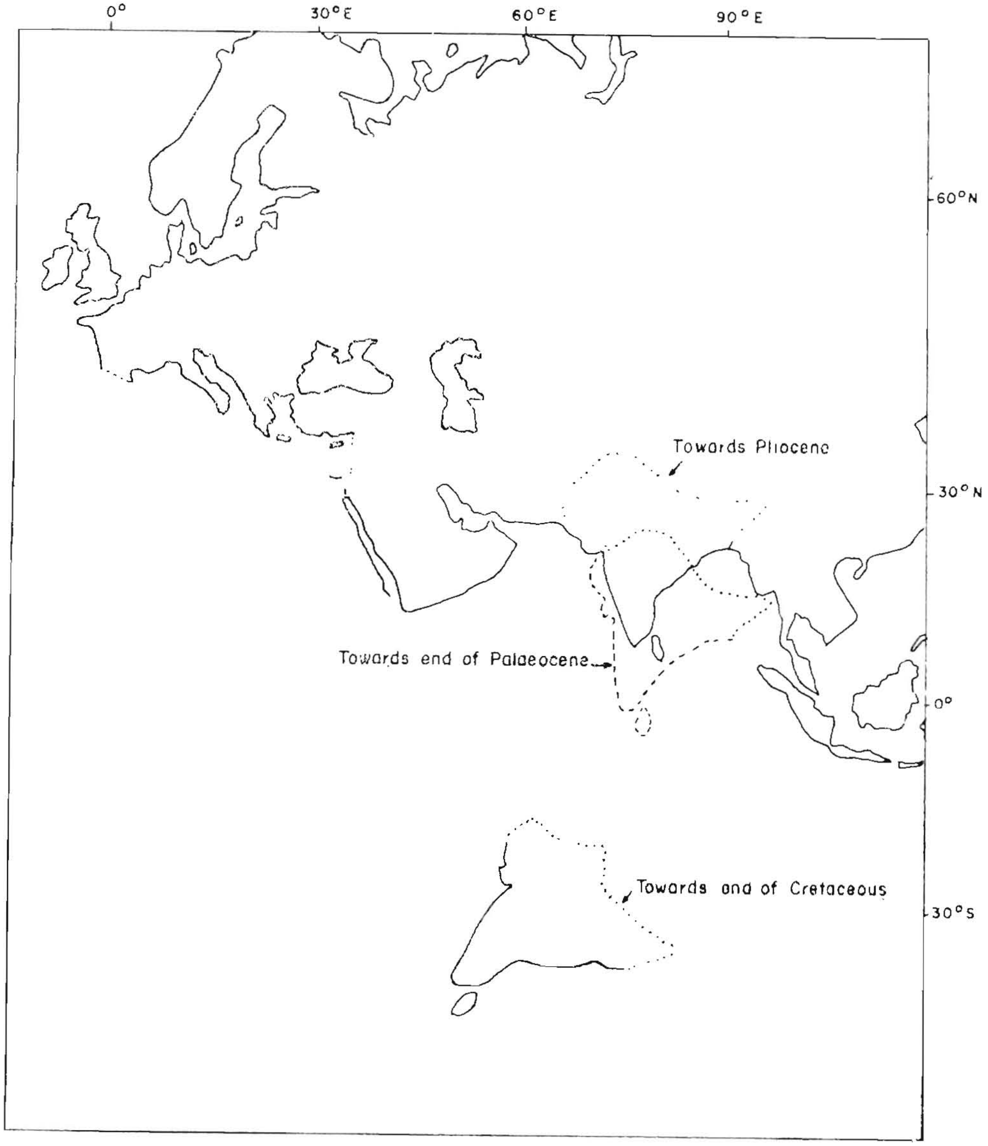


Fig 28. Positions of india relative to Eurasia towards end of Cretaceous, end of Palaeocene and Pliocene (inspired from Smith, 1974)

became extinct along the east coast of southern India during Miocene, as mentioned earlier. The west coast of Kerala, Karnataka with its humid climate served as a refugium for the humid Indo-Malesian genera.

Geographical isolation of the humid south-west part of Sri Lanka with its aseasonal equatorial climate has been responsible for the exceptional endemism of its dipterocarps. Land connection ceased with India for the first time in Miocene (Jacob, 1949). When connections were re-established across the shallow Palk Strait in subsequent periods, the intermediate territory between the humid south-west India

— south-west Sri Lanka had turned dry and acted as a barrier for the exchange of the dipterocarps between Kerala and wet zone of Sri Lanka.

Similar geographic and climatic isolation of Africa across the arid Saharo-Sindian belt may explain the evolution of an entire new subdivision Monotoideae in that continent (Meher-Homji, 1979).

CONCLUSIONS

In the present talk, I have tried to give an ecological interpretation to the impressive fossil record brought to light by the eminent palaeobotanists of the country. This helps us to explain the vegetational history linked to the climatic changes through the geological ages.

Vis-a-vis the present day vegetation, the factor of greatest concern is man himself through his thoughtless actions. Man in order to make his ends meet is in a constant struggle with the nature. With the primitive man this struggle was fair and need-based. With the advent of the technical man and the population explosion in its wake, the struggle has become one sided. Human interference in the landscapes has reached an unprecedented level of degradation bringing entire ecosystems to the verge of collapse. I would end this talk on a note of plea for conservation of nature and minimum interference with the fast dwindling natural resources. I may also add a note of concern for the fossil sites, especially Tiruvakkarai. There is a tendency among the elite to remove large pieces of fossils to decorate private and public homes and gardens. An entrepreneur even suggested starting an industry of making table-tops with these precious fossils. The public at large still remains to be educated in conserving our proud heritage against the immediate gains realised through short-term policies against the Mother Nature.

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