PHOTOGRAPHS

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CHAPTER ONE

INTRODUCTION: SOUTH ASIA

One-fifth of mankind occupies this region which forms the westernmost part, and so that closest to Europe, of the populous and humid marginal lands of Asia. South Asia has closer links to the Western world in its culture and its history than the other major divisions of the marginal lands – China and Southeast Asia. Its early civilisation, revealed in the cities of the Indus plains, Mohenjodaro and Harappa dating from 2500 B.C., had contacts with the earlier Sumerian civilisation of Mesopotamia. The languages spoken by the majority of the region's inhabitants share a common ancestry with those of Europe. The people themselves could also claim that their genetic make-up owes a great deal to forbears common to peoples in the Mediterranean area.

In religion South Asia developed its own distinctive and widely influential theocracies, and the size of the debt of Graeco–Judaeic–Christianity to Buddhist ideas has yet to be fully appreciated. From Hinduism, still the faith and way of life of about 400 million of the region's 625 or so million people there sprang Buddhism as a reformed religion which, although claiming only about ten million adherents today and now the majority faith only in Ceylon, spread vigorously through Southeast and Eastern Asia. The two other religions claiming sizeable numbers of followers are of foreign origin. Christianity, the faith of about twelve million, came to South India in the early centuries of its existence, and there persisted to be reinforced as the faith of the European mercantile nations from the fifteenth century. Islam arriving later from the Middle East, both through Arab trade and through overland invasion, flourished more strongly to become the faith of upwards of 130 million, and the *raison d'être* for Pakistan as a separate nation.

The history of South Asia over nearly four centuries has brought the region close to the West, and although the bonds of empire have been shed in recent decades, the political and economic heritage remains. India and Pakistan, before their partition and independence the Empire of India, and Ceylon experienced in common, but as separate entities, several centuries of British rule, which culminated in their independence being achieved by governments in which the ideal of democracy was a basic assumption. Whether or not democracy as it is understood in the West can survive its transplantation to South Asia is an open question, but one of vital interest to the 'free nations' of the world. Some of South Asia's most sympathetic friends in the West may sometimes wonder whether its problems are of a kind and scale that require for their solution a measure of authoritarian leadership that universal suffrage seems unlikely to produce. India is attempting what some have called the greatest experiment in democracy, giving all adults the vote, and making it possible for illiterate peasants to take a meaningful part in elections. Ceylon also has followed the democratic pattern of Britain, her one-time tutor. So did Pakistan, until irresponsibility in the democratic process so seriously threatened the country's unity and progress that a more authoritarian rule was imposed and a fresh approach was made towards creating responsible democratic government from the village level upwards.

In part because of their interest and concern to see democratic ideals, as they understand them, upheld in South Asia, the wealthier non-Communist countries of the West, in particular the U.S.A., have been generous in the assistance they have given to India, Pakistan, and Ceylon. But help has come also from the countries of the Communist bloc; the Soviet Union has given technical and material aid to India to help expand heavy industry; Ceylon has engaged in barter trade with China, exchanging rubber for rice; Pakistan has received military equipment from China.

These three countries of South Asia have much in common both in their past and in their present. Their pasts are closely interwoven. Even though they are now separate sovereign states within the Commonwealth, and despite the bitterness that taints their interrelationships – the Kashmir issue between India and Pakistan, which has twice flared into warfare, and the less violent but intractable issue of the large Tamil minority in Ceylon – they are still closely tied by human bonds. The huge Moslem minority still living in India stands hostage to Pakistan's behaviour towards India.

All three are badly in need of economic development to enable them to raise living standards. Their peoples are mostly subsistence farmers; the proportion of people employed in industry or living in cities is still small, though increasing. Capital in the form of finance, materials, equipment, and technological skill is desperately needed so that jobs can be created for the rapidly expanding population. High rates of population increase, and low rates of capital accumulation are common problems. Standards of living are dismally low for the majority, and the spectre of famine still stalks the land – particularly in India where all problems assume a formidable scale.

To maintain unity within diversity is a common problem for all three. Pakistan has the obvious problem of forging the widely separate and different wings of West and East into a national unity, of trying to create more bonds than the single one of religion. India's problems stem rather from size and linguistic diversity which tends to give everyone a dual loyalty: to his immediate cultural group, speaking his own language, and self-governing to a degree within the linguistic state, and to the Union of States that is India. In Ceylon the problem is smaller in scale but no less acute: the problem of satisfying the national aspirations of the Sinhalese-speaking Buddhist majority while preserving the rights of the Tamil-speaking Hindu minority, many of whom could claim their ancestors have resided a millennium in Ceylon.

CHAPTER TWO

THE PHYSICAL BACKGROUND

1. FOUNDATIONS AND FORM OF THE LAND*

In its rocks and their physiographic expression in the landscape, South Asia reveals great contrasts. South India contains some of the oldest rock formations known, and some of its landscapes have been exposed to subaerial erosion through scores – perhaps hundreds – of millions of years. On the other hand, parts of the Himalaya form one of the youngest mountain chains in the world and a zone of instability is associated with the whole Himalayan system and its contact with the stable 'shield' of central and Peninsular India. The alluvial sediments which have filled the depression flanking the rising Himalaya to form the Indo–Gangetic Plains have themselves been involved in structural movements persisting into historic time.

Structural and Physiographic Evolution

The principal events in the geological history of South Asia are reviewed here only in so far as they seem important to an understanding of the present geography of the region. Attention is focused on those aspects of geological structure and landscape morphology that affect man's ability to make a living: on gentle slopes and productive soils to cultivate, on economically useful minerals to work, on water resources to harness for irrigation or power.

Fig. 2.1.1 shows the main features of the geology of South Asia.

The structural relationships of the major formations in the subcontinent are shown diagrammatically in the sections in Fig. 2.1.2.

The stable 'shield' of Peninsular India and Ceylon is regarded by some geologists as having formed part of an ancient continental landmass referred to as Gondwanaland, which is thought to have broken up, through the process of 'continental drift' to form parts of what are now South Africa, Brazil, and Western Australia. In common with these areas the Peninsular Shield is made up largely of very ancient formations. Granites and gneisses are widespread and are probably the oldest rocks. The *Dharwar–Aravalli* series include a great variety of metamorphosed sedimentary and igneous material, possibly as old as the granites and gneisses, and conveniently bracketed with them as of Archaean age, i.e. early Pre-Cambrian. These Archaean formations cover much of the Peninsula and occur also in the Shillong Plateau, which has been detached from the main mass by the foundering and alluviation of the Ganges–Brahmaputra Delta region. The Archaean rocks in places contain valuable minerals: India's major iron ores of Bihar and Mysore, the manganese of Madhya Pradesh, gold, copper, asbestos, and mica.

The younger Pre-Cambrian (*Cuddapah*) series represent the sediments deposited in basins within the Archaean basement rocks and are found principally in Madhya Pradesh, and Andhra Pradesh where they form impressive scarplands. In the latter area they are overlain by Vindhyan sedimentary rocks (? Lower Palaezoic, Cambrian–Ordovician) which are more extensively found in the north of the Peninsula. The Vindhyan Range along the line of the Narmada–Son rivers is the most impressive outcrop.

Of greater economic importance are the Gondwana Group, in geological age extending from Upper Carboniferous through Permian and Triassic

* It is assumed that the reader has access to a good atlas (e.g. *Oxford Atlas* or *Philips' Library Atlas*) in which most places mentioned in the text can be located. The official form in which Indian geographical names are now transliterated sometimes varies from their customary spelling in English language texts and atlases. A list of the more important variations in spelling will be found as an appendix.

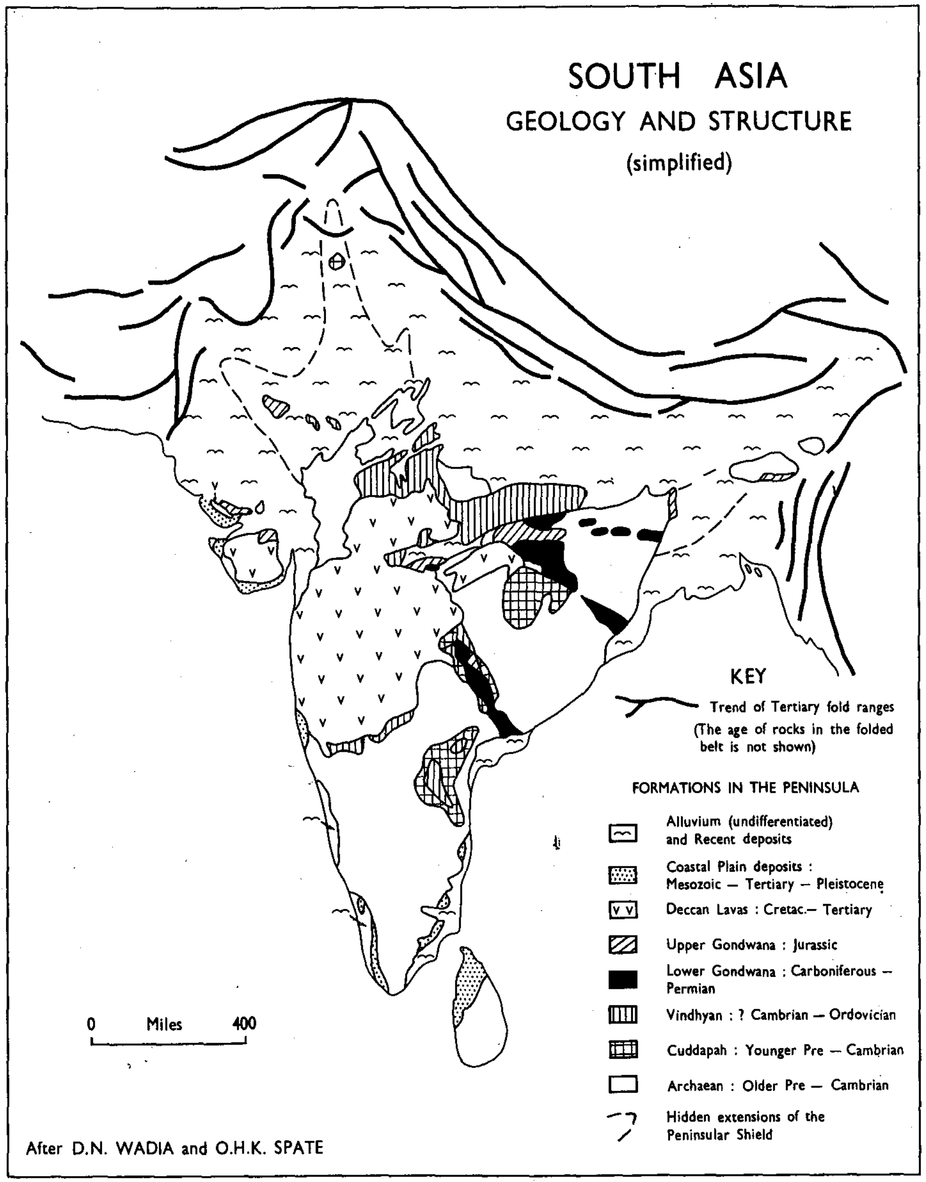


FIG. 2.1.1 Geology and structure

time into the Lower Jurassic. The deposits of this group are preserved in rift-like troughs still followed in the main by major drainage lines, e.g. the Damodar and Godavari valleys. Coal seams, often of great thickness and little disturbed by folding, are found along the troughs and probably extend westwards beneath the Deccan lavas. The coal is known to lie beneath the older alluvial deposits of the Ganges Plain in East Pakistan.

The Gondwana deposits are continental in origin,

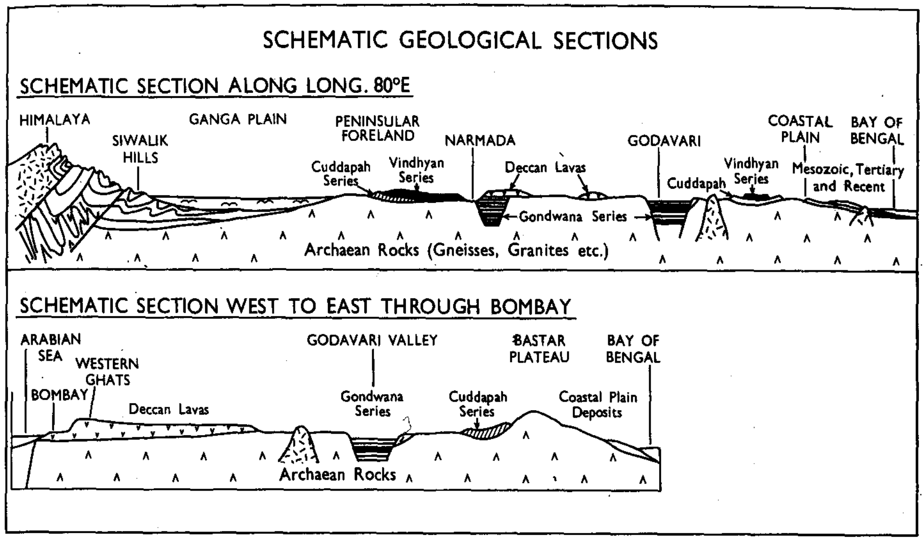


FIG. 2.1.2 Schematic sections

and one has to turn to the coastal plains of the Peninsula to find appreciable areas of marine formations of Mesozoic–Tertiary age. Apart from a small marine deposit in the watershed of the Narmada–Son rivers, evidence of marine transgression is lacking in the interior. It would seem that the Peninsula remained a relatively stable landmass over long periods of geological time, while the seas worked gently on the Coromandel coast to produce a narrow zone of plain built up of low cuestas of marine sediments.

Early in the Tertiary and beginning in late Cretaceous time, there occurred fissure eruptions of lava on an immense scale, which buried the northwestern part of the Peninsula beneath thousands of feet of basalt. Near Bombay the lava is 10,000 ft. thick, and it is surmised that it must have extended some way westwards and now lies deep beneath the Arabian Sea. Faulting along the line of the Western Ghats, and tilting of the lava plateau generally eastwards produced the main features of the present landscape.

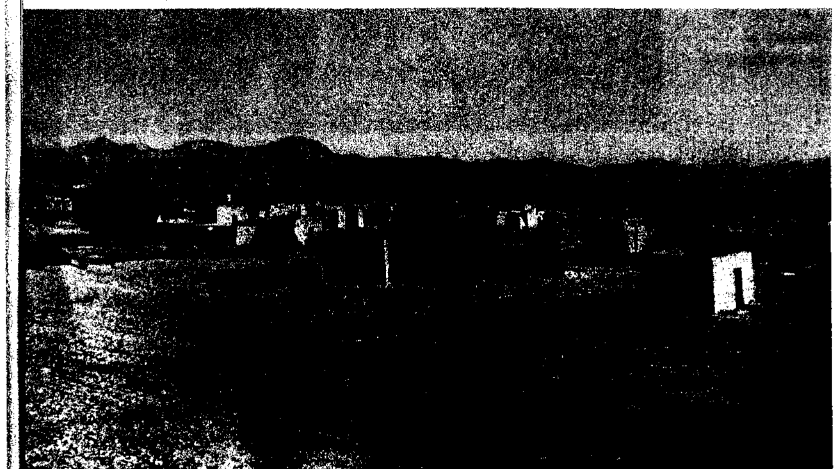
It may well be that eruptions of the Deccan lavas were connected with the crustal instability associated with the Himalayan orogeny. To the north of the Peninsular 'shield' of mainly ancient rocks covered in places with younger continental, coastal, and extrusive igneous rocks, there lay a more or less broad depression, or geosyncline, into which the bordering continental landmasses of the Peninsula and Central Asia had long been discharging through their rivers the products of erosion. During Tertiary time the deposits in the geosyncline dating from Pre-Cambrian to Tertiary were folded and thrust upwards to form the Himalaya. The process was long-continued and as the mountain chains grew, erosion fast worked upon them, and great rivers carried vast quanties of material into the marine gulfs that separated the young ranges from the Peninsular 'shield', then probably a large island. Continued uplift and fracturing raised more ranges, incorporating some of the recent deposits, which in turn were exposed to erosion. As the marine gulfs retreated, conditions were locally favourable at various times to the formation of coal and petroleum and the accumulation of salt. Coal of Cretaceous and Tertiary age is found in workable quantity in Assam, Jammu, the Salt Ranges, and Baluchistan; oil-bearing structures are located in the Salt Ranges, the Assam Valley, Gujarat, and the Tamilnadu coastal plain, natural gas-wells at Sui (West Pakistan) and Sylhet (East Pakistan); the Salt Ranges have long been a source of rock salt. Vertical movement of the Himalaya may not yet have ceased, and certainly during the Pleistocene period displacements measured in thousands of feet took place. The mountain belt still suffers earthquakes;

severe shocks have taken place at places as widely separated as Quetta, Kashmir, Himachal Pradesh, Bihar, and Assam. On the geological map (Fig. 2.1.1) the various formations of the Himalaya have not been distinguished. The Outer Himalayan belt, with the hills of the Assam–Burma border, and the mountain belt of Baluchistan and the northwest are largely of Mesozoic and Tertiary age. Rocks of almost all ages are found incorporated into the main Himalaya.

The youngest element in South Asia's structure is the alluvium of the Indo-Gangetic Plains and the numerous smaller lowland areas. It is important to realise the variety of materials that are generally grouped under the heading 'alluvium' and the way in which differences in site in relation to present rivers affect their agricultural value. The term alluvium includes fluvial deposits laid down at various times through the Pleistocene up to the present. The most recent floodplain deposits include some very fertile material, while the older alluvia, long exposed to the leaching effect of rainfall and standing often above the levels where present-day floods might introduce fresh plant nutrients in the form of soluble salts and silt, tend to give rise to poorer soils.

There is evidence, particularly in the Ganges Delta, that the alluvium has not been entirely stable even in recent historic time. The 'older', Pleistocene, alluvial surfaces of the Ganges–Brahmaputra have been dislocated by faulting, with subsequent influence upon the local drainage pattern. Striking changes in course by some of the major distributaries and tributaries, such as the 'Old' Brahmaputra and the Tista, have had important repercussions on navigation and settlement over the past two hundred years, a very short time geomorphologically speaking.

A distinct type of deposit associated with the Pleistocene in northwest Pakistan is loess which mantles parts of the Potwar Plateau between the Salt Ranges and the outer ramparts of the Himalaya. Disturbance of the vegetation cover through over-grazing has led to severe gullying in the loess.



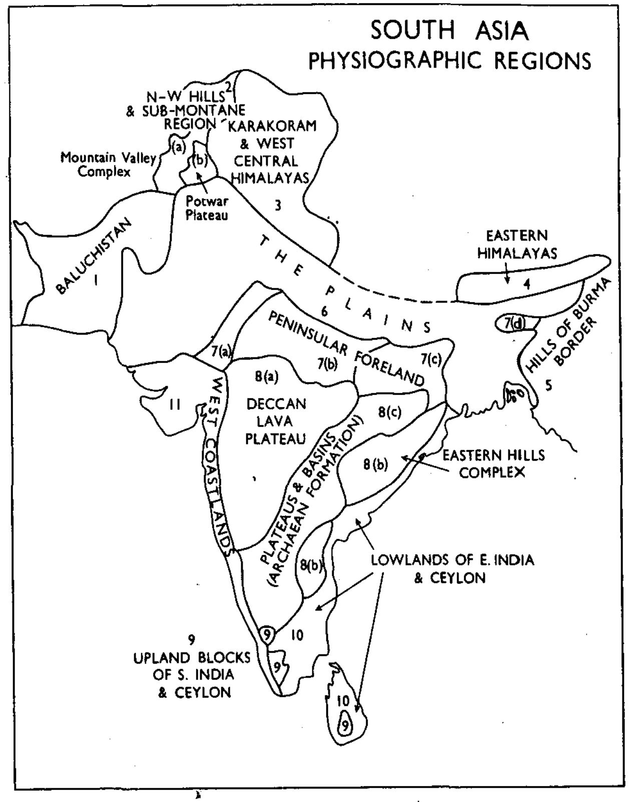
1. *Baluchistan-Indus Plains:* The semi-arid Kachhi Plain and bare rocky Sulaiman Range beyond a mud-walled village with its mosque in the centre

Major Physiographic Regions

The scheme of physiographic regions outlined below and shown in Fig. 2.1.3 leans heavily on Spate's work. Its purpose is to provide a regional framework within which to fit the varied facts of human, physical, and biogeographic significance. The relationships between man and his physical environment are further elaborated in later sections.

1. Baluchistan.
2. Northwestern Hills and Submontane Region.
3. Karakoram and Western Himalaya.
4. Eastern Himalaya.
5. Hills of the Burma border.
6. The Plains.
7. Peninsular Foreland.
8. Plateaus, troughs, and basins of the Peninsular Interior.

FIG. 2.1.3 Physiographic regions



9. Upland blocks of Southern India and Ceylon.
10. Lowlands of Eastern India and Ceylon.
11. West Coast lowlands.

1. In **Baluchistan** the influence exerted on the structure of the Tertiary fold mountains by the hidden northwesterly projection of the Peninsular Shield can be seen in the north–south trend of the Sulaiman and Kirthar ranges (north of Karachi), which break the generally east–west trend of the folds forming the Himalaya and the ranges of the Iranian complex. Fringed to the east by alluvial fans, the Sulaiman and Kirthar ranges present to the traveller from the Indus Plains a forbiddingly bare and rugged front, rising in the volcanic Takht-i-Sulaiman, to over 11,000 ft. Westwards the east–west trend of the system is restored in the ranges of Central Baluchistan and the Makran coast. Between the Chagai Hills and the Siahan Range are several basins of internal drainage, containing *playa* lakes, such as Hamun-i-Mashkel. In the Makran and the eastern half of Baluchistan the intermontane basins drain eventually to the sea.

2. **The Northwestern Hills and Submontane Region.** The Gomul River just north of Takht-i-Sulaiman effectively separates the Baluchistan region with its predominance of broad high upland features from the region to the north where valleys and mountainous spurs make up much of the terrain. Structurally this is a most complicated corner, where the massive southeast–northwest-trending ranges of the Great Himalaya and Karakoram point across the Indus and Hunza valleys to the east–west and northeast–southwest-trending systems of the Pamir and Hindu Kush. The mountain and valley complex is best described in terms of its rivers and their basins, several of which constituted the territories of feudal states. The Kurram waters the Bannu Plain. To its north is the smaller Kohat Plain. The broad Vale of Peshawar is floored with

alluvium brought down from the west by the Kabul River and from the north by the Swat and its parallel tributary the Panjkora, these latter two valleys forming the territory of the former 'tribal' states of Swat and Dir respectively. The valley of the Upper Kunar which flows south to join the Kabul in Afghanistan, is the state of Chitral. Almost as isolated is the basin of the Gilgit River in the western extension of the furrow occupied by the upper course of the Indus before it cuts south and west in its spectacular gorge around the flanks of Nanga Parbat (26,629 ft.) which marks the western extremity of the Great Himalaya. South from this bastion the Kagan and Kishen valleys drain to the Jhelum.

Enclosed between the Salt Range, the Himalayan foothills, and the Indus, the Potwar Plateau is a distinctive region characterised by close-textured low rocky ridges following the strike of the Siwalik formations and masked in places by a cover of water-sorted loess.

3. **The Karakoram and Western Himalaya.** In Kashmir and the mountain zone extending eastwards into Nepal the parallelism of structural elements provides a key to the landscape. Approaching the Himalaya from the Punjab Plains, the first evidence that one is entering the orogenic belt is the abrupt change in scenery in the Siwalik Hills. Carved by erosion out of the fractured and distorted deposits of mainly coarse detritus derived from the Himalayan ranges as they grew to full stature in late Tertiary and early Pleistocene times, the Siwaliks strike parallel to the mountain front for hundreds of miles, presenting a formidable barrier to transverse movement on account of the ruggedness of the terrain rather than its relief which is rarely as much as 3000 ft. above sea-level (cf. the 1000 ft. or so of the adjacent plains). Between the Siwaliks and the Outer or Lesser Himalaya there are occasional breaks in the close succession of rocky scarp and jungly vale, and the landscape opens out in a submontane alluvial basin a few miles in width, e.g. the 'dun' of Dehra Dun and the Kangra Valley east of Pathankot.

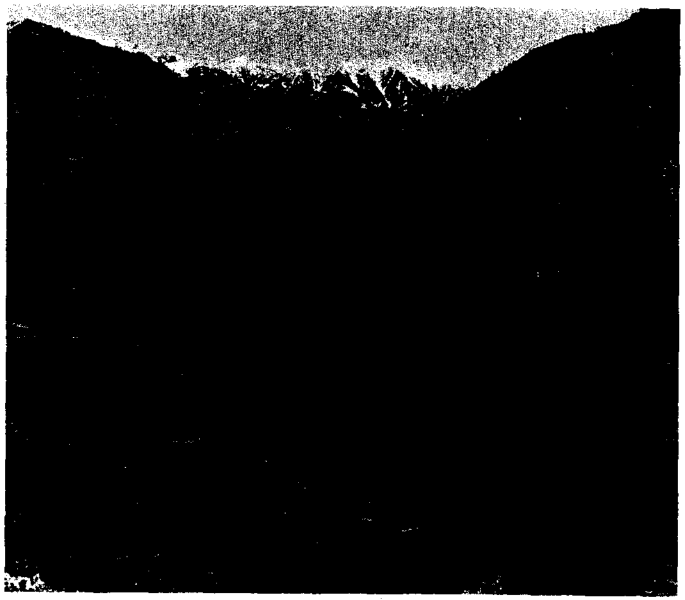
The Outer Himalaya are 'lesser' only in comparison to the world's greatest range to which they form a broad pedestal. Away from this context, the Pir Panjal which separates the Vale of Kashmir from the Punjab Plains, and the Dhaola Dhar in Himachal Pradesh, rising to over 15,000 ft., would be substantial mountain ranges in their own right. Further east in the Kumaon Division of Uttar Pradesh the Outer Himalaya are less impressive in altitude but form a broad belt of deeply and maturely dissected plateau 70 miles wide, with crest levels rising from 6000 ft. to 12,000 ft. towards the flanks of the Great Himalaya.

Only in the Vale of Kashmir 20–25 miles wide and more than 80 miles along its axis parallel to the Pir Panjal, is the progression of steps upward to the grand peaks interrupted. The synclinal basin of the Vale is floored with a variety of alluvial deposits, lacustrine, fluvial, and fluvioglacial, through which the Jhelum River meanders at 5200 ft. above sea-level before entering the deep gorge it has cut through the Pir Panjal.

From Nanga Parbat, immediately north of the Vale of Kashmir, the Great Himalaya sweep south-east and east for 1200 miles. Several major rivers rise on its southern flanks – the Jhelum, Ganga (Ganges), Chenab – while others rise in the high plateaus of Tibet to traverse the mountain ranges (e.g. the Sutlej) or like the Indus and Tsangpo (Brahmaputra) to flow parallel to them for hundreds of miles finally outflanking the Himalaya to reach the plains through deep gorges almost 1500 miles apart.

Generally the Indian frontier lies a little north of the line of the high peaks of the Central Himalaya, but in the west the state of Jammu and Kashmir extends far beyond the Great Himalaya, across the high open valley of the Upper Indus to include the Karakoram. This 250-mile stretch of almost uninhabited mountains contains the world's greatest concentration of high peaks, crowned by K2 (28,250 ft).

4. **The Eastern Himalaya.** Eastwards from Sikkim the character of the mountain system is different in several respects from that of the Western and Central Himalaya. The Siwalik belt is lacking or at best a very minor feature. Transverse rivers such as the Arun and the Tista break the Outer Himalayan belt into numerous spurs projecting from the main chain of mountains, and consequently prevent the structural strike from dominating the landforms. East of Kanchenjunga (28,146 ft.) high peaks become less frequent. The Tibetan peak Namcha Barwa (25,445 ft.) overlooking the bend of the Tsangpo (Brahmaputra) is the last of the great summits west of the river, beyond which the crest line falls progressively along the waterparting between tributaries of the Brahmaputra and the Salween.



2. *Western Himalaya:*
Kagan Valley, a tributary of the river Jhelum close to the borders of West Pakistan and Kashmir. The Middle Himalayan summits are here upwards of 12,000 ft. This photograph, taken in March, shows snow still lying within the high forest. The lower slopes are terraced to permit rain-fed cultivation of *rabi* wheat and oilseeds and *kharif* maize. The numerous flat-roofed homesteads on the ridge in the foreground are some indication of population pressure on this rugged terrain. The landslide scars and gully erosion could well be the consequence of deforestation in order to open up land for subsistence farming.

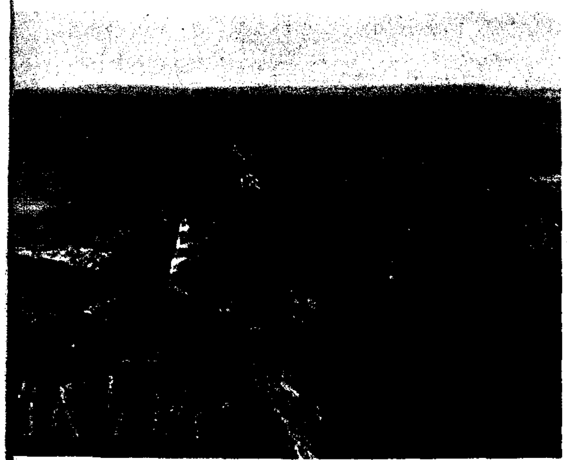
5. **Hills of the Burma border.** Differing markedly from the Himalaya in the scale of their relief and in their morphology, the ranges which sweep southwest and south from the easternmost part of Assam none the less stem from the same orogeny. For the most part the Cretaceous and Tertiary strata of the region are relatively unresistant shales and sandstones arranged in simple anticlines and synclines. The trend of the close folds is clearly indicated in the parallelism of the elongated trellised drainage pattern, particularly well seen in the Chittagong Hill Tracts of East Pakistan and the adjacent hill country of southern Assam. In the north where the Patkai and Naga Hills form the Burma–India border the system reaches its highest elevation of 12,550 ft. in the Saramati peak. Generally, however, heights over 7000 ft. are exceptional and the level of ridges declines southward to average 2000–3000 ft. between the Chittagong coast and the Kaladan Valley.

6. **The Plains** which represent the present surface of the more or less deep alluvial fill of the trough marking the contact zone between the stable Peninsular Shield and the Himalayan fold system may be treated as a single physiographic unit despite the variation in detail there is within them. While alluviation in the floodplains of rivers great and small has been the common genesis of the regions' features, differences in age and scale are significant in characterising subregional divisions.

The plains are in the main the product of the larger rivers rising in the Himalaya – the Indus and its Punjab tributaries, the Ganga and its tributaries, and the Brahmaputra. Relatively speaking the tributaries from the Peninsular foreland, principal among them the Son, have contributed little by reason of their smaller scale, gentler gradient and the lesser precipitation in their catchments. The alluvial deposits of the great river systems may conveniently be differentiated on the basis of age and the consequent degree of obliteration of the features which distinguish an actively developing floodplain – levees, backswamp depressions, abandoned meander ox-bows, etc.

The *active floodplains* contain the usually braided and changing channels of the river separated by more or less temporary islands of young alluvium, sandy or clayey depending on distance from the channel responsible for their deposition. Low bluffs or levees mark the limits of the active floodplains. In the deltas particularly, the active floodplains are areas of frequent change which can affect a considerable breadth of country tens of miles in extent. Elsewhere as in the Middle Ganga Plain and Punjab the active floodplains are more permanently fixed between bluffs.

Meander floodplain and *cover floodplain* are terms suggested by recent Canadian surveyors of West Pakistan landforms to describe the still relatively young alluvium no longer subject to periodical



3. *Western Ghats* south of Bombay, showing the horizontally bedded lava exposed along the deeply dissected edge of the Deccan Lava Plateau. In several locations similar to this the abrupt slope has been utilised to generate hydro-electric power.

reworking by the rivers (see below, Fig. 4.2.5). In the case of the meander floodplains, the levees, meander belts, and backswamp features of the past active stage may still be discerned, while in the cover floodplain such features have been obscured by the levelling effect of sheet flooding which has gradually reduced the raised elements of the landscape and filled in the depressions.

A still older element of the alluvial landscape is the *scalloped interfluve* or 'old alluvial' surface. The term 'scalloped interfluve' is expressive of the way in which the flanks of the older alluvial interfluve areas have been cut into by the meandering of the active rivers. These older surfaces, in some cases dated as Pleistocene, are most widespread in the higher parts of the Punjab and Ganga Plains, and in the latter are found in quite extensive remnants in the Barind and Madhupur Tract of the delta in Bengal. Benches of similar age and material fringe the Tertiary hill country of East Pakistan where they are valued as relatively level but drainable land for tea plantations. From the Upper Ganga Plain westwards into the Punjab the interfluves may carry patches of sandy soil sometimes wind blown and hummocky, while their edges may be extensively fretted by gullies cut back from the present river.

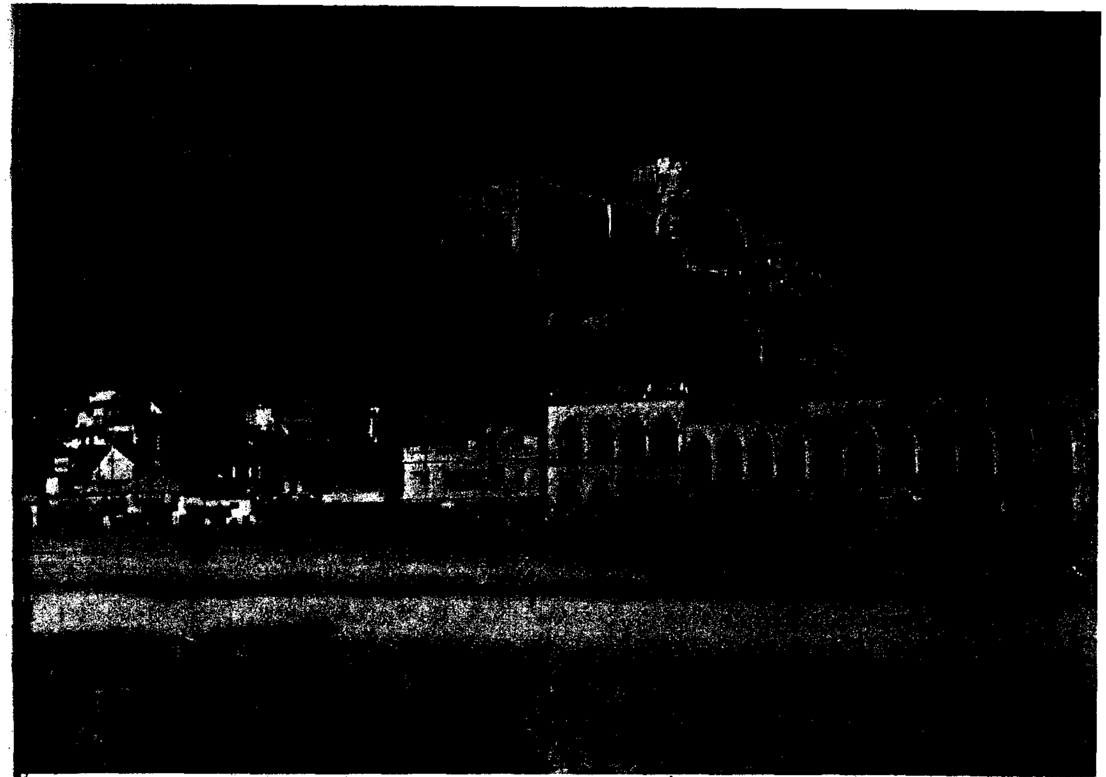
Independent of the great rivers, the plains increase in slope as the mountain belt is approached. Here is a zone of confluent alluvial fans constituting a continuous piedmont plain into which the short generally intermittent streams from the hills lose themselves. In Uttar Pradesh this belt of often gravelly, porous alluvium is known as the *bhabar*, and is succeeded down-slope by the *terai*, a marshy zone where the water-table reappears at the surface in a spring-line of headward-sapping gullies. Bhabar and terai are not found in this form throughout the piedmont belt, though comparable features with variations according to rainfall regime and local conditions are widespread. In the piedmont of Bengal and the Assam Valley the terai is well developed in a marshy zone known as the *duars*.

Because of its low relief continuous with the alluvial plains and its past links with former river systems in the Ganga–Sutlej interfluve, the **Thar Desert** may conveniently be considered here. Much of the surface is sand, arranged into dune formations and in many areas 'fixed' by scanty vegetation. Clay bands beneath the sand give rise to saline lakes towards the Indus in Khairpur. Peninsular Shield rocks similar to those forming the Aravallis underlie the whole area, outcropping in places as rocky inliers in the sandy waste. Similar scattered inliers occur in the Punjab Plains near Sargodha, between the Jhelum and Chenab rivers, forming the Kirana Hills which rise 1000 ft. above the alluvial plain and provide the most northerly surface evidence of the projecting shield around which the Himalayan folds have been wrapped.

7. **Peninsular Foreland.** Under this term may be grouped the areas made up of the geologically 'solid' stuctures which flank the plains on the south.

In the west, the Aravalli Hills (7a) consist of rugged ridges of Pre-Cambrian rocks decreasing northwards from about 5600 ft. to disappear beneath the alluvium of the plains around Delhi. A region of lower relief (7b) developed on Vindhyan sandstones and Archaean gneiss extends from the Aravallis to the valley of the Son, east of which are the gently rolling plateaus of Chota Nagpur (7c) where occasional isolated hills stand out abruptly as much as 3000 ft. above the general surface.

The Chota Nagpur Plateau slopes away to the northeast, beneath the Ganges alluvium, but its structures persist to form a foundered link to the Shillong Plateau (7d) of Assam. This mass of Archaean rock rising abruptly in a 5000-ft. wall



4. *Granite inselberg*, capped by a Hindu temple, Tiruchirapalli (Trichinopoly), Tamilnadu. One of many such outcrops which rise above the gneissic plateaus of South India. Robert Clive lived in one of the houses in the foreground.

towering over the delta plain of East Pakistan, marks the easternmost visible prong of the Peninsular Shield.

8. **Plateaus, troughs and basins of the Peninsular Interior.** The area physiographically most distinctive in this broad region is the Deccan Lava Plateau (8a) in the northwest, a countryside characterised by great expanses of nearly level plateau formed by the lava flows into which the rivers have cut a landscape of gently stepped broad valleys. From its high western edge, extensively over 2500 ft. above sea-level, the plateau slopes gently eastwards, its main area being drained by the Godavari, Bhima, and Krishna rivers. North of the Ajanta Hills the drainage is westwards along the structural troughs followed by the Tapti and Narmada, which separate the lava areas of the Satpura Hills and Malwa Plateau from the main mass.

The Eastern Hills (8b) comprise the plateaus of Bastar, mainly of Archaean rocks and extensively over 3000 ft. in the north, and the several ranges of Cuddapah and Vindhyan sedimentary rocks south of the Krishna.

The region of open plateaus and basins in the Archaean rocks (8c) lying between the Eastern Hills and the Deccan lava country is most clearly differentiated from the latter in Mysore State. The western edge of the plateau is here more than 5000 ft. high, but generally its peneplain surface lies at about 3000 ft., here and there studded with granite inselberge that tower sheer-sided 1000 ft. and more above the plateau. Northeastwards the plateau of granites and gneisses is essentially similar but at a lower general level of about 2000 ft. The limit of this Telangana Plateau to the northeast is the Godavari–Wainganga trough where a structural rift valley in the Archaean rocks preserves Gondwana coal measures.

Beyond the Wainganga, around Raipur, the Chhatisgarh Plain occupies a basin of Cuddapah sedimentary rocks overlooked by the Maikal scarp in Deccan lava to the north and enclosed on the south by the Bastar Plateau.

9. **Upland blocks of Southern India and Ceylon.**

The abruptness with which these Archaean blocks rise above the adjacent gneissic plateau surfaces set them apart physiographically though there is doubt about whether they are structurally separable.

The Nilgiri Hills rise to 8760 ft. and extensively over 6000 ft., below which level the block slopes steeply away on all sides; to the 3000-ft. Mysore Plateau to the north; most sharply towards the Coimbatore Plateau (about 1200 ft.) to the southeast; and to the west in a sinuous, much fretted edge, characteristic of the Western Ghats, tumbling 1200 ft. per mile over a bare five miles to the Malabar coastal lowland.

South of the Palghat Gap, the first clear break in the high western edge of the Peninsular plateaus south of the Tapti Valley, the highland blocks reappear. ~~Unlike the Nilgiris~~, the blocks here present their steepest face to the north (where the Anaimalai and Palni Hills overlook the Palghat Gap) and southeast towards Madurai and Tirunelveli in the scarps of the Palni and Cardamom Hills. The highest summit is at 8841 ft. in the Anaimalais but the proportion exceeding 6000 ft. is less than in the Nilgiris. From the Cardamom Hills southwards the plateau belt narrows, losing height somewhat and culminating in a peak of about 5400 ft. within a score of miles of Cape Cormorin.

The high country of Ceylon is essentially similar to the southern mainland blocks though its limits, especially to the southwest, are not so distinct. A peak 8281 ft. high crowns the highest platform surface of the plateau. The relief of Ceylon is treated in more detail below (Chapter 5.2).

10. **The Lowlands of Eastern India and Ceylon.** From Orissa to Tamilnadu and Ceylon the lowlands comprise a number of distinctive repeating elements:

(i) Broad benchlands cut in the Archaean gneisses and Vindhyan sedimentary rocks back the younger sedimentary and alluvial features and represent the lowest of the series of plateau steps that mount into the interior of the Peninsula and Ceylon. This plateau element is well developed in Nellore (Southern Andhra Pradesh), Coimbatore (Tamilnadu), and lowland Ceylon.

(ii) Seemingly outliers of the next higher plateau step are a series of hill masses in Tamilnadu conveniently grouped under the collective Tamilnad Hills.

(iii) Low cuestas of Mesozoic and (more extensively) Tertiary marine sediments, standing up to 300 ft. above sea-level, cover a significant area southwards from the Ponnaiyar River (inland from Cuddalore) and have their counterpart in the northern tip of Ceylon. This element, its red soil capping dating perhaps from Pleistocene times, may be linked genetically to the 'old alluvial' benchlands of Bengal and to similar features of the Kerala lowlands.

(iv) Young alluvial plains at their widest in the deltas of the major rivers Godavari, Krishna, and Cauvery, form an almost continuous belt from the Mahanadi to Cape Cormorin.

(v) The coastline itself shows ample evidence of progradation, both mainland and Ceylon coasts consisting frequently of actively silting lagoons behind off-shore bars which are being extended by longshore drifting.

11. **The West coast lowlands** from Kutch to Cormorin may be seen as the product of marine erosion sawing into the steep western flank of the Peninsular plateaus, lava in the north, Archaean rocks in the south. The whole coast may be pictured as hinged about Goa, the Maharashtra–Gujarat shoreline often showing features of submergence, while that of Mysore–Kerala is emergent.

The Mysore–Kerala section of the coastal belt comprises three elements:

(i) A benchland with old leached soils along the foot of the plateau edge, often cut in Tertiary sediments.

(ii) A belt of alluvium along the larger transverse valleys and tending to fill in the lagoons cut off from the sea by

(iii) The line of multiple beach ridges.

The Maharashtra coast, or Konkan, as far as Bombay, is so cut up by spurs from the Ghats enclosing the basins of short rivers which terminate in drowned valleys as to deter longitudinal communications by land. The lateritic benchland element is present, but alluvium is restricted to the valley bottoms. North of Bombay a coastal plain becomes more evident, and although the rivers enter the sea through short estuaries, drowning has not been so severe as to prevent the active accumulation of silt and mud to form tidal marshes. The Western Ghats stand back from the coast in Gujarat, extending northward till the Tapti and Narmada valleys finally break their continuity.

Across the Gulf of Cambay the Kathiawar Peninsula is a low plateau of Deccan lava fringed with a benchland above a coast no longer dominantly submergent. Kutch, which separates it from the Indus Delta, consists of a number of Mesozoic sedimentary and basaltic 'islands' in a 'sea' of mud-flats, perhaps once the estuaries of rivers which used to traverse and perhaps to drain the now arid Thar Desert.

2. CLIMATE

Climatologists now recognise that South Asia forms a more or less distinct climatic province whose weather systems have little connection to those of neighbouring provinces. No longer can one speak in terms of a single 'monsoon climate' affecting the southern and eastern margin of Asia. Ideas about the mechanisms controlling the climate of the subcontinent have changed greatly over the past decade or so with increasing knowledge of movements in the upper atmosphere and of their relationship to surface conditions. It is beyond the scope of this book to discuss the latest theories at length, but an attempt is made below to suggest how these theories may help our understanding of climate as it affects man in the region. Whatever the outcome of scientific debate, the winds, the temperatures, and the precipitation experienced by the inhabitants, suffered by them, and utilised by them in their struggle to survive will follow the same regimes and be subject to the same vagaries as in the past few thousand years. Our main concern is to present the realities of climate as one basis for the better understanding of the varied character of the geography of the region.

Most of us are now accustomed to the idea that excessive heat or cold or humidity in the outdoor environment of the place where we live can be effectively and inexpensively controlled indoors. The ~~peasant farmer of South Asia~~ is still a long way from that stage of economic and technological advance when he can escape from the actualities of climate and weather by taking refuge in an air-conditioned office or living-room. The European working in India in the nineteenth century enjoyed a slight advantage over the local peasant in being able to employ a servant to work the 'punkas' which kept the air in motion over his master's head, or to operate the primitive air-conditioners – grass screens in the doorways, on to which water is sprinkled, so humidifying and cooling the air passing through. Blanford* quotes extensively from a resident in the Punjab writing about its seasons. Although not applicable in detail throughout South Asia, especially as far as the coldness of the cold season is concerned, the following extracts may help the 'denizen of the temperate zone' conceive the very different seasonal march of the monsoon climate.

'Like the rest of India, the Punjab has really but three seasons: the summer or hot season, the rains, and the winter . . . the cold season. The hot season begins in April. . . . The west wind holds sway and . . . is a veritable hot wind. A denizen of the temperate zone can hardly realise to himself the dessicating, truly scorching heat of this wind. When exposed to it one may imagine one is facing an open furnace. In order to enjoy fresh air at this season one must take exercise in the early dawn, between 4 and 5 in the morning; for no sooner has the sun risen than the heat sets in again. . . . At sunrise . . . houses must be closed, only a small door being left open for communication with the outside. . . . Man and beast languish and gasp for air. . . . Vegetation suffers equally: almost all green things wither; the grass seems burnt up to the roots; bushes and trees seem moribund; the earth is as hard as a paved highway; the ground is seamed with cracks; and the whole landscape wears an aspect of bareness and sadness. At length, in June, the hot winds cease to blow, and are followed by a calm; and now indeed the heat is truly fearful; all things pine for the rain. . . .

'The southerly and easterly winds bring first clouds and violent storms with heavy rain showers, which are repeated daily, or at all events every two or three days; and finally the rains. . . . In July the trees begin a second time to burst into leaf; grass springs up once more, and soon a vegetation is developed, that, fostered by warmth and moisture is scarce to be kept within due bounds. . . . After from four to six weeks of heavy rain, often falling unin-

* Blanford, Henry F., *A Practical Guide to the Climates and Weather of India, Ceylon and Burmah* (London, 1889), pp. 127–29.

terruptedly for 2 or 3 days in succession, it clears up, and sometimes some weeks pass without further rain; after which a week or two more of rainy weather bring the season to a close. Grateful as is the coolness brought by these showers, the more oppressively hot and sultry is it, when the rain ceases and holds off, if only for half a day. The atmosphere weighs on one like a heavy coverlet; and then comes the daily and nightly plague of mosquitoes. Insect and reptilian life is now active; of evenings it hums and buzzes and croaks all around. . . . Woodwork swells, and doors and windows can be fastened only with much difficulty. Shoes and all articles of leather become quickly coated with fungus, books become mouldy and worm-eaten, paper perishes, linen becomes damp. . . .

'The period which immediately follows the rains up to October is the most unhealthy season in the year. Decaying vegetation under an ardent sun generates miasma (pollution) the consequences being fever, dysentery, and not infrequently cholera. Towards the end of the rains one rejoices indeed to see the heavy dark clouds disappear, but the heat soon becomes once more so great, that one longs for the cold season . . . watching for some sign of the cool westerly and northerly winds. With the beginning of October these winds set in steadily, clearing the skies, and now the blue firmament appears in all its splendour. . . . From October to Christmas, as a rule, the weather is clear and fine, the air is pure and most delicious. . . . In December and January . . . the nights are positively cold. . . . During the second half of the cold season we have in the Punjab a good deal of rain. . . . In February we have a short spring; many trees unfold their leaves. . . . But this spring is of short duration, and in March it is already warm on the plains and the hot summer is at hand; an occasional dust storm, however, for a while keeps off the summer heat. . . .'

The Monsoon

Although the word has been applied to the climate of one-third of Asia, and has also been borrowed for use in other parts of the world, 'monsoon' rightly belongs to the Indian Ocean. It is derived from the Arabic (and thence Urdu) word 'mausim', denoting 'season', but was originally applied to the distinct seasonal winds blowing between Arabia and the East Indies, the winds which Arab traders used to drive their ships to and fro on their annual voyages in quest of spices, ivory, and fine fabrics. Through Portuguese and Dutch the word entered the vocabulary of the British merchants and rulers in India, and for these land-lubbers it came to mean the seasonal rhythm of wet and dry rather than the changing wind systems familiar to sailors. In fact the monsoon in common parlance tended to refer specifically to the wet–hot season, heralded by a fanfare of violent storms and torrential rain – the 'breaking of the monsoon'. However the word was used, its application to the climate of the area carried the sense of marked seasonality.

Two basic factors are strongly influential in the climate of the sub-continent: the mountain girt high plateaus which separate India–Pakistan from the rest of Asia on the north, and the great expanse of ocean washing the Peninsula and Ceylon and extending and widening southwards beyond the Equator. Only in Baluchistan and Kashmir does the region with which we are concerned extend appreciably beyond the mountain wall. The Himalaya, backed beyond the Brahmaputra (Tsangpo) and Indus valleys by the Kailas and Karakoram ranges, the latter with the Hindu Kush branching southwest to continue the rampart into Afghanistan, tower continuously over 12,000 ft. and for great distances over 18,000 ft. These ranges effectively bar the movement of air-streams at surface level between the subcontinent and 'inner' Asia and vice versa. By contrast, to the south no relief feature stands high enough to prevent the free flow of air-streams from the surrounding seas into the subcontinent when the pattern of air pressure permits. However, as will be seen below, the Himalaya play more than a merely passive and protective role in the climate of the region, and might be held to rank high among the factors involved.

*The Mechanism of the Indian Monsoon**

The account which follows leans heavily on Pierre Pédelaborde, *The Monsoon* (London, 1963). In the present state of knowledge, many of its conclusions can be only tentative, but they probably represent a closer approximation to truth than do traditional explanations.

* Readers who are content to take the dynamics of the monsoon as read may turn to the descriptive treatment of climate which follows on p. 19.

In order to begin to understand the modern concept of the monsoon it is essential to discard most of the preconceptions deriving from traditional explanations founded upon a more or less purely thermal genesis of the seasonally reversing surface air-currents which characterise the system. Traditional accounts viewed the monsoons as land and sea breezes operating on a gigantic continental scale. Modern explanations of the monsoons have to take into account the vastly greater knowledge we now have of the atmosphere in depth, of the movements that take place in the upper atmosphere; of the influence of these movements on air-flow at or near the surface, and perhaps above all, of the dynamic qualities of the atmospheric circulation.

It is important to appreciate that there is a two-way interaction between air-flow and pressure pattern. Movement of air in a simple cyclonic depression (in the Northern Hemisphere) is in an anti-clockwise direction, while that in an anticyclonic system is in a clockwise direction. When air is forced by the relief of the land to flow along an anti-clockwise or cyclonic curve, there is a dynamic effect which tends to produce a pressure pattern characteristic of a depression – i.e. low pressure on the left of the path of the flow of air. Conversely air following a clockwise path will tend to produce anti-cyclonic conditions on the right of its path. Such dynamically induced pressure patterns appear in South Asia as a consequence of the manner in which the high mountain ranges influence the flow of the *jet-stream* which is discussed further below.

Not only does the relief of the land play a creative part in the dynamics of climate, but it also has a strong influence on cloudiness and rainfall. Air passing across abrupt changes of slope is caused to rise to elevations where temperatures may fall below dew point so provoking condensation and perhaps precipitation. The *orographic lifting* of air induced by the Himalaya, the Western Ghats, and the hills of Assam has a marked effect on rainfall in those areas. The other main process inducing air to rise in quantity is the *convergence* of streams of air leading to the increase in 'thickness' of the air-stream which finds an outlet in ascent from which cloudiness and precipitation can often result through cooling. Conversely, *subsiding* air is warming, and so becomes clearer as it descends, bringing dry weather. Such subsidence is generally associated with *divergence* of air-streams at the surface, but takes place also where air-flow is down a slope.

Meteorologically there are basically two seasons in the subcontinent:

(i) the season of the Northern Hemisphere's winter when the northern circumpolar circulation dominates the scene dynamically,

(ii) the season of the 'wet monsoon'. The north polar influences having withdrawn north of the mountain wall, equatorial maritime air is permitted to invade the region, bringing with it more or less heavy precipitation. The influence of the southern circumpolar circulation is felt in the strong surges of air of the southern 'trade winds' sweeping north of the Equator.

Winter. During the northern winter there is a general cyclonic circulation of air moving from west to east around a polar depression in the 'free air' of the troposphere. This depression overlies a high-pressure centre at the surface over the Arctic and is the result of the subsidence of very cold air refrigerated by radiation into space during the long polar winter night. Such subsidence in creating a surface 'high' tends to produce a 'low' in the free air above it, from which the air is subsiding.

Around the polar depression air is moving from west to east, the greatest velocities of flow being in the jet-streams which are normally located at the equatorward edge of the circumpolar whirl. The position of the jet-stream fluctuates between about 20° N. and 35° N. during winter, but in detail is considerably influenced by the Himalaya and high mountains to their west and north: the Tibetan Plateau, Karakoram, Pamirs, and the Hindu Kush (Fig. 2.2.1). This mass of high land, projecting upwards to altitudes sufficient to have a significant effect on air movements in the troposphere (the lower atmosphere to a height of 4–10 miles), causes the jet-stream of winter to bifurcate. The stronger branch of the jet follows a path which inscribes an anticyclonic (clockwise) arc across Afghanistan followed by a cyclonic (anticlockwise) arc along the southern flank of the Himalaya. A 'high' pressure system forms south of the jet-stream over Afghanistan and northwest Pakistan, from which air tends to subside over India, warming and stabilizing as it does so and bringing generally settled clear sunny conditions to South Asia.

While its main influence is to stabilize conditions

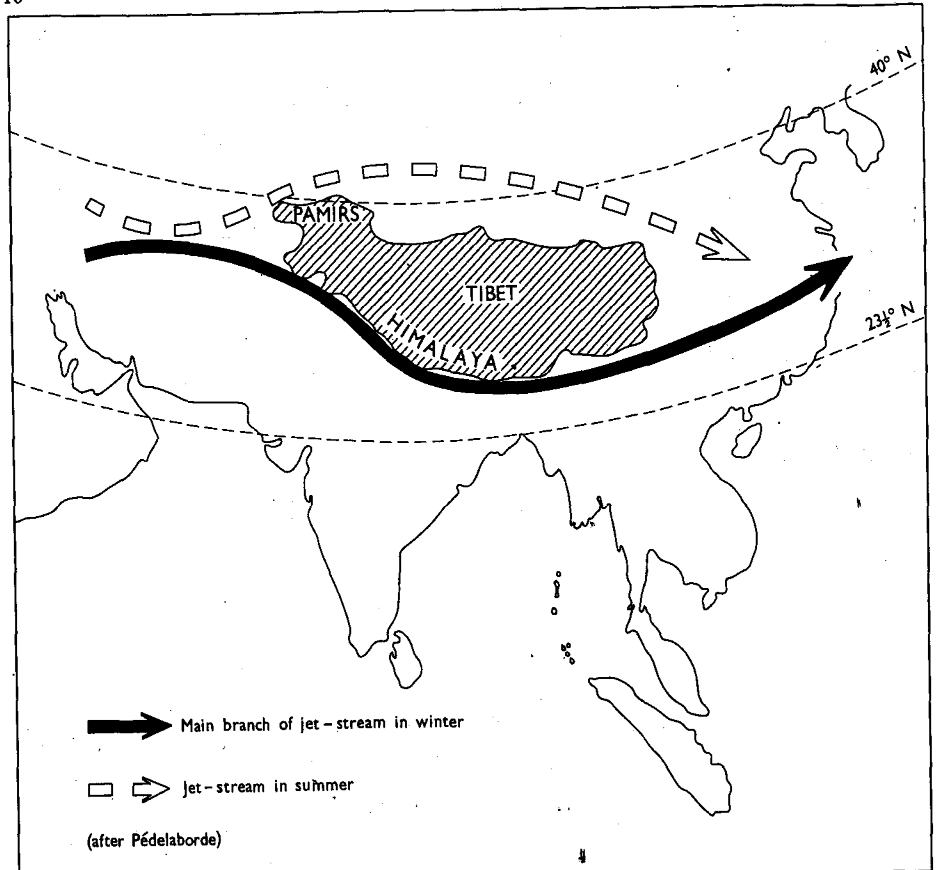


FIG. 2.2.1 Jet-stream: winter and summer

over the region, the jet-stream may be held responsible for periodical disturbances in the northwest of the subcontinent.

Low-pressure systems in temperate latitudes tend to follow paths immediately beneath the jet-stream. Such disturbances are found to move along the eastern Mediterranean and into northwestern Pakistan – India, appearing here as perturbations or waves, rather than as well formed frontal depressions. They occur as troughs of low pressure with strongly convergent air in the westerly stream at above 2000 metres. In South Asia they generally overtop a gentle easterly (trade wind) flow of air at the surface. Sharp cold rainstorms from towering clouds and a drop in temperature accompany the passage of such troughs, being followed soon by clear weather. From October to April between four and eight westerly perturbations occur each month. The disturbances however are not intense and precipitation, while of useful quantity for agriculture in the Punjab, Kashmir, and northwest Pakistan, is not heavy, nor does it persist far down the Ganga Valley, Patna being its extreme limit to the east. The weakness of the disturbances is partly a function of their being associated with an air-stream which is subsiding as it enters the subcontinent, and has little incentive to rise, being a cooler current overtopping a warmer at the surface. Much of the precipitation that does result is probably induced orographically when the air is forced up along the flanks of the Himalaya.

In winter the subcontinent can be regarded as

divided into a wetter northwesterly and a drier southeasterly province, due to the limited effect on precipitation extended by the westerly waves. Over Peninsular India meteorological conditions combine to assure the constancy of the trade winds, generally light breezes in the stream of stable, warming, and so dry air. Drought is the expectation of most of the region throughout the winter.

A further factor among the meteorological influences of this season is the intertropical convergence, or I.T.C. Pushed south by the dominant influence of the circumpolar system of the northern winter the I.T.C. is none the less present in the latitude of Colombo, which consequently has no really dry month. The nature of the I.T.C. is further considered below.

Summer: the transition from winter. A distinctive characteristic of the Indian climate, sensibly if not strictly meteorologically, is its threefold division into (i) the cool and mainly dry winter, (ii) the hot and mainly dry season from about March or April into early June, and (iii) the wet monsoon, 'bursting' in June and lasting into September or later. A transitional autumnal period of various duration and weather, depending on latitude, links the 'wet' and the 'cool' seasons, but hardly ranks as a separate season. The meteorological elements in dispute for control over the subcontinent are those which dominate respectively, winter and summer. Through the hot–dry season between winter and the 'burst' of the wet monsoon there is a gradual change as the sun's apparent march towards the Tropic of Cancer brings with it a reduction in the dynamic power of the cold polar air-mass which has held the initiative throughout the long polar night of winter. As the circumpolar whirl diminishes in speed so does its power to send offshoots of polar air into low latitudes, including South Asia, and to maintain its branch of the jet-stream south of the Himalaya.

Solar heating over northwestern Pakistan–India gradually establishes a thermal 'low' at the surface, but while the jet-stream remains south of the Himalaya, it maintains its dynamic anticyclone aloft over Afghanistan and the plateau borderland of West Pakistan. This 'lid' of subsiding warming dry air prevents the surface thermal 'low' from having sufficient effect as a lifting agent to carry air aloft and so to bring about precipitation. While such conditions persist in the northwest into May, the monsoon has already broken in Burma. Here, beyond the eastern end of the Himalaya, the jet-stream's cyclonic path has produced a dynamic depression aloft which does nothing to inhibit the uplift of converging air-streams coming in from the south across Burma, where rains are heavy in May. These more unstable conditions affect the neighbouring parts of India and East Pakistan, where pre-monsoon rainfall is important to agriculture.

At this stage, in May, we see the subcontinent again divisible into two climatic provinces: a western one, now drier, and an eastern, now wetter. Even after the monsoon bursts more generally, the division remains true, and the same basic factors continue to operate though the comparative size of the two provinces alters in favour of the wetter region.

Summer: the wet monsoon. The 'break' or the 'burst' of the wet monsoon, has puzzled climatologists for many years, but it is only recently that our increased knowledge of upper air movements seems to open the way for an explanation to fit all the phenomena, though as yet no one theory has general acceptance. Fig. 2.2.2 of two cross-sections through the atmosphere along longitude 90° E. shows the strength of the resultant westerly and easterly air movements averaged for five-day periods.* The Tibetan Plateau and the Himalaya are represented by the shaded area. In the earlier section two branches of the jet can be seen, one lying just south of the Himalaya; light easterly winds blow at the surface over the Peninsula. By 6–10 June the southern branch of the jet-streams has gone and India is invaded by strong westerly currents at the surface, the southwest monsoon.

The removal of the jet-stream to north of the Tibetan Plateau leads to a reversal of the curvature of flow of free air to the north and northwest of the subcontinent (Fig. 2.2.1). Over northern Iran and Afghanistan the trajectory of free air takes on a cyclonic curve (anticlockwise), leading to a dynamic depression aloft where previously there was an anticyclone. Here then, to the northwest of Indo-Pakistan there develops a dynamic depression overlying

* The sections are adapted from Yeh Tu-Cheng, Dao Shih-Yen, and Li Mei-Ts'un, 'The Abrupt Change of Circulation over the Northern Hemisphere during June and October', in Bolin, Bert (Ed.) *The Atmosphere and the Sea in Motion* (New York, 1959).

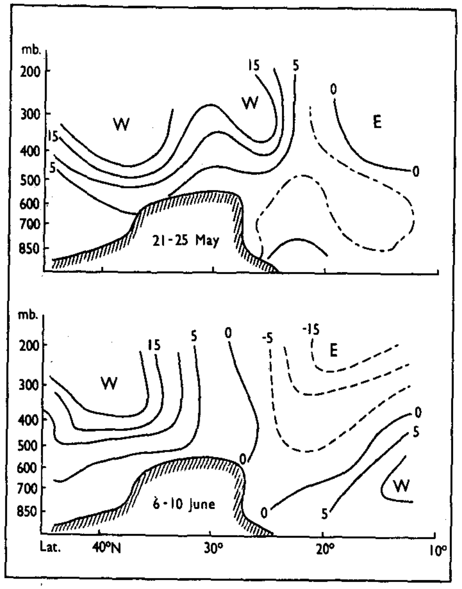


FIG. 2.2.2 Cross-sections through atmosphere along 90° E. Average wind speed in metres per second

the thermal depression already established at the surface, and it appears that this event may well be the trigger that sets off the 'burst' of the monsoon, allowing the vigorous inflow of equatorial air deep into India.

The intertropical convergence (I.T.C.), up till now situated between latitudes 10° N. and 20° N. is no longer prevented by polar air and the dynamic barrier of the jet-stream from moving north over India. There is, however, in the Antarctic circumpolar whirl a dynamic force from the Southern (now the winter) Hemisphere to give the trade winds their momentum, so that they cross the Equator, turning from southeast to southwest as they come under the contrary Coriolus force deflecting them to the right in the Northern Hemisphere. That it is a progression of surges of air from the south rather than suction into a fluctuating 'low' over northwest India–Pakistan that influences the movement of the I.T.C. seems to be demonstrated by the way in which the I.T.C. advances steadily north into the Ganga Valley (and can be observed so doing on the synoptic weather charts) and suddenly reappears near the Equator, to repeat its advance once again. There is no 'retreat' of the I.T.C. as one would expect if it were a simple frontal surface between contrasting surface air-masses.

The well-known 'pulsations' in the monsoon weather are due to waves of dynamic origin which develop in the I.T.C. (whose constituent air-streams are too homogeneous to give rise to frontal depressions of the type associated with the polar front in temperate latitudes). Over India such waves often develop into cyclonic vortices and the wet monsoon is punctuated by the cycle of their development as they pass westwards up the Ganga Valley. They bring periods of heavy rain, separated by more or less brief respites of clear weather, during which, however, the strong sunshine so raises temperatures and at the same time evaporates moisture from the sodden ground as to produce the unpleasantly sticky conditions which are harder to bear than the cooler if more thoroughly soaking weather of the rainy spells.

The amount of monsoon rainfall differs greatly from region to region over the subcontinent, and also is subject to considerable variability from year to year in the same region. Among the most important factors accounting for the distribution of rainfall is relief. The southwest air-streams when they strike the Western Ghats at right-angles rise abruptly to produce strong upcurrents and generally heavy precipitation along the crest of the Ghats. A little to the east air is tending to subside and a rain shadow effect is produced. The Himalaya play a dual role, stimulating uplift and also because of their great height channelling the monsoon air-flow northwestwards up the Ganga Valley. This channelling effect adds to the tendency to convergence and is probably responsible for carrying heavy rainfall much further into the northwest than might otherwise be the case. Relief has a strong effect in the northeast also, where currents coming in across the Bay of Bengal are funnelled over Sylhet and the Assam Hills, producing phenomenal rainfall at Cherrapunji as they rise abruptly against the Garo Hills.*

The northwestern corner of the subcontinent is relatively dry during summer despite the presence of the intense surface 'low' over the Thar Desert–Indus Valley, and the absence of relief barriers to the inflow of equatorial air. The primary reason for these dry conditions lies in the thinness of the monsoon

* Cherrapunji holds the world record for rainfall with an average annual fall of 425·1 inches; as much as 36·4 inches have fallen in twenty-four hours in the month of June, when the average fall is 106·1 inches.

flow towards its western flank, here only 500 metres thick, and furthermore, overlaid by a 'lid' of warm anticylonic air originating in the subtropical cell of high pressure standing over the Sahara and extending a ridge across Iran–Afghanistan. This lid limits the possibility for uplift of the surface air and so minimises precipitation.

Between these extremes of thickness the chance of convergent upflow and precipitation depends on the extent of the influence of the 'lid' which sometimes causes the spread of drought conditions far to the east of the normally arid areas of the Thar, Indus, and Punjab. Occasionally the 'lid' effect is withdrawn to the west and the monsoon air is allowed to escape upwards to bring torrential rain to the semi-desert.

A further cause of irregularity in monsoon rainfall is the occurrence of tropical cyclones particularly over the coasts of the Bay of Bengal, and especially in late summer. India averages thirteen tropical cyclones per annum. They are very destructive at the head of the Bay of Bengal when their impact may be combined with a 'hurricane wave' and wind-driven seas. The 'hurricane wave', which may be only 1 ft. in amplitude, is caused by the very low pressure in the eye of the cyclone, but other waves, driven by the violent winds may mount to 30 ft. and more when they are funnelled up a confined estuary. Hence the repeated calamitous cyclones that occur in the Meghna and other estuaries along the sea edge of the Ganges–Brahmaputra Delta. Tropical cyclones also affect the Coromandel coast of Tamilnadu and Andhra Pradesh. The late autumn (October–November) rainfall maximum of Madras is attributable in part to these cyclones, in part to the I.T.C.

In mid-October the southerly branch of the jet-stream returns to its winter position south of the Himalaya, indicating that once more Northern Hemisphere polar dynamics are in command of the situation. The return of the jet-stream to the Indian scene is accompanied by the restoration of light easterly air-streams to the surface, the trade winds. Drought conditions are re-established over northern India–Pakistan while the I.T.C., under the weakening dynamism of the southern circumpolar system with the end of winter, continues to allow a degree of convergence to bring rain to a progressively smaller area of South India and Ceylon.

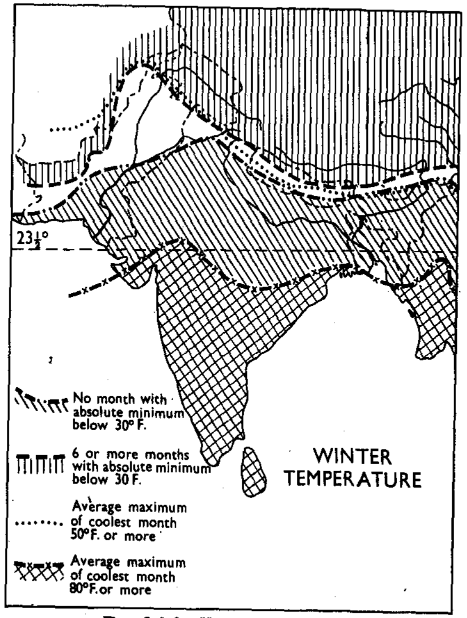


FIG. 2.2.3 Temperature: winter

Temperature and Rainfall

Whatever the dynamics and pressure patterns that ultimately control atmospheric movements over the subcontinent, the climatic elements to which man, animals, and plants are most sensitive are temperature and rainfall.

Winter temperature. Thanks to the protective influence of the mountain systems to the north and northwest, India and Pakistan enjoy higher winter temperatures north of the tropic than are experienced in comparable latitudes elsewhere in Asia. Fig. 2.2.3 shows a number of winter isotherms, three of which indicate clearly the influence of the mountain wall.

(i) *The isotherm for six or more months with an absolute minimum temperature of below 30° F.* avoids entirely the Indo–Gangetic Plains, and follows the mountains, entering the region only in Kashmir and the high northerly third of Baluchistan.

(ii) That for the *average maximum for the coolest month at 50° F.* follows a very similar path along the Himalaya–Hindu Kush.

(iii) The isotherm for the *absolute minimum temperature at or below 30° F.* follows essentially the same course east of the River Sutlej's traverse of the

Himalaya, but west of this it enters the plains to follow the course of the Sutlej downstream to its junction with the Indus, and so west to skirt the mountain edge and run parallel to the Makran coast. Thus the plains of the Punjab, in West Pakistan and India, and the foothills lying to the northwest experience occasional frosts, these becoming more regular northwestwards across the Indus into the Vale of Peshawar and beyond. But temperatures in the plains fall very little below freezing; the absolute minimum recorded at Jacobabad is 30° F., Multan 29° F., Lahore 28° F., Delhi 31° F., Agra 28° F.

This corner of the subcontinent, furthest from the sea, enjoys a modest degree of continentality, which gives it a more invigorating cool season (except perhaps for the ill-clad and the underfed) than is found elsewhere. Close to the hills, in Peshawar and Rawalpindi for example, light snowfalls occur but the temperature never falls below 26° F. at Peshawar. The plains here stand at over 1000 ft., a fact which accentuates the effect of the continentality and northerly latitude as far as temperature is concerned.

It will be noted that none of the three isothermal lines discussed above suffers any deflection from its west–east orientation within the borders of northeastern India. Not until immediately beyond India's most eastern limits do two of the lines swing abruptly south to parallel the watershed between the Salween and the northernmost tributaries of the Irrawaddy.

The fourth isotherm shown on Fig. 2.2.3 is that for the *average maximum temperature of 80° F. or more in the coolest month.* It is seen to lie mainly just south of the Tropic of Cancer, and runs from Kathiawar to close to the mouth of the Ganga, almost precisely delimiting 'peninsular' from 'continental' India and suggesting by its position the combined effect of latitude and marine influence.

With the sole exception of Chitral and the adjacent areas of montane and intermontane Kashmir, no part of the subcontinent has an average maximum of less than 50° F. in the coolest month. Although this is rather a crude measure, it is an indication that as far as temperature is concerned plant growth can continue to some extent throughout the cool season. In the Peninsula and Ceylon conditions are pleasantly warm. At Bangalore (3021 ft. above

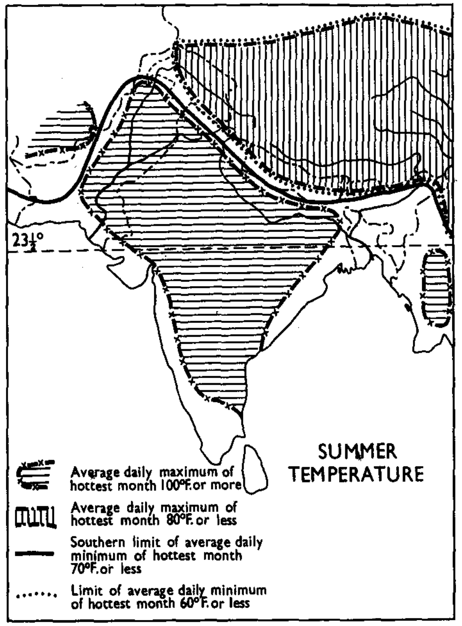


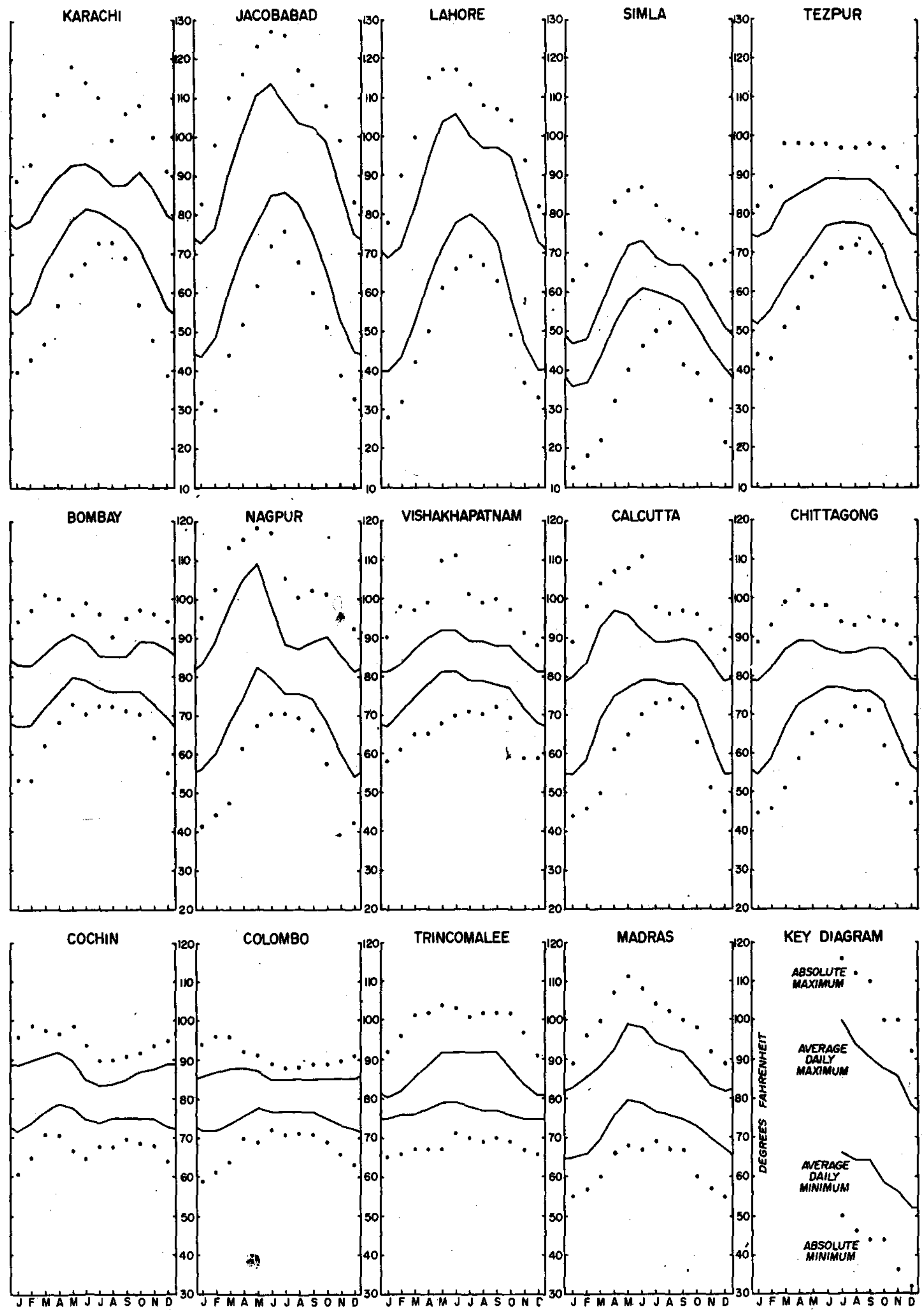
FIG. 2.2.4 Temperature: summer

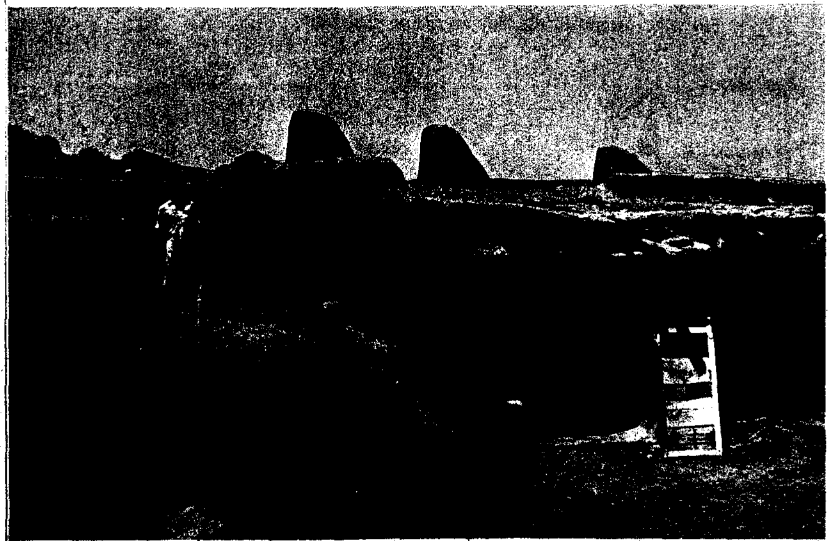
sea-level) the absolute minimum is 52° F.; at Madras 57° F. Infrequent disturbances bring occasional cloudy skies to the northwest, but these seldom persist beyond western Uttar Pradesh. Otherwise the cool season is generally one of clear blue skies, warm days, with calm or light breezes.

Summer Temperature. Fig. 2.2.4 depicts certain summer isotherms, all of which suggest more nearly homogeneous conditions than in winter. The greater part of the subcontinent is contained within the isotherm for the average daily maximum of 100° F. or more in the hottest month. The mountain fringe and all but a small section of the coastal zone escapes such sustained extremes of heat. The unfortunate stretch of coastal lowland is in northern Tamilnadu and southern Andhra Pradesh, an area with an anomalous rainfall regime. While elsewhere midsummer temperatures in the coastal zone are moderated by on-shore breezes and at latest from June by the monsoon rains, the Carnatic then lies on a lee-shore and in the extended rain shadow of the Western Ghats.

The annual regime of temperature for fourteen

FIG. 2.2.5 Temperature regimes (for location of stations see Fig. 2.2.9)





5. *Farmer's house at Chhor near Mirpur Khas*, Hyderabad, West Pakistan. This area is particularly hot in summer so the houses are designed to minimise the amount of sunshine and heat admitted, and to introduce any breeze that blows (from the southwest) through the fixed ventilators on the roof. The thick walls are of sun-dried brick finished with mud plaster.

selected stations is shown in Fig. 2.2.5. The graphs are for the average daily maxima and minima, month by month; the unconnected points represent the absolute maximum and minimum temperature for each month (i.e. the highest and lowest readings ever recorded).

From an examination of the graphs the following salient features emerge:

1. The characteristic regime shows a relatively steep climb in temperature from a midwinter minimum (December or January) to a maximum in May or June, the peak of the hot dry weather.

2. With the break of the monsoon, bringing fairly general cloud if not rain the temperature drops less abruptly through July–August–September. In some cases this falling-off takes the form of a trough on the graph, as temperatures rise again to a secondary maximum in September–October, reflecting the reduction in frequency of rainfall and in cloud cover.

3. Generally temperatures fall more steeply again from October to December, marking the change in meteorological conditions following the re-establishment of the jet-stream south of the Himalaya.

4. In winter the diurnal range of temperature is greater than in summer at most stations, a consequence of lower minima resulting from night radiation in clear weather.

5. Diurnal and seasonal range tends to increase with latitude and with continentality of position: compare Bombay and Nagpur, Karachi and Jacobabad.

Several progressions may be noted. Colombo's near equatorial equability, is modified in Trincomalee where rainfall is mainly in winter, the associated cloudiness reducing temperatures. The progression Colombo–Cochin–Bombay–Karachi illustrates the transition into a thoroughly monsoonal regime, the ranges of absolute and average diurnal and annual temperatures increasing polewards.

Nagpur, in the heart of South Asia, may be taken as illustrating the typical monsoon regime. Compared with Bombay its range is greater on each count. Towards Calcutta there is again some modification, but that its regime is rather less equable than Bombay's may be attributable to its position inland, some sixty miles from the open sea. The graphs of Chittagong on the East Pakistan coast and more clearly still, Tezpur in the Assam Valley show the moderating influence exerted on temperature by the pre-monsoonal rainy weather of March–April–May referred to on p. 17 above. Such rains are appreciably less significant in West Bengal.

The contrast between the temperature regimes of Calcutta and Vishakhapatnam could be explained in terms of the latter's closer proximity to the sea, which reduces absolute, diurnal, and annual ranges. Madras has much the same regime as Vishakhaptnam but suffers higher temperatures in May–June–

July when it receives little or no rainfall from the southwest monsoon whose air-stream is subsiding and so clearing as it flows down from the Western Ghats and the Mysore Plateau.

Northwestwards from Nagpur the monsoon rains arrive later and last a shorter time, consequently their cooling influence is less clearly felt. Winters however are quite cool, and here one sees the combined effect of latitude continentality and occasional cloudiness. Lahore and Jacobabad have essentially similar regimes, but that of the latter is more extreme. It has been included as being notorious for having one of the highest absolute maxima recorded for an inhabited place: 127° F. As has been mentioned above, winter temperature minima in the plains of the northwest are only exceptionally low enough to inhibit plant growth. Summer maxima, however, *averaging* over 100° F. for six months at a time, and over 110° F. for two of these are wilting to plants and extremely enervating to animals including man.

Lastly, Simla is included as typical of the Himalayan hill-stations to which British rulers in India used to flee to escape from the stifling heat of the plains. Its regime is in general closely parallel to that of Lahore. Although at 7224 ft. above sea-level (cf. Lahore 702 ft.) Simla's average minima in winter are only three to four degrees below that of the plains city, though its absolute minima are much lower. Its average maxima march ten degrees or so above its minima, keeping a good thirty degrees below the maxima at Lahore.

Rainfall

Of all the climatic elements rainfall plays the most significant role in the life of South Asia. While temperatures are rarely so extreme as to arrest plant growth, deficiencies of moisture due to the vagaries of rainfall are accepted as a normal hazard in agriculture. Most parts of the region experience complete drought for several weeks each year, and in many areas rainfall frequently varies so considerably from 'normal' as to affect farming adversely.

The map of *rainfall incidence* (Fig. 2.2.6) summarises the comments on precipitation made above in the section on climatic dynamics. In this map the subcontinent is divided into regions having similar rainfall regimes (though not similar rainfall totals). A rainy month is regarded as one during which

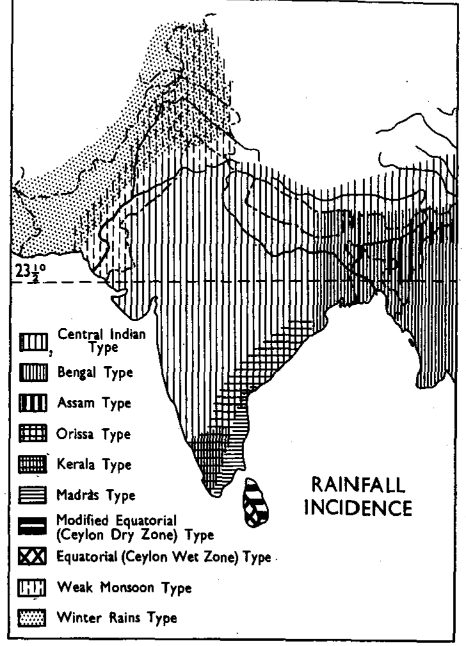


FIG. 2.2.6 Rainfall incidence

more than one-twelfth of the mean annual rainfall is normally received. Other maps and diagrams are essential to a full appreciation of rainfall, and it must be stressed that this map attempts to express only one aspect of it. While the formula used brings out well the significant differences in proportion of wet to dry months in characteristically monsoonal areas, it tends to mask the inadequacies of monthly means. Ten types of rainfall incidence are distinguished on the basis of the occurrence of the rainy months throughout the calendar year.

1. The basic type to which others can be regarded as modifications, is the *central Indian type* in which the rains begin in earnest in June, and continue for four months. None of the remaining eight months of the year receives one-twelfth of the annual rainfall, but this is not to say that no significant amount of rain occurs. The discussion of the rainfall dispersion diagrams below will bring out the importance of rainfall outside the main rainy season. The central Indian type of rainfall incidence is seen to extend over almost the whole of northwestern India, east to include Uttar Pradesh and most of Madhya Pradesh, south to include Maharashtra and the

interior and northern parts of Mysore and Andhra Pradesh.

2. In the *Bengal type*, which covers Bihar, West Bengal, East Pakistan, and the adjacent tips of Orissa and Assam, substantial rains begin earlier giving a five-month rainy season from May to September.

3. In the *Assam type* there are earlier rains still, and the season extends to six months, from April to September. The influence on the Bengal and Assam types of the somewhat different mechanism of the monsoon experienced in Burma was referred to above.

4. Southwards of the central Indian type the influence of the intertropical convergence (I.T.C.) in its late season position is felt on the east coast, being augmented by tropical cyclones in late summer and autumn. The *Orissa type*, of Orissa, almost all except southern Andhra Pradesh, and western Mysore is one in which the rains start in June (as in the central Indian type) but persist into October or November, giving five or six months with more than one-twelfth of the annual rainfall.

5. In the *Kerala type* of the southwest coast and plateaus the rains come earlier (May) and last six months in the specified amount.

6. The *Madras type* is one of the subcontinent's 'anomalies'. Deprived of the main onset of monsoon rains by the sheltering effect of the Ghats, the Coromandel coast has to wait until August or September for the start of appreciable rains, and the rainy season lasts only four to five months.

7. The *Ceylon dry zone type* of the northern and eastern parts of the island has not more than a month or two with less than one inch. Such a statement although statistically supportable, may give the impression of less droughty conditions than actually obtain all too frequently in the dry zone. Maximum rainfall (over one-twelfth the annual average) occurs from October to January.

8. The *Ceylon wet zone* of southwest Ceylon has a regime approximating to equatorial with no pronounced dry season and a double maximum from April–June and October–November.

9–10. At the other end of the subcontinent, the central Indian type degenerates into the *weak monsoon type* which overlaps with the *winter rains type* in the Western Mountains and northern Punjab Plains.

Areas shaded as the weak monsoon fringe receive rains in the three months from July to September. Winter rainfall begins in December or January, and persists into April or May.

The rainfall dispersion diagram set out in Fig. 2.2.7 illustrates the gradational nature of the regional boundaries shown on the map of rainfall incidence. Variability of rainfall – in any month from year to year, and in annual total from year to year is characteristic of the region. Each graph is based upon a run of statistics, covering usually twenty years (ten years in the case of a few stations). The graph is constructed as follows. The highest figure for each month forms the uppermost line; the lowest forms the bottom line (often this line fails to appear above zero). Between the top line and the next (the upper quartile) are the highest quarter of the recordings, while the lowest quarter of readings lie below the next lower line (the lower quartile). The shaded area, the interquartile range (I.Q.R.), thus contains half the readings and in a sense can be read to mean that as often as not the rainfall will fall within this range. Fig. 2.2.8 showing the annual totals of rainfall treated in like manner will be discussed along with each station's pattern of monthly rainfall.

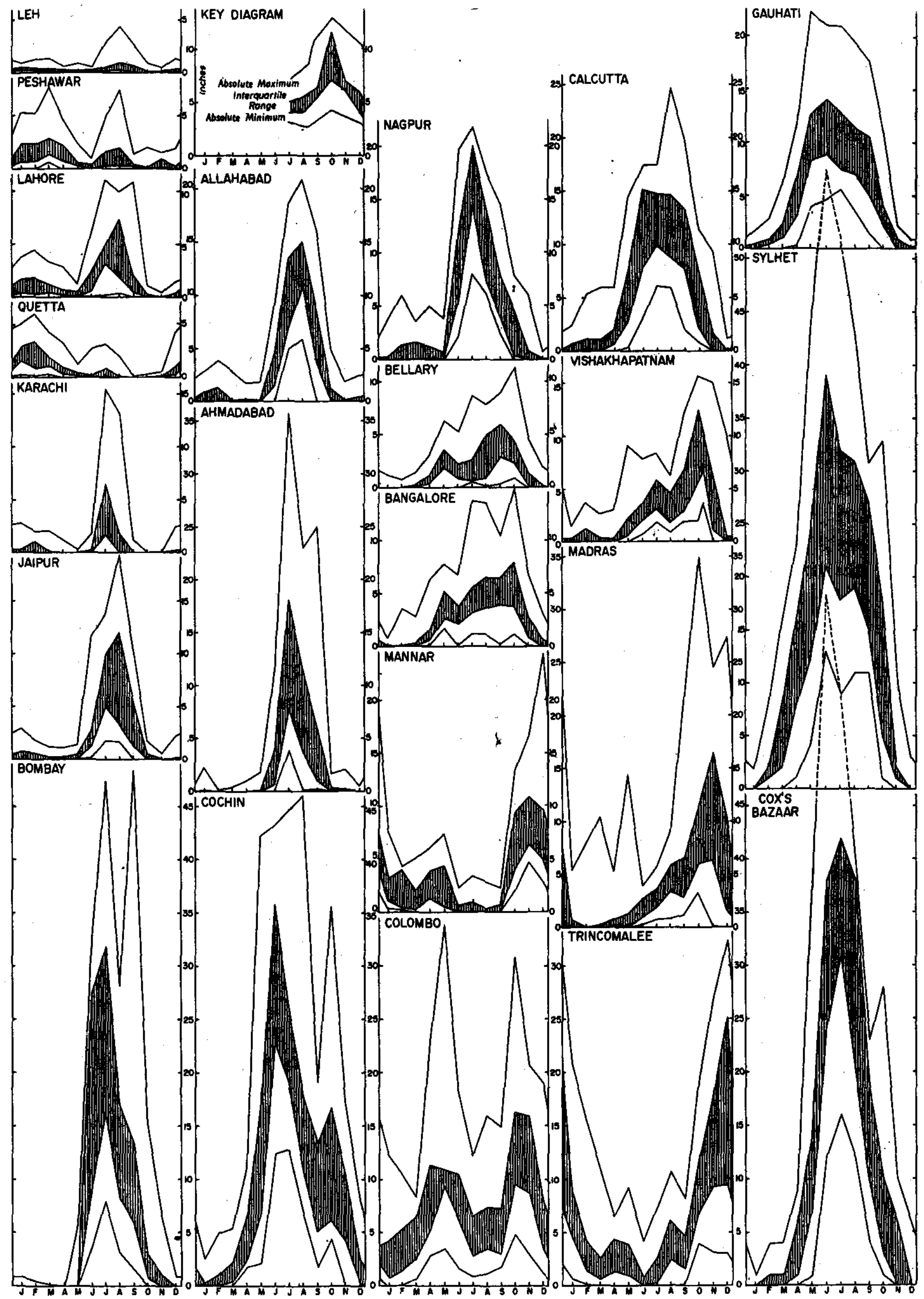
The reader is warned against reading the diagrams to mean that, for example, the monthly totals shown by the uppermost line all occurred in the same year! The graph for any single year might well show an erratic progress within the limits of the maximum and minimum values shown.

The rainfall dispersion diagrams will be discussed station by station, grouped according to regional type of rainfall incidence to which they belong.

1. *Central Indian type* (Stations: Jaipur, Ahmadabad, Bombay, Allahabad, Nagpur, Bellary).

Nagpur may be taken as our starting-point, since it represents the mean situation for the type region. The monsoon rains start here in June. From this month throughout July, August, and September the rains are normally heavy, but their range of variability is not inconsiderable. June has brought as little as 2.3 inches, or as much as 19.7 inches, but this could be attributed to the vagaries in the date of the break of the monsoon. By July the wet monsoon is firmly established, and the total ranges between a minimum of 8 inches and a maximum of 22 inches: the I.Q.R. for this peak month is between 14.4 and 20 inches. From the July maximum the

FIG. 2.2.7 Rainfall: monthly dispersion diagrams



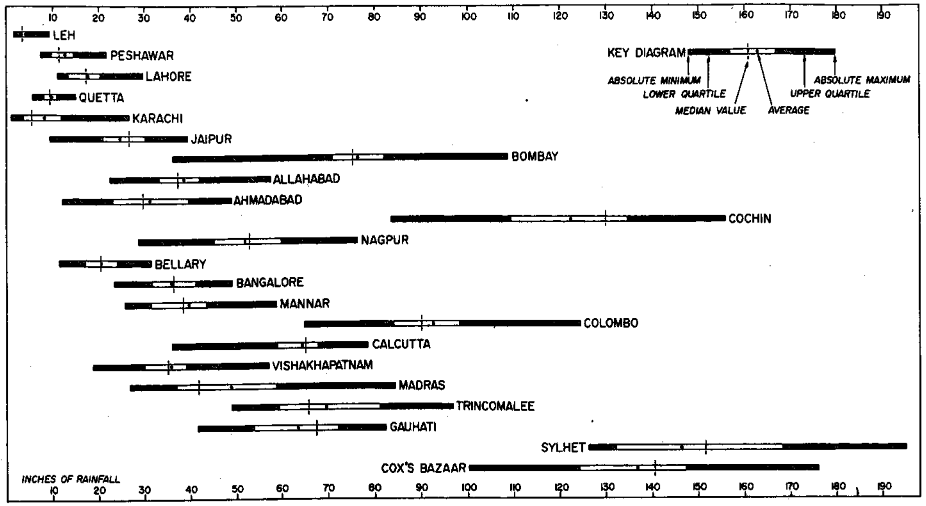


FIG. 2.2.8 Rainfall: annual dispersion diagrams

The unshaded portion of each bar is the interquartile range for annual rainfall, within which the dot indicates the *mean* (average) and the pecked line the *median* (the central point above and below which half the readings fall). In the case of most stations in the subcontinent where the rainfall is concentrated in three to five months of the year, the pattern of annual variation closely resembles that of the few rainy months.

totals fall off in August and September. In the latter month it is noteworthy that the minimum is about 2·5 inches, and even the I.Q.R. begins at 4 inches, little enough when a single twenty-four-hour spell has been known to bring almost 7 inches of rain. By October the minimum expectation has plunged to nil where it remains throughout the eight months ending in June. Appreciable rain may come in October, but the chances are that the rainfall will be between 0·5 and 4·8 inches, most of which might come in a single storm!

The narrowing of the I.Q.R. from November to May is a measure of the real drought of the cool–dry and hot–dry seasons. While the highest rainfalls recorded throughout the dry season range from 1 inch to over 6 inches, the mean expectancy of rain is very low, and negligible in December and January. Throughout the pre-monsoon period of February to May the mean expectancy is between nil and 1·6 inches, and so may be discounted as far as agriculture is concerned. In Fig. 2.2.8 Nagpur is seen to represent a fairly central tendency for all the stations. The extreme range of its annual rainfall is between 28·5 and 76 inches, the I.Q.R. being 45 to almost 60 inches. Thus despite a mean annual rainfall of about 52 inches, in one year out of four less than 45 inches may be received.

The other stations in the central Indian type may now be compared with Nagpur to bring out any significant differences.

Allahabad, lying further north, differs mainly in the later incidence of heavy rain. June has been known to bring 9·3 inches but the mean expectation is of between 1·5 and 5 inches and in some years no rain at all has been recorded. July sees the minimum at 5 inches, the maximum 18·6 inches, but the highest rainfalls belong to August (maximum 21 inches: interquartile range (I.Q.R.) 11–15 inches). Compared with Nagpur, the rains come later and end sooner. For ten months (September–June) the monthly minimum can be nil and by October the best that can be expected is 5 inches, and on balance not more than 1·5 inches. The dry season is a little drier than at Nagpur.

In the range of its annual rainfall Allahabad shows a rather narrower and lower range of variation round an I.Q.R. of 33–42 inches. With 40 inches regarded in a very general sense as the minimum annual rainfall capable of supporting rain-fed agriculture, it is interesting to note the occurrence of

this liability in rather more than 50 per cent of years, as far down the Ganga Plain as Allahabad.

Lying further west and a little north, Jaipur's pattern is very close to that of Allahabad, differing only in having a rather lower expectation of rainfall throughout the year, and naturally in the annual totals.

Lahore marks the transition between the 'central Indian' and 'winter rainfall' types, but belongs rather to the former. Marking its westerly position in relation to the main monsoon air-stream flowing up the Ganga Plain from the southeast, Lahore has its maximum rainfall in August (more often than not) though its *mean* maximum is in July. Although winter rainfall is slight, a secondary maximum is recorded in January–February. There is, however, a risk of little or no rain one year in four in every month of the cool–dry and hot–dry seasons.

In *Ahmadabad* and *Bombay* the basic patterns of Nagpur, Allahabad, and Jaipur are seen again but in exaggerated form. Ahmadabad is the drier of the two, not achieving quite such high totals in July–August–September as does Bombay, and tending to end its rains conclusively in October, whereas Bombay's I.Q.R. for that month lies between 1·5 and 3 inches. Both stations show extreme variability in September when the maximum rainfalls diverge widely from the I.Q.R., and both agree in their sustained drought from November to May during which seven-month period the I.Q.R. scarcely rises from its zero level! This is in some contrast with the more easterly stations of Nagpur and Allahabad where the pre-monsoon showers, unreliable though they are, invite comparison with Bengal and East Pakistan.

In Fig. 2.2.8 Ahmadabad and Bombay show more pronounced differences in the amount and degree of variation in their annual rainfalls. Ahmadabad's total ranges between 12 and 49 inches, with the I.Q.R. 23 (almost) to 39·5 inches. Bombay's extreme range is between 36 and 108·5 inches, but its I.Q.R. is less wide than that of Ahmadabad, 71–81·5 inches.

2. The *Bengal type* of rainfall incidence is represented by *Calcutta* which differs from Nagpur in two ways: the rains begin earlier (so that May normally expects between 2·5 and 7·5 inches, and can receive almost 15 inches) and maintain a higher total steadily throughout the four months June–September, with October, like May, likely to have reasonable falls. As at Nagpur, December is dry, with the I.Q.R. at *nil*. Within the same incidence-type, *Cox's Bazar* on the eastern side of the Bay of Bengal shows a similar pattern at the much higher rainfall total of 140 inches on average. Here the pre-monsoon fall (the 'little rains') are significant as early as April.

3. *Assam type*. Further east and northeast the fact that the April rains exceed one-twelfth of the annual rainfall justifies separating this region from Bengal. *Sylhet* and *Gauhati*, immediately south and north of the Shillong Plateau, show basically similar patterns, but contrast strongly in the total rainfall in the main rainy season. Sylhet with a mean rainfall of 146 inches (extreme maximum 195 inches) suffers the full onslaught of the monsoon air-streams while Gauhati (mean rainfall 63 inches, extreme maximum 82 inches) enjoys a measure of protection in the lee of the plateau. Compared with central India the dry season, though quite as severe while it lasts is of shorter duration; December and January are extremely dry, November and February–March may be so but normally receive an inch or two, all of it may be in a single downpour.

4. *Orissa type*. Southwards from the central Indian type, the principal change is in the duration of the rainy season into September and October, with the maximum in the latter month. The pattern is clearly seen in the graph for *Vishakhapatnam* where the rains generally persist into November, which however may sometimes mark the start of the dry season. On the Orissa coast cyclones probably contribute to the late season rains, but an important influence at this time is the I.T.C.

5. *Bangalore* and *Cochin* both qualify for inclusion in the *Kerala type*, having a six-month rainy season, but they differ in detail. Cochin, on the west coast is open to the early vigour of the inflowing monsoon in May–June, and receives its maximum rainfall then, with a secondary peak in October. At Bangalore, with a much lower total, the wet season is of similar length but the I.Q.R. lies between 2–4 inches (June) and 4–8 inches (October). Bangalore seems to benefit from the northward march of the I.T.C. in May, but once the southwest monsoon sets in during June, its interior position in the rain shadow of the Western Ghats leads to definite reduction in rainfall. The influence of the 'retreating' I.T.C. at both stations is seen best perhaps in the

October–November rainfall, and the less pronounced drought of December.

6. *Madras* has a quite anomalous regime. The southwest monsoon has little effect, and though there is a steady increase in rainfall from April to September the amount averages less than 5 inches in any month, and less than 2 inches in April to June. Late in the year the retreating I.T.C. is strongly supplemented by cyclones on the coast. Maximum falls of over 8 inches in twenty-four-hour periods are recorded for October to January. Madras suffers badly from unreliability of rainfall. Even in November–December, when rainfalls average 14 and 5·5 inches, and the I.Q.R. is 6·5–16·5 inches, and 2·3–7 inches respectively, the monthly totals may occasionally touch zero. Contrariwise, in the dry season from January to June, occasional monthly totals of 22, 5·5, 10·5, 5·5, 14·5 and 4 inches have been known.

7. The *dry zone of Ceylon*, represented by *Mannar* and *Trincomalee*, may be regarded as a region transitional in type between Madras and Colombo. The late season maximum is found here, and Trincomalee has a run of four months (October–January) with over one-twelfth of the annual average rainfall of almost 65 inches. Mannar whose average rainfall is just under 40 inches, has a similar overall pattern of incidence. Both stations show a minor maximum in April–May and some tendency for the January rains to persist into February, and in both (but particularly in Mannar) can be seen the risk of absolute drought occurring in *any* month between February and September.

8. *Colombo* in the *wet zone of Ceylon* has a more nearly equatorial regime, showing a double maximum following the equinoxes. Applying the formula used here to define the rainy season, we find here the first example of a station having two well defined rainy seasons: April–June and October–November, when each month has more than one-twelfth of the annual total. It should be noted, however, that no month has a mean rainfall of less than 2·7 inches, though the extreme minima of January and February may occasionally be nil.

9–10. *Weak monsoon and winter rains types.* The remaining stations, in the northwest of the subcontinent all demonstrate semi-arid to arid conditions, with low and very variable annual totals. The four stations while indicating the regime characteristic of the region are not fully representative as to the amount of rainfall received. Along the outer side of the Himalaya, in the Vale of Kashmir and the submontane belt immediately east of the Indus, rainfall totals are generally rather higher than in any of these four stations. Thus Srinagar averages 26 inches annually.

The double origin of rainfall in the northwest is seen in each graph, though barely so in the case of *Leh* where the monthly totals are so very low on account of this town's sheltered location north of the Indus and the main Himalaya. *Peshawar* and *Quetta* show the pattern well, both favouring slightly the late winter and spring as the wetter season of the year. At *Karachi* the summer monsoon brings most of what little rainfall is received. No month, however, is without risk of complete drought in this city of notorious variability of rainfall, and the probability of no rain is very high in April–May and September–November, when the I.Q.R. fails to rise above zero. The annual total shows great variation also (Fig. 2.2.8). As is typical of semi-arid climates, precipitation when it comes may be torrential and in July and September falls in twenty-four hours greater than the annual average total have been recorded.

Fig. 2.2.9 shows the location of the several climatic stations mentioned and the distribution of mean annual rainfall. Selected climatic data for these stations is tabulated (Table 2.2.1) on p. 31.

Climatic Regions

The preceding sections have demonstrated the gradualness of changes from place to place in the amount and seasonal distribution of rainfall and temperature. Perhaps the only exceptions to this generalisation are found in the way rainfall decreases more or less abruptly in the lee of the Western Ghats, and the sharpness of climatic change within and beyond the Himalaya, a characteristic of high mountain regions. Apart from these orographically determined zones of abrupt gradation, 'progression' and 'transition' are the terms most appropriate in describing climatic realities. A number of climatic 'types', characteristic of the core of particular regions may be identified, but lines drawn to separate climatic regions should be regarded in most cases as indicating broad zones of transitional conditions.

The map of climatic regions (Fig. 2.2.10) draws

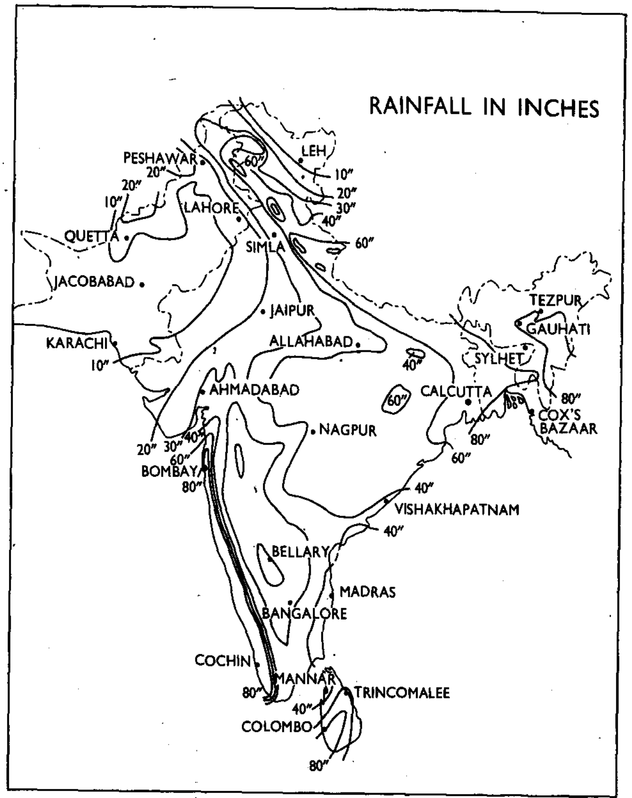


FIG. 2.2.9 Rainfall: mean annual isohyets and location of climatic stations

upon several climatologists and geographers who have attempted to classify climate, in two cases on a world-wide basis, in one instance with monsoon Asia as the objective. Although he does not map his climatic types, Pédelaborde's approach to the problem from the viewpoint of causes rather than in the consequences of climate for man has influenced the scheme put forward here.* Among other authorities consulted are the works of the classical climatologists Köppen and Thornthwaite.†

The Type Regions

I. Ceylon type
  (*a*) Wet zone
  (*b*) Dry zone
II. Kerala–Assam–East Pakistan type
III. Coromandel coast (Madras) type
IV. Central India–Malabar type
  (*a*) Malabar coast
  (*b*) East central India
  (*c*) West central India
  (*d*) Rain shadow belt
  (*e*) Semi-desert (of Gujarat–Rajasthan)
V. Lahore type
VI. Karachi type
VII. Himalayan type

I. *Ceylon type*: equable with a low range of temperature. Only on this ground can it be regarded as approximating to an equatorial climate. Aspect in relation to moisture-bearing air-streams controls the very significant local differences in the amount of seasonal rainfall. It is essential to distinguish:

I (*a*) Wet zone (see diagrams for Colombo).
I (*b*) Dry zone (see Trincomalee).

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* Pédelaborde, P., *The Monsoon* (London, 1963).

† For Köppen and Thornthwaite's classifications a readily available source is Trewartha, G. T., *Introduction to Climate* (London, 1954).

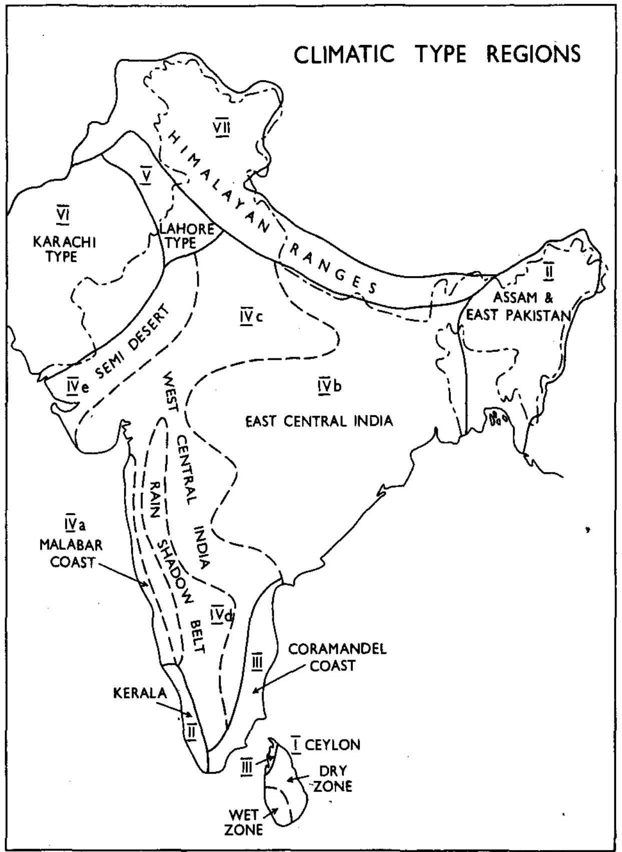

FIG. 2.2.10 Climatic-type regions

II. *Kerala–Assam–East Pakistan type*: compared with Ceylon there is a distinct but brief dry season, two months generally receiving less than an inch of rain. The range of temperature is slightly greater than in Ceylon, though (to quote Pédelaborde) 'there is no true winter'.

III. *Coromandel coast (Madras) type*: the main rains come in October–November, in large part from tropical cyclones, which helps explain the coastal nature of this type region. The southwest monsoon air-stream is subsiding as it passes over the region in June–July. Consequently little or no rain falls, and temperatures remain high throughout the summer.

IV. *Central India–Malabar type*: this covers the greater part of India and can be regarded as representative of the 'standard' monsoon regime and its minor variants. The march of seasons characteristic of the South Asian monsoon climate is found throughout the region with slight variations in the duration of the several periods.

(i) Winter (December–February) is generally quite dry with warm clear days and cool nights.
(ii) Early spring (March–April) is still generally dry but temperatures rise and may be uncomfortable by day.
(iii) Late spring (May–mid-June) brings humid air and in southern Malabar and West Bengal appreciable rainfall occurs.
(iv) From mid-June to mid-September the wet monsoon brings heavy rains and reduced temperatures.
(v) Autumn (mid-September–November) is marked by a fall in temperature as air begins to flow from the east and north. Gradually drought conditions are established throughout the region.

Subdivision of this type region is on the basis of rainfall amount.

(*a*) *Malabar coast*: northwards from Kerala to the Gulf of Cambay the length of the dry season increases, though total rainfall averages generally not less than 70 inches. In the south, Mangalore has four months with less than 1 inch of rain. Goa and Ratnagiri have five, and Bombay seven months.

(*b*) *East central India* comprises most of Madhya Pradesh, Bihar, Orissa, and West Bengal, with a part of Andhra Pradesh and the submontane plains of eastern Uttar Pradesh. The 40-inch annual isohyet arbitrarily separates the area from a drier

(*c*) *West central India*: rainfall totals 25 to 40 inches (and with these lower amounts variability increases).

(*d*) *The rain shadow belt* parallels the length of the Western Ghats through Maharashtra, Mysore, and Tamilnadu, widening at its centre into Andhra Pradesh. Over about half the belt rainfall is less than 25 inches. It is rather better distributed in the south where the influence of the 'retreating' I.T.C. is felt.

(*e*) *The semi-desert* of Gujarat–Rajasthan has the highest variability of annual rainfall of any part of India. With a total of less than 25 inches (e.g. Jodhpur 14 inches) a variability of over 30 per cent makes agriculture hazardous indeed in this region which deteriorates westwards into the wastes of the Thar or Great Indian Desert.

V. *Lahore type* of the Punjab Plains is an extreme continental version of the central India type, modified by having some useful winter rainfall, more valuable (inch for inch) than the modest falls of the summer monsoon since it is less subject to evaporation. Summers are very hot, winters cool with rare night frosts. The proportion of winter rainfall in the total increases northwestwards.

VI. *Karachi type* extends from the Thar Desert into the plateaus of Baluchistan. The mountain ranges intercept a certain amount of moisture but the region as a whole is the eastern extremity of the Afro-Asian deserts in the belt of subtropical high pressures. A meteorological 'lid' generally inhibits rain-producing uplift of any moisture-bearing air-streams which may penetrate the region.

VII. *Himalayan type* (including the northwestern hill country): orographically induced rain or snowfall occurs at all seasons to some extent. Summers are mild, winters not excessively cold (except beyond the main Himalayan ranges).

TABLE 2.2.1

Climatic Data

Temperature °F. Rainfall in inches

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
JACOBABAD													
Av. Daily Max. Temp.	73	77	91	102	111	114	109	104	103	99	87	75	95
,, ,, Min. ,,	44	49	61	71	78	85	86	83	76	66	53	45	66
,, ,, Temp.	58·5	63	86·5	86·5	94·5	99·5	97·5	93·5	89·5	82·5	70	60	80·5
,, Rainfall	0·2	0·3	0·2	0·2	0·1	0·3	0·9	0·9	0·2	<0·1	<0·1	0·2	3·5
KARACHI													
Av. Daily Max. Temp.	77	79	85	90	93	93	91	88	88	91	87	80	84
,, ,, Min. ,,	55	58	67	73	79	82	81	79	77	72	64	57	72
,, ,, Temp.	66	68·5	76	81·5	86	87·5	86	83·5	82·5	81·5	75·5	68·5	78
,, Rainfall	0·5	0·4	0·3	0·1	0·1	0·7	3·2	1·6	0·5	<0·1	0·1	0·2	7·7
LAHORE													
Av. Daily Max. Temp.	69	72	83	95	104	106	100	97	97	95	83	73	89
,, ,, Min. ,,	40	44	53	63	72	95	80	78	73	59	47	40	61
,, ,, Temp.	54·5	58	68	79	88	92·5	90	87·5	85	77	65	56·5	75
,, Rainfall	1·1	0·9	0·9	0·5	0·7	1·7	5·5	5·3	2·4	0·3	0·1	0·4	19·8
PESHAWAR													
Av. Daily Max. Temp.	63	66	75	85	98	106	103	99	96	88	77	67	85
,, ,, Min. ,,	40	43	52	60	70	77	79	78	71	58	46	39	59
,, ,, Temp.	51·5	54·5	63·5	72·5	84	91·5	91	88·5	83·5	73	61·5	53	72
,, Rainfall	1·4	1·5	2·4	1·8	0·8	0·3	1·3	2·0	0·8	0·2	0·3	0·7	13·5
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
QUETTA													
Av. Daily Max. Temp.	50	54	64	74	84	93	95	93	87	77	65	55	74
„ „ Min. „	27	30	38	45	52	59	65	62	50	39	31	27	44
„ „ Temp.	38·5	42	51	59·5	68	76	80	77·5	68·5	58	48	41	59
„ Rainfall	1·9	2·0	1·7	1·0	0·4	0·2	0·5	0·3	<0·1	0·1	0·3	1·0	9·4
AHMADABAD													
Av. Daily Max. Temp.	85	88	97	104	107	101	93	90	93	97	93	86	95
„ „ Min. „	58	59	67	74	79	81	79	77	76	72	65	59	71
„ „ Temp.	71·5	73·5	82	89	93	91	86	83·5	84·5	84·5	79	72·5	83
„ Rainfall	<0·1	0·1	0·1	0·1	0·4	4·3	11·2	8·1	3·7	0·6	0·1	0·1	28·6
ALLAHABAD													
Av. Daily Max. Temp.	75	79	92	103	107	103	92	89	91	90	83	76	90
„ „ Min. „	47	51	61	71	80	83	80	79	77	67	54	47	66
„ „ Temp.	61	65	76·5	87	93·5	93	86	84	84	78·5	68·5	61·5	78
„ Rainfall	0·9	0·6	0·6	0·2	0·6	5·0	12·6	10·0	8·4	2·3	0·3	0·3	41·8
BANGALORE													
Av. Daily Max. Temp.	81	86	91	93	92	85	82	82	82	82	80	79	85
„ „ Min. „	57	60	65	69	69	67	66	66	65	65	62	59	64
„ „ Temp.	69	73	78	81	80·5	76	74	74	73·5	73·5	71	69	74·5
„ Rainfall	0·2	0·3	0·4	1·6	4·2	2·9	3·9	5·0	6·7	5·9	2·7	0·4	34·2
BELLARY													
Av. Daily Max. Temp.	87	93	99	102	102	94	90	90	90	89	87	85	92
„ „ Min. „	63	67	73	78	78	76	75	74	73	71	67	63	71
„ „ Temp.	75	80	86	90	90	85	82·5	82	81·5	80	77	74	81·5
„ Rainfall	0·1	0·2	0·2	0·8	1·9	1·7	1·6	2·4	4·9	4·2	2·0	0·1	20·1
BOMBAY													
Av. Daily Max. Temp.	83	83	86	89	91	89	85	85	85	89	89	87	87
„ „ Min. „	67	67	72	76	80	79	77	74	76	76	73	63	74
„ „ Temp.	75	75	79	82·5	85·5	84	81	80·5	80·5	82·5	81	75	80·5
„ Rainfall	0·1	0·1	0·1	0·1	0·7	19·1	24·3	13·4	10·4	2·5	0·5	0·1	71·2
CALCUTTA													
Av. Daily Max. Temp.	80	84	93	97	96	92	89	89	90	89	84	79	89
„ „ Min. „	55	59	69	75	77	79	79	78	78	74	64	55	70
„ „ Temp.	67·5	71·5	81	86	86·5	85·5	84	83·5	84	81·5	74	67	79·5
„ Rainfall	0·4	1·2	1·4	1·7	5·5	11·7	12·8	12·9	9·9	4·5	0·8	0·2	63·0
COCHIN													
Av. Daily Max. Temp.	89	90	91	92	90	85	84	84	85	87	88	89	88
„ „ Min. „	72	74	77	79	78	75	74	75	75	75	75	73	75
„ „ Temp.	80·5	82	84	85·5	84	80	79	79·5	80	81	81·5	81	81·5
„ Rainfall	0·9	0·8	2·0	4·9	11·7	28·5	23·3	13·9	7·7	13·4	6·7	1·6	115·3
JAIPUR													
Av. Daily Max. Temp.	74	78	89	99	105	103	94	90	93	94	85	76	91
„ „ Min. „	47	51	60	70	78	81	78	76	73	65	54	48	65
„ „ Temp.	60·5	64·5	74·5	84·5	91·5	92	86	83	83	79·5	69·5	62	78
„ Rainfall	0·4	0·3	0·3	0·2	0·6	2·2	7·7	8·1	3·2	0·5	0·1	0·3	23·9
MADRAS													
Av. Daily Max. Temp.	85	88	91	95	101	100	96	95	94	90	85	84	92
„ „ Min. „	67	68	72	78	82	81	79	78	77	75	72	69	75
„ „ Temp.	76	78	81·5	86·5	91·5	90·5	87·5	86·5	85·5	82·5	78·5	76·5	83·5
„ Rainfall	1·4	0·4	0·3	0·6	1·0	1·9	3·6	4·6	4·7	12·0	14·0	5·5	50·0
NAGPUR													
Av. Daily Max. Temp.	83	89	98	105	109	98	88	87	89	90	85	81	92
„ „ Min. „	56	60	68	76	82	79	75	75	74	68	60	54	69
„ „ Temp.	69·5	74·5	83	90·5	95·5	88·5	81·5	81	81·5	79·0	72·5	67·5	80·5
„ Rainfall	0·4	0·7	0·6	0·6	0·8	8·8	14·6	11·4	8·0	2·2	0·8	0·5	49·4
SIMLA													
Av. Daily Max. Temp.	47	48	57	65	72	73	69	67	67	63	57	51	61
„ „ Min. „	36	37	44	52	58	61	60	59	57	51	45	40	50
„ „ Temp.	41·5	42·5	50·5	58·5	65	67	64·5	63	62	57	51	45·5	55·5
„ Rainfall	2·4	2·7	2·4	2·1	2·6	6·9	16·7	17·1	6·3	1·3	0·5	1·1	62·1
TEZPUR													
Av. Daily Max. Temp.	74	76	83	83	87	89	89	89	89	86	81	75	83
„ „ Min. „	52	56	62	67	72	77	78	78	77	71	61	53	67
„ „ Temp.	63	66	72·5	75	79·5	83	83·5	83·5	83	78·5	71	64	75
„ Rainfall	0·5	1·1	2·3	6·2	9·9	12·0	14·4	14·4	8·2	4·2	0·7	0·2	74·1
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
COLOMBO													
Av. Daily Max. Temp.	86	87	88	88	87	85	85	85	85	85	85	85	86
„ „ Min. „	72	72	74	76	78	77	77	77	77	75	73	72	75
„ „ Temp.	79	79·5	81	82	82·5	81	81	81	81	80	79	78·5	80·5
„ Rainfall	3·5	2·7	5·8	9·1	14·6	8·8	5·3	4·3	6·3	13·7	12·4	5·8	93·1
TRINCOMALEE													
Av. Daily Max. Temp.	80	82	85	89	92	92	92	92	92	88	84	81	87
„ „ Min. „	75	76	76	78	79	79	78	77	77	76	75	75	77
„ „ Temp.	77·5	79	80·5	83·5	85·5	85·5	85	84·5	84·5	82	79·5	78	82
„ Rainfall	6·8	2·6	1·9	2·3	2·7	1·1	2·0	4·2	4·2	8·7	14·1	14·3	64·9
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year