GEOLOGY
OF
INDIA AND BURMA

BY

M. S. KRISHNAN
M.A., PH.D., A.R.C.S., D.I.C., M.A.I.M.E.
GEOLOGICAL SURVEY OF INDIA

THE MADRAS LAW JOURNAL OFFICE
MADRAS
1949

PRINTED AT
THE MADRAS LAW JOURNAL PRESS
MYLAPORE, MADRAS
1949.

PREFACE.

The first edition of the official Manual of the Geology of India by Medlicott and Blanford appeared in 1879 and a second edition by R. D. Oldham was published in 1893. They were out of print by 1910 or thereabouts. Students of geology were, however, fortunate in the publication, by Mr. D. N. Wadia, of his excellent book 'Geology of India' in 1919, and the subsequent editions. For about a quarter of a century it has been the only book available on the subject. A new book on Indian Stratigraphy needs therefore no apology to make its appearance, especially at a time when the subject is attracting the attention of an increasing number of students and the educated public alike.

I have endeavoured to include all the most important and useful information up to the time of going to Press subject to the limitations set by the size and standard of this book. But, as my official duties have kept me away from Calcutta since the latter part of 1941, I have not had the advantage of the unrivalled library facilities available at Calcutta at the time of the final revision of the manuscript.

From the time I began the manuscript, I have received constant encouragement from Dr. Cyril S. Fox, Director of the Geological Survey of India, who found time, amidst his manifold duties, to read it through. I am indebted to him for many useful suggestions, for permission to make use of the Geological Survey publications for illustrations, and for obtaining for me the sanction of the Government of India to publish the book. It is a pleasure to acknowledge the valuable help I have received from my colleagues Messrs. N. K. N. Aiyangar and M. S. Venkataraman at all times during

the preparation of the manuscript and during its publication. To Dr. K. Jacob I am grateful for assistance and helpful criticism in connection with the chapter on the Gondwana System and in the preparation of the plates illustrating that chapter.

Several difficulties cropped up soon after the manuscript was handed over to the Madras Law Journal Press for publication. My warmest thanks are due to the management and staff of the Press for surmounting the difficulties and successfully bringing out the book in spite of the unprecedented conditions created by the war, and for the courtesy shown to me at all times.

M. S. KRISHNAN.

CONTENTS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

PAGES

CHAPTER XIX.

CHAPTER XX.

LIST OF ILLUSTRATIONS.

PLATES.

TEXT-FIGURES.

TABLES.

MAPS.

ABBREVIATIONS USED IN THE TEXT.

Bull. Bulletin.

G.S.I. Geological Survey of India.

J. or *Jour.* Journal.

J.A.S.B. Journal of the Asiatic Society of Bengal.

Mem. Memoirs (G.S.I.)

M. G. D. Mysore Geological Department.

Op. cit. Work cited (*i e.*, the publication mentioned before the particular reference).

Q.J.G.S. Quarterly Journal of the Geological Society, London.

Q J.G M M S. Quarterly Journal, Geological Mining and Metallurgical Society of India.

Pal. Ind. Palaeontologia Indica (G.S.I.).

Rec. Records (G.S.I.).

Rep. Reports.

Sc. or *Sci.* Science (and allied words).

Ser. Series (*N.S.* New Series).

T.M.G.I. Transactions, Mining and Geological Institute of India.

A few other abbreviations are used which should be easy to decipher as they are commonly used in scientific works.

In all the references, the numerals refer, in order, to the volume, page or pages, and year of publication.

ERRATA

Page	*Line*	*For*	*Read*
154	17	in	is
162	26	sibnite	stibnite
180	33	arkos	arkose
199	30	clerly	clearly
224	6	Nyungbaw	Nyaungbaw
229	29	*Fenestropora*	*Fenestrapora*
231	16	*Ortholhetes*	*Orthothetes*
,,	33	*genardi*	*gerardi*
234	26	*Ahtyris*	*Athyris*
235	1	Dobra	Dogra
242	7	Dinosurs	Dinosaurs
269	16	Godawari	Godavari
336	8	*Halabia*	*Halobia*
356	29	*suerbus*	*superbus*
393	15	*Terabratula*	*Terebratula*
407	9	Gasropods	Gastropods
409	1	Hiniyur	Niniyur
437	2	6	66
483	35	Acquitanian	Aquitanian
486	25	*Carbula*	*Corbula*
498	1	*Hyaenelurus*	*Hyainailouros*
,,	5	Griffids	Giraffids
508	17	Eratics	Erratics

CHAPTER I.

INTRODUCTION AND PHYSICAL GEOLOGY.

The Divisions of India.—A physical map of India shows strikingly that the country can be divided into three well-marked regions each having distinguishing characters of its own. The first is the *Peninsula* or Peninsular Shield (' shield ' being a term used for geologically very old and stable parts of the crust) lying to the south of the plains of the Indus and Ganges river systems. The second division comprises these *Indo-gangetic alluvial plains* stretching across northern India from Assam and Bengal on the east, through Bihar and United Provinces, to the Punjab and Sind on the west. The third is the *Extra-peninsula*, the mountainous region formed of the mighty Himalayan ranges and their extensions into Baluchistan on the one hand and Burma on the other.

These three divisions exhibit marked contrast in physical features, stratigraphy and structure.

Physiographically the Peninsula is an ancient plateau exposed for long ages to denudation and approaching peneplanation. Its mountains are of the relict type, *i.e.*, they represent the survival of the harder masses of rocks which have escaped weathering and removal ; they are thus not directly attributable to their structure. Its rivers have, for the most part, a comparatively flat country with low gradients to traverse, and have built up shallow and broad valleys. The Extra-Peninsula, on the other hand, is a region of tectonic or folded and overthrust mountain chains, of geologically very recent origin. Its rivers are youthful and are actively eroding their beds in their precipitous courses and carving out deep and steep-sided gorges. The Indo-gangetic plains are broad, monotonous, level expanses built up by recent alluvium through which many rivers flow sluggishly towards the seas.

Stratigraphically the Peninsula is a 'shield' area composed of geologically ancient rocks of diverse origin, most of which have undergone crushing and metamorphism. Over these ancient rocks lie a few basins of pre-Cambrian and later sediments and extensive sheets of horizontally bedded lavas of the Deccan trap formation The Mesozoic and Tertiary sediments are found mainly along the coastal regions. The Extra-Peninsula, though containing some very old rocks, is predominantly a region in which the sediments, laid down in a vast geosyncline continuously from the Cambrian to early Tertiary, have been ridged up and folded. They thus show enormous thicknesses of sedimentary rocks representing practically the whole geological column, which have been compressed and ridged up into dry land only since early or middle Tertiary times. The core of the mountains is composed of granitic intrusions of presumably Tertiary age. The southern fringe, bordering on the plains, consists of fresh-water and estuarine deposits of Mio-Pliocene age derived largely from the rising Himalayas. The gangetic plains are built up of layers of sands, clays and occasional organic debris (peat-beds, etc.) of geologically very recent date (Pleistocene and Recent), filling up a deep depression between the two other units.

Structurally, the Peninsula represents a stable block of the earth's crust which has remained quiescent (*i.e.*, unaffected by mountain building movements), since practically the close of the Archaean era. The later changes have been of the nature of normal and block faulting which have let down parts of it bounded by tensional cracks or faults. Along its coasts, there have been marine transgressions which have laid down sedimentary beds of Gondwana, Cretaceous or Tertiary ages, but not of great magnitude. In contrast with this, the Extra-Peninsula has recently undergone earth movements of stupendous magnitude. Its strata are marked by complex folds, reverse faults, overthrusts and *nappes* of great dimensions. There is reason to believe that these movements are still in progress, though feeble, for this region is still unstable and is frequently visited by earthquakes of varying intensities. The Gangetic plains owe their origin to a sag in the crust, probably formed contemporaneously with the uplift of the Himalayas. This sag or depression has since been filled up by sediments derived from both sides, and especially from the lofty chains of the Himalayas which are actively being eroded by the many rivers traversing them. The little geological interest which these plains hold is confined to its rich soils and to the history of its river systems ; indeed, the alluvium effectively conceals the solid geology of its floor, a knowledge of which would be highly interesting. These alluvial plains are, however, of absorbing interest in human history, being thickly populated, and the scene of many important developments and events in the cultural and social history of Hindustan.

CLIMATE.

India and Burma together have an area of over 1,830,000 sq. miles, Burma alone occupying 261,000 sq. miles. India stretches between N. latitudes 8° and 37° and E. longitudes 61° and 97°, Burma extending further east to a little beyond 100°. From Cape Comorin to the north of Kashmir the distance is about 2,000 miles, this being exceeded by the distance between the western border of Baluchistan and eastern border of Burma by some 400 miles.

Within its extensive domain, India presents a variety of climatic conditions, but the dominant feature is the tropical monsoon. A part of the country, that beyond the latitude of Calcutta, lies to the north of the Tropic of Cancer. The interior of the country, owing to its inland or continental nature, is subject to extremes. The mountain barrier of the Himalayas plays an important part not only in influencing the distribution of rain in Northern

India, but also in preventing this region from experiencing the cold winters characterising the territories to their north.

The south-west monsoon reigns from the end of May to December, the earlier half being the general rainy season The latter half marks the 'retreating monsoon' during which some parts of the eastern coast, particularly the Madras coast, receive some rain. The north-east monsoon is active during the cold weather but the winds are dry before they blow over the Bay of Bengal.

During the cold weather (December to February) the temperature reaches a minimum, especially in the Punjab and the north-west which show mean temperatures below 55^0 F. In Upper India there is a region of high pressure from which winds radiate to the south and south-east. North-east winds are experienced in Bengal and these pick up moisture from the Bay of Bengal and precipitate it on the Madras coast and Ceylon. Some cyclonic storms are also experienced in N. W. India during this period but these are due to winds travelling eastwards from the Mediterranean.

During the succeeding months of March to May, the temperature rises steadily to a maximum, the interior of the country registering 110 to 120^{0}F. in early May. Strong winds blow from the north-west down the Ganges valley, familiarly known as 'norwesters.' Though, during this period, there is a low pressure region in Northern India, there is no flow of moisture bearing winds from the Indian Ocean as there is obstruction to such a flow in the intervening low pressure equatorial belt. It is only towards the end of May that this latter is wiped out and the south-west winds establish themselves.

The south-west monsoon strikes the Malabar and Arakan coasts and is deflected northwards by the hills present along these coasts. The Deccan plateau falls in the rain-shadow and hence receives only a small amount of rain which diminishes steadily from west to east. The

Western Ghats receive over 100 inches of rain during the monsoon whereas the 'shadow' region gets only 25 inches or less. The winds sweeping up through the Bay of Bengal strike the Arakan and Assam hills, the latter forcing the winds up to an altitude of some 5,000 feet when all their moisture content is precipitated as rain. The neighbourhood of Cherrapunji is known to receive the highest rainfall in the world, amounting to over 400 inches per annum. Part of the monsoon winds is deflected up the Ganges valley to as far as western Punjab, bringing rain to these regions between the middle of June and the end of August. There is of course more rain along and near the Himalayan foothills than away from them and hence Southern Punjab and Rajputana are regions of low rainfall

A broad and rather irregular belt of low rainfall (20-30 inches) stretches from the interior of Madras in a northerly direction through Bombay and Central India to the Punjab. But South-western Punjab, western Rajputana, Sind and Baluchistan constitute a region of very low rainfall (up to 10 inches per annum) and enclose the tract known as the *Thar* which is a semi-desert.

The latter part of the south-west monsoon season is marked by a gradual rise of pressure in Northern India which has the effect of obstructing and relatively pushing back the monsoon current. The winds therefore appear to 'retreat' and precipitate the moisture content along the east coast of Madras, during October and November. This is in fact the chief rainy season of this part of India. The north-east monsoon begins to be effective only at a later period but actually contributes less rain than the retreating south-west monsoon.

PHYSICAL GEOLOGY.

MOUNTAINS.

Peninsular India.—The chief mountain systems of the Peninsula are the Eastern and Western Ghats, the

Satpura and the Vindhya mountains and the Assam ranges.

The Western Ghats.—These form a well-marked feature along the western coast of India from Cape Comorin to the Tapti valley. The southern half is constituted by gneisses and charnockites whereas the northern half is predominantly made up of Deccan traps. The gneisses and charnockites form rugged and irregular ranges varying in height from 2,000 to 6,000 feet, but with a few peaks rising still higher. In Travancore they are called the Anaimalai and Cardamom hills, while the Palni hills are also to be considered as their easterly branch. In Malabar there is a large gap or pass in the mountains, called the Palghat gap, which has served as the main line of communication between the coastal strip and the eastern districts.

Just south of Mysore, the Western and Eastern Ghats meet, forming a knot of hills known as the Nilgiri mountains which attain the highest altitude of any peninsular ranges. The well-known peak of Doddabetta (8,640 feet) is the highest, but there are several lesser peaks over 6,000 feet high in this region. The Nilgiris are formed of the charnockites (hypersthene-granulites) which give rise to rolling, though somewhat rugged, topography, without steep escarpments or knife-like ridges which characterise the Himalayas. This is a consequence of the type of rocks, since these granitoid, igneous and metamorphic rocks generally produce rounded hills and gently sloping valleys. The Western Ghats continue northwards through the western margin of the Mysore plateau and Coorg. The Ghats of Mysore and Southern Bombay are called the Sahyadris, the Sanskrit name by which they are described in the Hindu epic Ramayana. Further north the gneisses are replaced by the traps which form flat-topped and step-like hills from Belgaum to Gujarat. It is the step-like appearance, due to the weathering of the horizontal layers of the traps, which has given the name 'Ghats' to the hills.

It is an interesting fact that, though the Western Ghats are quite close to the Arabian Sea, they form the watershed of the peninsula. The coastal strip to their west is only 20 to 30 miles broad and the westerly slopes are often much steeper than the easterly ones. The Western Ghats are exposed to the full vehemence of the south-west monsoon as they lie somewhat slantwise across the path of the monsoonic winds. Hence they receive over 100 inches of rain per annum.

Eastern Ghats.—The Eastern Ghats are a series of more or less detached hill ranges from near Balasore in Orissa to Nellore, and thence south-westward through Arcot and Salem to the Nilgiris. They comprise the 'Eastern Ghats' proper of Orissa, the hills of the Northern Circars of Madras, Nallamalais, Nagari hills, Javadi hills, Shevaroys and the Nilgiris. They are much less in altitude than the Western Ghats, the average being about 2,000 feet. They are composed of various Archaean and Purana formations, such as the khondalites, charnockites, gneisses and granites, and also the Dharwarian and Cuddapah rocks. They receive less rain than the Western Ghats in consequence of which their forests are comparatively less dense. They have no geological or topographical continuity, so that they are really a series of detached hills of the relict type.

The Satpura Mountains.—The Satpura Mountains consist of a series of parallel ridges between the Narbada and Tapti, extending from Rajpipla in Bombay through Central India, the northern part of the Central Provinces and part of Bihar south of the Ganges In the western portion they are composed mainly of the Deccan trap; further east they comprise, in succession, the Mahadeva or Pachmarhi hills of Gondwana formations, the Maikal range of the Amarkantak area of Deccan traps and Archaeans, and the hills of Sirguja, Ranchi, Hazaribagh and Monghyr. They have a general E.N.E.—W.S.W. trend. The heights of the various units vary greatly. The peaks in the Mahadeva hill are as much as 4,000 feet in altitute (the highest peak in Pachmarhi hills being 4,380 feet) while the Amarkantak peak is 3,490 feet. The Satpuras form the main watershed of the Peninsula east of the Aravallis. The Narbada and the Son rise on the northern slopes from the central region while the Tapti, Wardha, Wainganga, Mahanadi, Brahmani, etc., drain their southern slopes.

Vindhya Mountains.—The Vindhyas comprise the ranges to the north of the Narbada river, extending from Indore through Bhopal and Baghelkhand, the eastern portion in Baghelkhand being known as the Kaimur Range. The Vindhyas are really scarps of the plateau region composed of rock formations of the Vindhyan system *viz.*, the Kaimur, Rewa and Bhander sandstones. These hills have an elevation of 2,000 to 4,000 feet.

Assam Ranges.—These comprise the Garo, Khasi and Jaintia hills, which are collectively known as the Assam or Shillong plateau and which are bordered along the southern edge, which forms a scarp, by a fringe of Tertiary rocks. Their general trend is E.N.E.—W.S.W. (to N.E. —S.W.). They form an elevated tract between the Brahmaputra valley on the north and the Eastern Bengal plains on the south. Their continuation to the north-east is called the Mikir hills. The Assam ranges have an average elevation of 4,000 to 5,000 feet and are composed mostly of Archaean gneisses, granites and the Shillong series of rocks. They are all well forested and the southern portion receives the heaviest rainfall in the world. Cherrapunji in the Khasi hills is famous as receiving over 400 inches of rain per annum, as already mentioned.

The Aravalli Ranges.—The Aravallis form a marked feature across Rajputana and extend from the plains of Gujarat north-eastwards to Delhi, a distance of over 400 miles. Though they apparently terminate at the two extremities noted above, they may probably have formerly extended northward into Garhwal and southward into South India and the Laccadives. For, if we examine the Aravalli formations in Rajputana, it will be noticed that they tend to splay out towards the south and their natural continuation would appear to be in Mysore as well as in the submerged ridge now forming the Laccadives.

The Aravallis constitute one of the finest examples of a true tectonic range. They existed as high mountains, probably rivalling the Himalayas of the present day, at the close of the Archaean era. The original uplift, mainly a compressional movement, was of pre-Vindhyan but post-Delhi age, while a later uplift occurred in post-Vindhyan, probably Mesozoic times. The latter was probably a block-uplift (horst) as suggested by Sir Lewis Fermor in his paper on the Aravalli mountains (Rec. G.S.I., LXII, 391-409, 1930). They have thus remained as a mountain system throughout the greater part of the earth's history. They form the major watershed in Northern India separating the drainage of the Bay of Bengal from that of the Arabian sea. Their highest peaks at the present day reach to over 4,000 feet altitude. The Aravalli ranges consist mainly of highly folded and metamorphosed rocks of the Delhi and Aravalli systems, which form a great synclinorium. The main ridges are made up of quartzites and they divide the Vindhyan formations into two regions of rather different facies.

EXTRA-PENINSULAR RANGES.

Arcuate Disposition.—The mountains surrounding the Peninsula on the north, north-west and north-east are, as mentioned already, tectonic ranges and have been formed at a late geological age, *i.e.*, during the Middle and Upper Tertiary. Their curvilinear disposition is very striking, all of them consisting of circular arcs with their convexity turned towards the Peninsula, *i.e.*, towards the rigid crust against which they appear to have been thrust.

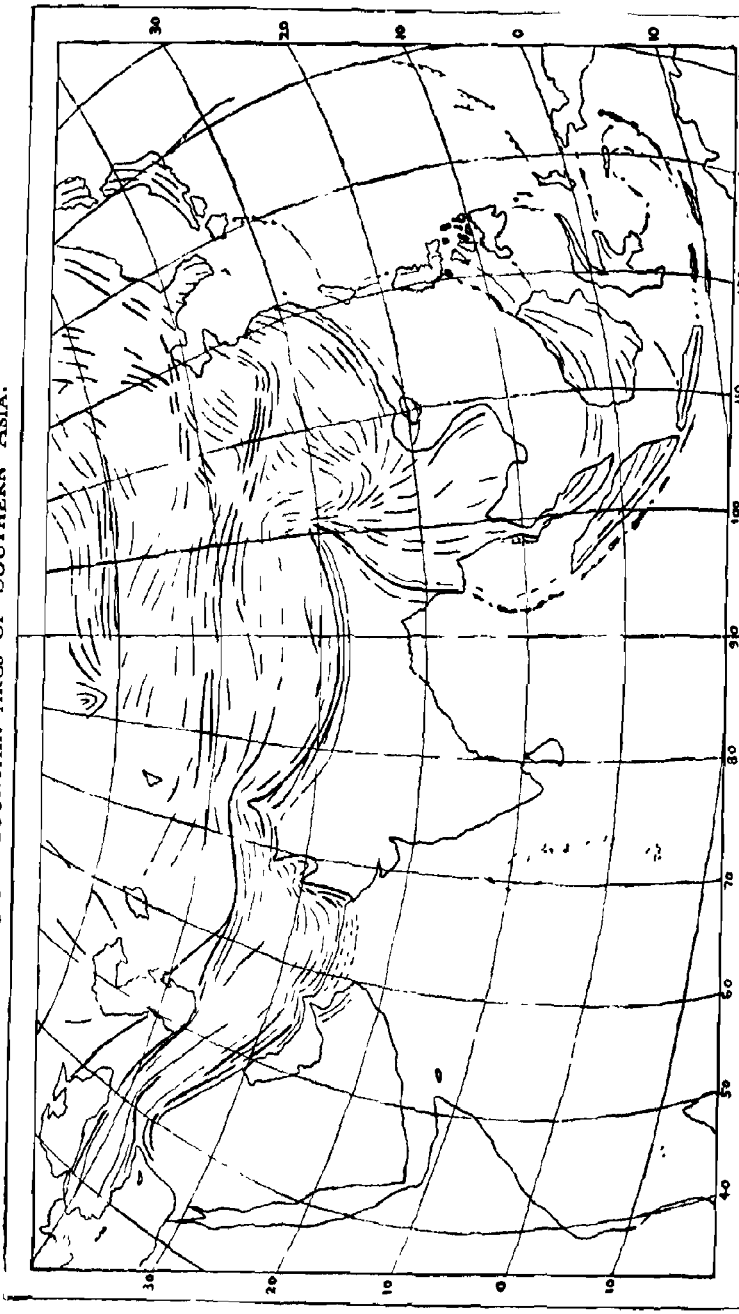
Of these, the Himalyan and the Burmese arcs are of immense radius. The Himalayas extend with a smooth sweep from Assam to Kashmir, for a length of about 1,500 miles. The north-western arm however consists of arcs of smaller radii which succeed one another at short intervals. The three main arcs here are the Hazara mountains with the Samana range and Safed Koh ; the Sulaiman ranges which terminate near Quetta ; and the system composed of the Bugti hills, and the Kirthar and Mekran ranges.

The Himalayan arc is followed northwards by a succession of ranges across the great Tibetan table-land, their courses being more or less parallel to the Himalaya, but the curvature of the arcs gradually decreasing northwards. Thus it will be seen that the Aling Kangri range, the Karakoram and the Kun Lun become progressively straighter, the last being practically a straight mountain system. In the case of the north-western ranges, the transition from the strongly curved outer ranges to the slightly curved inner ones is more rapid and distinct than in the Himalaya as will be clearly seen, for instance, in the case of the Sulaiman and its associated ranges. The convexity of the arcs is in all cases towards the rigid mass of the Peninsular shield and indicates the apparent direction of thrust.

Tibet.—The Tibetan plateau has an average altitude of 16,000 feet. To its north-west is the Pamir plateau (12,000 feet) which connects up with the Tien Shan plateau further north. The Tibetan plateau is now generally covered to a large extent by alluvium and loess. It has a large number of lakes which were formerly much more extensive and probably connected with some system of drainage. Now however, they are mostly brackish and are, together with the whole region, becoming desiccated, consequent upon the rise of the Himalayas which have

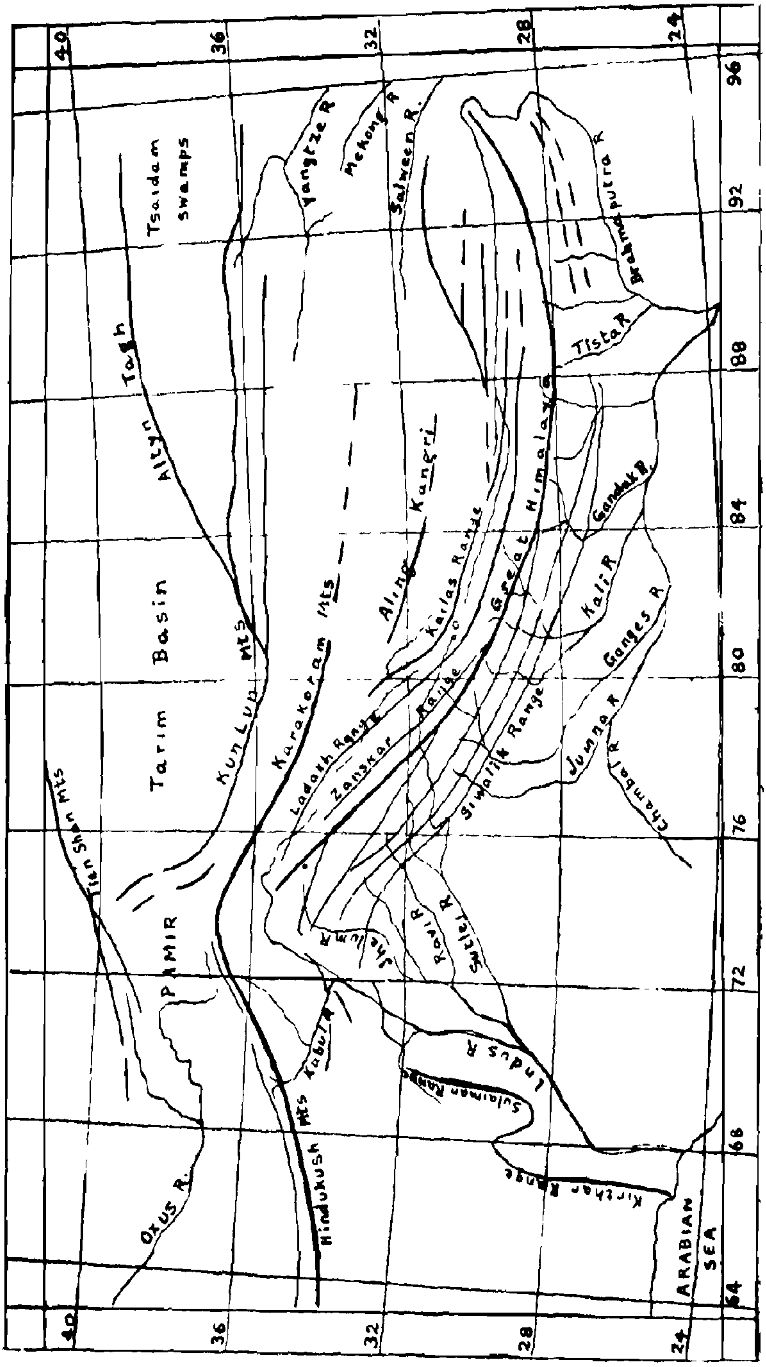
MAP I

THE MOUNTAIN ARCS OF SOUTHERN ASIA.



MAP II

HIMALAYAN AND CENTRAL ASIAN RANGES (AFTER BURRARD).



effectively shut off the moisture-bearing winds from the Indian Ocean.

Karakoram.—The Karakoram range forms, so to say, the back-bone of the Tibetan region and is continuous with the Hindukush range to its west. The Karakoram carries the peaks K² (28,250 feet), Gasherbrum (26,470 feet), Masherbrum (25,660 feet), etc. South of the Karakoram is a range of snow-clad mountains named Aling Kangri. How far to the east they extend is not known. Between Aling Kangri and the Kailas Range lies the Trans-Himalaya of Sven Hedin, the great Scandinavian explorer to whose explorations in Tibet we owe a great deal of our knowledge. This Trans-Himalaya region is the real watershed between the northerly drainage flowing into Tibet and the southerly drainage destined for the Indian Ocean.

Kailas and Ladakh Ranges.—Some distance south of the Trans-Himalaya is the Kailas Range, the latter being parallel to, and some 50 miles north of, the Ladakh Range. About 19 miles north of the sacred Manasarowar lake, the Kailas Range contains a cluster of peaks of which the chief is Mount Kailas (22,028 feet). South of the Kailas range comes the Ladakh Range which takes its name from the province of Ladakh in Tibet. This range, which can be followed from Baltistan to Eastern Tibet, forms the watershed between the latter and Nepal. To the west, it probably merges into the Haramosh Range on which the peak Rakaposhi (25,550 feet) is situated. The highest peak of the Ladakh Range is Gurla Mandhata (25,355 feet). There are several gaps in the Ladakh Range; one of them is traversed by the Sutlej; a second, some 15 miles wide, is seen south-west of Manasarowar; the third and largest is a gap 65 miles wide, north of Chomo Lhari, which is drained by the Nyang, a tributary of the Tsang-po. The Indus river is inextricably connected with this range for it first flows on the northern side of the range for 120 miles from its source, then crosses it to the south near Thangra, flowing W.N.W. for nearly 300 miles along the southern flank; the river again cuts across the range northward just before it is joined by the Shyok river.

The Zanskar Range.—This is really a northerly branch of the Himalaya lying between the Ladakh Range on the north and the Great Himalaya on the south. A good part of this range is unexplored territory. Its best known peak is Kamet (25,477 feet). The range is traversed by the Dras and the Zanskar rivers. There are several passes over this range, some of the well known ones being Dharma (18,000 feet), Kingri Bingri (18,000 feet), Shalshal (16,200 feet) and Niti (16,500 feet).

The Himalayas proper.—The Himalayas can be divided longitudinally into four zones, parallel to each other:—

1. *The Siwalik Zone* of foot-hills, 5 to 30 miles wide, whose altitude rarely exceeds 3,000 feet. This region is generally covered with a damp and unhealthy forest. The rainfall varies between 50 inches in the west to 100 inches in the east.

2. *The Lesser Himalayas*, a zone 40 to 50 miles wide, of an average altitude of about 10,000 feet. This consists of parallel ranges in the Nepal and Punjab region but of scattered mountains in Kumaon. In this are found remnants of the fringes of the old Gondwanaland. The zone between 5,000 and 8,000 feet is covered by evergreen and oak forests and that between 8,000 to 12,000 feet by coniferous forests. In the lower slopes are found *chir* (*Pinus longifolia*), *deodar* (*Cedrus deodara*) and the blue pine (*Pinus Excelsa*), whereas above 8,000 feet are found birch, spruce and silver fir.

3. *The Great Himalayas* or Central Himalayas, comprising the zone of high snow-capped peaks which are about 80 or 90 miles from the edge of the plains. This zone shows both sedimentary and old metamorphosed rocks which have been intruded by large masses of granite, probably of different ages. This consists of a

lower, alpine, zone up to 16,000 feet and an upper, snow-bound zone usually above 15,000 to 17,000 feet. The alpine zone contains rhododendrons, trees with crooked and twisted stems, thick shrubs and grass.

4. *The Trans-Himalayan Zone*, about 25 miles in width, containing the valleys of the rivers rising behind the Great Himalayas. These river basins are about 14,000 feet above the sea level and consist of rocks of the geosynclinal or Tibetan facies.

In the Darjeeling—Nepal region, the Himalayas have an E.—W. trend. To the east, the ranges have an E.N.E. or N.E. course, while to the west they first have a west-north-westerly course and then a north-westerly course. The main range throws off minor ranges (all on the convex side, except in one case) which first proceed in the original direction of the main range at the point of branching but gradually swing parallel to the main range.

Regional Description of the Himalayas.

The Himalayas have also been divided by Sir Sidney Burrard into four transverse regions, *viz.*, the Assam, Nepal, Kumaon and Punjab Himalayas.

The Assam Himalaya is the portion between the peak Namcha Barwa (25,445 feet) in the Mishmi country, situated where the Tsang-po makes a bend to cut across the mountains, and the Tista river, and is 450 miles long. The Kula Kangri group of peaks (24,784 feet) and Chomo Lhari (23,997 feet) occur in this portion. The Himalayas are known to continue beyond Namcha Barwa but though that portion of the country is little known, geological and structural observations indicate that they make a very sharp bend and turn southward to traverse through Burma. The Assam Himalaya rises very rapidly from the plains, the foothills region being narrow and the Sub-Himalayas comparatively lower than in other parts.

The Nepal Himalaya (500 miles long) is the portion between the Tista on the east and the Kali on the west and has on it the peaks of Kanchenjunga (28,146 feet), Everest (29,002 feet), Makalu (27,790 feet), Annapurna (26,492 feet), Gosainthan (26,291 feet) and Dhaulagiri (26,795 feet). The range throws off a northerly branch near Dhaulagiri.

The Kumaon Himalaya (200 miles long) is limited by the Sutlej river on the west. The best known peaks here are Nanda Devi (25,645 feet), Badrinath (23,190 feet), Kedarnath (22,770 feet), Trisul (23,360 feet), Mana (23,862 feet), Gangotri (21,700 feet), and Jaonli (21,760 feet). The southerly bifurcation here becomes the Dhauladhar Range. It is in this region that the Bhagirathi river takes its source in the Gangotri glacier.

The Punjab Himalaya (350 miles) is the portion between the Sutlej and the Indus. The Sutlej cuts across the Himalaya where it exhibits a curvature. A southerly branch, the Pir Panjal, is given off near this. The northerly main range carries few peaks exceeding 20,000 feet. The Zoji-La (pass) over this is only 11,300 feet high. The northern slopes of the range are bare and show high plains with lakes, while the southern slopes are rugged and forest-clad. The Punjab Himalaya is not cut across by any river. Topographically it culminates in the Indus valley just beyond Nanga Parbat (26,620 feet), but geologically and structurally its takes a sharp southerly bend and, traversing Hazara, apparently merges into the Safed Koh range of Afghanistan.

The Baluchistan Arc.—The ranges corresponding to the Himalayas and the foothills are to be found in the Black Mountains of Hazara, the Kala Chitta and Margala hills, the Salt Range, the Sulaiman Range, Bugti and Mari hills, Kirthar Range and the Mekran Ranges, these again sweeping westwards into the mountains of South Iran.

The Burmese Arc.—The Himalayas behave similarly at their eastern extremity. The outer zone is continued into the Patkoi, Naga and Lushai hills and the Arakan Yomas, and further on into the Andamans, Nicobars and the Dutch East Indies. Parallel to this curve are several other ranges in Burma and the Chinese frontier. The Central Himalayan Zone apparently extends into the Myitkyina region, the Shan States and Tenasserim, continuing further down into the Malay Peninsula.

GLACIERS.

Snow line and limit of Glaciers.—The 'snow line' or the lowest limit of perpetual snow and ice is at different altitudes in different parts of the Himalayas and associated ranges. In the Assam Himalaya the snow line is at about 14,500 feet or higher, whereas in the Kashmir Himalaya it varies from 17,000 to 19,000 feet. This is probably due to the scantiness of moisture in the region of the North-western Himalaya and Tibet. It is an interesting fact that in all the ranges north of the main Himalayas, the snow line is at a higher elevation on the southern than on the northern slopes, because the sun's rays affect the southern slopes more than the northern. But the reverse is the case in the Great Himalayas since the southern slope receives much greater precipitation than the northern and is also steeper, the slope helping the gliding down of the ice quickly to low levels. The glaciers also descend to lower levels in the Punjab Himalaya than in the Assam Himalaya ; this is due partly to the lower latitude and greater condensation of atmospheric moisture as rain (rather than snow) in the Assam Himalaya.

The glaciers are now confined to the higher ranges. The more important ones are valley-glaciers flowing through longitudinal valleys, and having large dimensions. The hanging glaciers along short transverse valleys are less important and more affected by variations of temperature, seasonal snowfall, etc.

The following glaciers may be mentioned as important :—

TABLE I.—LENGTH OF IMPORTANT GLACIERS.

Name	Location.	Length miles
Fedchenko	Trans-Alai	48
Siachen	Karakoram	45
Inylchek	Tien Shan	44
Koikaf	"	31
Hispar	Karakoram	38
Biafo	"	37
Baltoro	"	36
Batura	"	36
Rimo	Punjab Himalaya	25
Punmah	" "	17
Rupal	" "	10
Diamir	" "	7
Sonapani	" "	7
Gangotri	Kumaon "	16
Milam	" "	10
Kosa	" "	7
Kedarnath	" "	9
Zemu	Nepal "	16
Kanchenjunga	" "	10

The glaciers of the Himalayas and Central Asia have been studied by the Geological Survey of India as well as by many explorers among whom may be mentioned Montgomerie, Conway, Longstaff, De Filippi, Visser, Dainelli and others.

Many of the Himalayan glaciers are much smaller than those listed above, being generally 2 to 4 miles long. In the largest glaciers the thickness of ice amounts to hundreds of feet, *e.g.*, Fedchenko 1,800 feet; Zemu 600 feet ; Baltoro 400 feet. The hanging and transverse valley glaciers are small and have a more rapid movement than the longitudinal valley glaciers. The daily movement varies from 1 inch to 3 feet or rarely higher, depending on the topography.

Recession.—The Himalayan glaciers are definitely receding gradually. In many of them large amounts of moraine material cover the ice near the snout. During the summer they melt and the water escapes through crevasses forming englacial streams issuing out of tunnel-like caves.

The Himalayan rivers are to a large extent fed by glaciers. They also receive affluents from streams traversing the Sub-Himalayan region. The larger, snow-fed rivers are often full during the summer because of the water contributed by melting snow and ice.

The present glaciers are mere remnants of the extensive glaciation of the Pleistocene period when very large areas of the mountainous tract must have been covered by snow and ice. Terminal moraines are found at as low altitudes as 6,000 feet in the region of the Lesser Himalayas. These and other glacial features such as fluvioglacial deposits and filled-up glacial lakes suggest that the Pleistocene glaciation was very widespread in the Himalayas and extended to very low altitudes.

RIVERS.

The rivers of India can be divided into the Peninsular and Himalayan rivers, each group having fairly distinct characters.

Peninsular Rivers.—The chief rivers of the Peninsula are the Subarnarekha, Brahmani, Mahanadi, Godavari, Kistna, Penner, Ponnaiyar and Cauvery, and also the west-ward flowing Narbada and Tapti. On the northern border of the Peninsula the Chambal, Betwa and Son are important rivers. The Peninsular rivers have all reached the mature stage of development since their courses are well graded and the valleys broad. They are therefore tending to reach their *base level of erosion.* Their lower reaches are broad shallow valleys through which they meander, and the larger ones have well-developed deltas. In the upper courses of many of these rivers, however, there are cascades and waterfalls which point to some uplift of the Western Ghats which probably occurred at the time of the disruption of the Gondwanaland in Tertiary times. There is evidence in support of the uplift of the western margin of the Peninsula in the occurrence of Miocene rocks near Quilon, early Tertiary rocks near Surat and Broach and Pleistocene beach deposits in Kathiawar.

The Peninsular rivers all rise in the Western Ghats quite close to the Arabian Sea, the only two large rivers with westerly courses being the Narbada and Tapti. This remarkable behaviour of the Peninsular drainage is attributable to the fact that the present Western Ghats, or possibly even the part of the Aravallis now found as a submerged ridge off the western coast of India, represent an ancient watershed. The country to the west of the Western Ghats was, at an earlier geological epoch, probably quite as extensive as that to its east, but foundered beneath the waters of the Arabian Sea soon after the eruption of the Deccan trap lavas, by faulting along the present western coast.

Waterfalls.—There are numerous waterfalls in the Western Ghats, many of them small, only 20 or 30 feet high and generally found in the courses of the westerly flowing streams. The Jog Falls (Gersoppa) on the Sharavati river on the borders of Mysore and Bombay comprise four magnificent falls called Raja, Rocket, Roarer and Dame Blanche arranged on a curve and having a sheer drop of 850 feet. The Sivasamudram falls on the Cauvery, about 300 feet high, are well known since they were among the first falls in India to be harnessed for power. The Pykara falls in the Nilgiris are a series of cascades which have recently been utilised for hydro-electric power. The Gokak falls (180 feet) on the Gokak river are near Belgaum. The Yenna falls near Mahabaleshwar have a drop of 600 feet.

The rivers flowing westwards from the Western Ghats are all torrential and short and have built no deltas. Moreover, apparently they have not been in existence for a long enough period since the uplift of the Western Ghats to be able to build up deltaic flats. The eastern coast however has been in existence more or less in its present form since the Jurassic period, but there were marine incursions in the Cretaceous and in the Middle Tertiary; for we find a fringe of Jurassic and later sediments along parts of the eastern coast.

The Narbada and the Tapti are unique in flowing westwards. But there is evidence that their courses are determined by fault lines, as will be particularly noticeable from the extraordinary straightness of the middle portion of the course of the Narbada. There are some falls in the course of these rivers, the Dhurandhar falls near Jubbulpore being well known. The Narbada flows through a rock basin of Pleistocene and recent alluvium and there is evidence in its lower course that it flowed formerly towards the south-west in Kandesh and was joined by the Tapti. Since then, however, the two rivers have separated in their lower courses. The absence of an extensive delta at their mouths is probably due to the force of the south-west monsoon which carries away the sediments brought by them into the Gulf of Cambay.

Along the northern border of the Peninsula there are several rivers which flow from the Vindhyas and Satpuras. Of these the Chambal flows through Gwalior into the Jumna near Etawah; the Betwa flows through Bhopal and Bundelkhand into the Jumna near Hamirpur ; the Son rises from the Amarkantak plateau and flows south of the Kaimur range and joins the Ganges near Patna. This northerly drainage from the Peninsula was, during the Mesozoic and the early Tertiary period, very prominent and contributed much sediment to the northerly sea.

HIMALAYAN RIVERS.

Between the Indus in Hazara and the North-West Frontier Province and the Brahmaputra in Upper Assam, the Himalayas give rise to over 20 important rivers. Beyond the Himalayan region, the Indus is joined by the Kabul river and the Kurram river in the N.-W.F.P., whereas the Brahmaputra is joined by the Luhit and Dibang rivers in the north-eastern corner of India.

The major Himalayan rivers are all snow-fed and rise in the glaciers of the Great Himalaya or in the Trans-Himalayan region. Later they join together to form the three mighty systems—the Indus, Ganges, and Brahmaputra. The fact that the chief watershed is beyond the line of great peaks is generally cited as evidence in favour of the drainage being *antecedent,* or having been in existence before the main phase of upheaval of the Himalayas occurred. The courses of the rivers, where they cross the high range, are at right angles to the latter, *i.e.*, they have a radial disposition with reference to the Himalayan arc.

Several of the important rivers have cut deep gorges, which are stupendous chasms with perpendicular walls, the river bed being often some thousands of feet below the top of the range on either side. Some attribute this to the erosive power of the streams downward as the mountains rose upward. Others think that they represent big fissures or fault-lines which confined the streams to their course, as for instance the Alaknanda which traverses a fault. Others again think that some of these may have been formed by the bursting of dammed up bodies of water in the Himalayan valleys, the escape of the waters bringing about the formation of waterfalls and subsequently gorges.

There are several cases of the recession of the heads of streams in the mountains by the action both of the streams and the glaciers which feed them. This *head erosion* has, in some cases, led to the source going to the northern slopes of the Great Himalaya and capturing the drainage of other streams. An excellent example of *river capture* or *piracy* is furnished by the Kosi whose tributary the Arun drains the northern slopes of the Great Himalaya of Nepal region. Other examples are found in the Indus and Ganges systems. Rivers have also inherited the valleys of glaciers in many cases ; the tributary streams in these cases are often found in hanging valleys, the junction being marked by cascades or waterfalls. The hanging tributary valleys may be sometimes a few hundred feet above the valleys of the main streams.

THE INDUS SYSTEM.

Indus (*Sanskrit* : Sindhu).—The River Indus is the western-most of the Himalayan rivers, and its sanskrit name, which also means 'the ocean,' is probably in allusion to its appearance in flood time in its course through the plains of the Punjab and Sind, the latter province being named after the river. It is one of the mightiest rivers of the world, draining the mountain slopes of many famous peaks—Aling Kangri, Tirich Mir, Gasherbrum, Masherbrum, K^2, Rakaposhi, Nanga Parbat, Takht-i-sulaiman, etc., and flowing through the countries of a great variety of peoples and having as its tributaries a galaxy of great rivers. The sources of the Indus are in Tibet near Mount Kailas, where there are two tributaries, the northern one Singi Kampa draining the slopes of Aling Kangri, and the southern one Gartang Chu flowing by Gartok.

It flows along the inner flank of the Ladakh range for 180 miles, cuts across it southwards near Thangra and flows along the southern flank of the same range and again cuts through that range to the north near Skardu. Further west it bends around the Nanga Parbat and finally flows southward towards the plains. Its chief tributaries in the mountains are the Zanskar, Dras, Shyok, Shigar, Gilgit and Kabul rivers.

Jhelum (*Sanskrit* : Vitasta).—One of the sources of the Jhelum is at Seshanag at the head of the Lidar tributary. The river passes through the Wular Lake of Kashmir and after Baramula cuts across the Pir Panjal range, making a marked bend near Muzaffarabad and finally flowing southward. The chief tributaries are the Sind, Kishenganga and Kunhar rivers.

Chenab (*Sanskrit* : Asikni).—Its two tributaries at the source, the Chandra and the Bhaga, join together and form the Chandrabhaga near Tandi, which then flows in a north-westerly direction for about 100 miles. Then the river flows through Chamba cutting a gorge through the Pir Panjal near Kishtwar in Kashmir. It enters the plains at Akhnur near Jammu.

Ravi (*Sanskrit* : Iravati) is the smallest of the Punjab rivers, rising in a mountain knot in the Lesser Himalaya and draining the southern slopes of the Pir Panjal and the northern slopes of the Dhauladhar range. It leaves the Bangahal basin through an inaccessible gorge with perpendicular walls and flows through Chamba State and the Dhauladhar range. Lahore is situated on this river. In its course of 130 miles in the mountains, it drops 15,000 feet in altitude.

Beas (*Sanskrit* : Vipasa) rises in the Pir Panjal near the source of the Ravi. It cuts through the Dhauladhar range and flows through Kulu, Mandi and Kangra.

Sutlej (*Sanskrit* : Satadru) is remarkable in that it has no tributaries of importance and is confined, in the Himalayan region, to a narrow trough 20 miles wide between the basins of the Beas and the Giri (Jumna). It rises beyond the Great Himalayas in the lake Rakas Tal which is supposed to be connected underground with lake Manasarowar. Numerous glaciers of Ganglung Gangri, Kailas, Kamet and Riwo Phargyul flow into the river. It flows north-westward in the plateau of the Province of Ngari Khorsam (15,000 feet altitude) through a thick mass of soft sediments. The river and its several tributaries have cut deep *canyons* through these sediments, the beds often lying 1,000 feet or more below the surface, this being due to the aridity of the region.

Near Shipki the river passes through a narrow gorge, 10,000 feet in altitude, in the Zanskar range within 4½ miles of the peak of Riwo Phargyul (22,210 feet). Ten miles below Shipki the right bank of the Sutlej rises as a sheer perpendicular wall 7,000 feet high. Its main tributary is the Spiti river which flows in a deep bed below the level of the alluvial terraces. The Sutlej becomes a torrential river from its confluence with the Spiti to the plains. It crosses the Dhauladhar range near Rampur through a narrow gorge and is deflected in its course by the Siwalik ranges. The deflection by the Siwalik ridges and the narrowness of its trough between the basins of the Beas and Giri, and the higher altitude of this trough as compared with those on both sides, probably point to this river being younger in age than several others.

The Sutlej is believed to have flowed straight out through Patiala and Bikaner to the sea but deflected westwards a few centuries ago by the advancing deserts of Rajputana.

THE GANGES SYSTEM.

The Jumna (*Sanskrit*: Yamuna) rises in the region of Jumnotri or Bandarpunch (20,720 feet). Behind the Mussoorie hills, the Jumna is joined by the Tons river which drains the area between Bandarpunch and Chor peak. The river then cuts across the Mussoorie hills and a little further down is joined by the Giri river which drains the area between Simla and the Chor peak. On leaving the hills it turns eastwards to join the Ganges at Prayag (Allahabad) but is said to have flowed straight out to the Arabian Sea in former days. A small river, known as the Saraswati and thought to be the *remnant* of the Saraswati river of the Vedic times, still flows in the plains some 20 miles west of the Jumna, near Thaneswar, and is lost in the Rajputana desert.

4

Ganges (*Sanskrit* : Ganga).—The many tributaries of the Ganges drain the area between Bandarpunch and Nanda Devi, some of them rising well beyond the Great Himalayan range. The feeders of the Ganges have been thoroughly explored by ancient Aryan explorers long before the Christian era and many of the sources are places of pilgrimage for the Hindus.

The two main tributary rivers are the Alaknanda and the Bhagirathi. The feeders of the Alaknanda are the Dhauli rising in the Zanskar range and coming through the Niti pass and the Vishnuganga rising on Mt. Kamet near the Mana pass. These two join at Joshimath (Vishnuprayag). Between Nanda Devi and Badrinath is the gorge of the Alaknanda through the main range. The Pindar river, coming from Nanda Devi and East Trisul, flows westward and joins the Alaknanda at Karna-prayag, and a little further west is the junction with the Mandakini just to the south of Badrinath and Kedarnath. This junction is the Rudraprayag. The junction of the Pindar with the Nandakna on the western slope of Trisul is Nandaprayag.

The main western tributary, the Bhagirathi, rises in the Gangotri glacier behind Kedarnath at a point called Gaumukh (13,000 feet high). The Jahnavi, the westernmost of the system, rises some distance north of the main range and joins the Bhagirathi 7 miles below the sacred Gangotri shrine, which lies 18 miles below Gaumukh. The Bhagirathi, after its confluence with the Jahnavi, cuts through the Central range between Bandar-punch (20,720 feet) and Srikanta (20,120 feet), the river bed being 13,000 feet below the level of the peaks. The Bhagirathi gorge is just a slit-like opening in the rocks with practically vertical sides.

The Alaknanda and Bhagirathi join together at Deoprayag (Devaprayag) north of the Mussoorie range and issue through a defile in this range.

Kali.—This river rises in the Milam glacier (12 miles long) at the head of the Gori Ganga, and the Lipu Lekh and other sources, all a little east of Nanda Devi. The eastern border of this basin is formed by the Api Nampa peaks (23,399 feet). The three main affluents, the Kali, Lissar (the lower part of which is the Dharma) and the Gori have parallel S.S.E. courses in their upper reaches, and all rise beyond the Great Himalaya. Between the Dharma and the Gori is the Peak Takachull (22,661 feet). The Sarju (Sarayu) flows south-eastwards in a line with the Pindar tributary of the Ganges further west.

Ramganga drains the southern face of the Lesser Himalayas of Kumaon between the Ganges and Kali basins. Its principal tributary is the Kosila which however joins the Ramganga only in the plains.

Karnali.—This river has the name Kauriala in the outer hills and Gogra in the plains. Its north-western sources reach a little north and west of Gurla Mandhata (25,355 feet) and just south of Manasarowar. In this region its basin is quite close to that of the Sutlej. After flowing southeast for some distance it breaks through the main line of peaks and flows S.S.W. It has a remarkable hair-pin bend at latitude 28° 40′: longitude 81° 30′. It is joined from the west by the Seti river rising just east of the peak Api and after another sharp bend it flows eastward and is joined by the Bheri. The Karnali in its upper course drains the whole of the Trans-Himalayan watershed, 200 miles long, between Gurla Mandhata and Diji pass, by two affluents, one flowing E.S.E. and the other W.N.W. to meet in the middle.

Gandak (*Sanskrit*: Sadanira) is known in Nepal as the Saligrami because it brings down large quantities of *Saligrams* (ammonite fossils) and in the outer hills as the Narayani. It drains the area between Dhaulagiri and Gosainthan. Its chief tributaries have cut through the Great Himalaya. The western tributary, the Kali Gandak, rises in the trough between it and the Ladakh range, traverses the Muktinath plateau and flows between Dhaulagiri and Annapurna-I peaks. The eastern ones are the Marsyandi, the Buri Gandak and Trisulganga. Just north of the Mahabharat range they all flow east-west and unite before breaking through that range.

Kosi (*Sanskrit* : Kousika) drains the area between Gosainthan and Kanchenjunga. Its tributaries are the Indravati, Bhote Kosi, Tamba Kosi, and Dudh Kosi. These four drain the crest of the Great Himalaya between Gosainthan and Everest (with Gaurisankar in the middle) and join together to form the Sun Kosi which flows parallel to the Mahabharat Lekh. The Bhote Kosi and Tamba Kosi have cut back some distance through the Central ridge. To the east of these are the Arun and the Tamur Kosi, the latter draining the western slopes of Kanchenjunga. The Arun is remarkable for it drains the trough north of the crest between Gosainthan and Kanchenjunga and has cut a great gorge through the main range east of Everest and Makalu. The Arun is called Phung Chu in Tibet. These join the Sun Kosi and the combined river breaks through the Mahabharat range.

THE BRAHMAPUTRA SYSTEM.

Tista (*Sanskrit* : Trisrota or Trishna) is the major river of Sikkim and rises east of Kanchenjunga. It flows east of Darjeeling into the plains where it is known to have changed its course several times.

Bhutan rivers.—Between Chomo Lhari and the Kula Kangri peaks are three independent rivers, the Amo Chu, Raidak and Sankosh, all of which flow into the plains independently and join the Brahmaputra.

Manas.—The Manas rises to the north and east of the Kula Kangri peaks and is composed of several affluents. The Lhobrak affluent rises on the north-west slopes of Kula Kangri and cuts through the main range by an impassable gorge.

Subansiri.—The sources of the Subansiri of Upper Assam are not well known. It probably drains both the northern and southern slopes of the main range and traverses it by gorges. It divides the Miri hills from the Abor hills in the outer Himalaya.

Brahmaputra.—The Tsang-po rises near the sources of the Sutlej and the Karnali near Manasarowar at a height of 16,000 feet. Its channel in Tibet is said to be rather shallow and navigable, lying in the trough between the Great Himalaya and the Ladakh range. Several of its feeders on both sides flow in an opposite (*i.e.*, westerly) direction to meet it, so that some authorities hold that this river originally flowed westwards. The Tsang-po portion, that between the source and its sharp turn around Namcha Barwa, is about 1,000 miles long. Its course across the Himalaya from Namcha Barwa southward is called the Dihang, and after it emerges into the plains it is called the Brahmaputra.

In the Sadiya frontier tract, the Brahmaputra is joined by the Dibang coming from the north-east and by the Luhit (or Zayul) which comes from the east and drains a large area between Assam and Burma.

RECENT CHANGES IN INDIAN RIVERS.

Indus.—In Rajputana, the Punjab and Sind, the desert is continuously encroaching on the river valleys. The ancient centres of civilisation like Harappa and Mohenjo Daro must have been located near large rivers but now lie buried beneath sands probably as a result of repeated floods. In the Lower Indus valley and the delta many prosperous cities have been flooded out and destroyed.

It is known that formerly the Sutlej and Jumna flowed out through Rajputana. The lost river, the Saraswati of Hindu tradition, was probably the river which occupied the bed of what is now Sotar or Ghaggar flowing past the neighbourhood of Nahan. The Jumna used to flow westward from Karnal north of Delhi. Both these combined together near Suratgarh in Northern Bikaner and formed the Hakra which flowed south-westward straight to sea, *i.e.*, into the Rann of Cutch. The Sind portion of this river was probably the present dry bed of the East Nara.

The Sutlej was also a separate river, flowing independently of the Indus in the early years of the Christian era. Whether it flowed into the Ghaggar is not known. But it now joins the Beas. Its old channel is said to be still recognisable between Sirsa and Umarkot.

The Rajputana desert is of very recent origin. The Rann of Cutch must have formerly extended northwards and Rajputana must have been a wooded and fertile land two or three thousand years ago.

Ganges-Brahmaputra.—Barely 200 years ago, the Ganges and Brahmaputra were separate rivers, 150 miles apart. Then the Brahmaputra flowed east of the Madhupur jungle and joined the Meghna east of Dacca. The Ganges flowed through Gour, Nadia and Chinsurah. There was a third river (? Tista) which apparently flowed down to the south between the above two.

Pataliputra, a great city of the Ganges valley for nearly 1,000 years till the fifth century A.D., is said to have been located near the junction of five great rivers—the Ganges, Sone, Ghogra, Gandak and Punpun. It was destroyed and buried by floods and now lies under the city of Patna.

Gour was a great city at the head of the Ganges delta between the fifth and sixteenth centuries. The formation of a swamp around the city caused a great epidemic in the year 1575 and a large part of the population perished.

The Brahmaputra changed its course from east of the Madhupur jungle to the one west of the jungle only about a century and a half ago. The Tista formerly used to flow into the Ganges but now joins the Brahmaputra.

RIVERS OF BURMA.

The chief rivers of Burma are the Irrawaddy, Chindwin, Sittang and Salween.

The Irrawaddy rises in Upper Burma about 29° N. latitude and has a drainage basin of 160,000 square miles. Yet it is an immense river when in flood. Its two tributaries are Nmai Hka and Mali Hka whose confluence is about 60 miles above Myitkyina. There are three narrow portions or defiles along the course, the first below Sinbo, the second below Bhamo, and the third near Thabeitkyin near the Ruby Mines district. The river is however navigable up to Bhamo. It flows through Mandalay and then Pakokku where it is joined by the Chindwin. Below this junction is the dry belt of Burma and the course runs through sandstone country amidst its own older terraces. It is thought that the river entered the sea near Prome about a third of a million years ago, *i.e.*, at the end of the Tertiary era, and that the delta below Prome has been built up since.

The river system is of Tertiary age, the lower portion being of post-Pegu age. Its chief tributaries are the Nam-tu and Chindwin. The Nam-tu is the chief river of the Northern Shan States, rising within a short distance of the course of the Salween in latitude 23° 20′ N. Its course south of Meng-tat is through a deep narrow valley. It is joined first by the Namma and further down by the Namhsin. The course, after being joined by the latter river, is through a deep gorge (Gogteik gorge) where a succession of rapids and pools is seen, and in which the stream may be 2,000 feet below the top of the hills at the sides. After receiving the waters of the Nam-Hka and Nam-panshe, it leaves the hills about 14 miles to the south-east of Mandalay. The course of the river is entirely in the Plateau Limestone. There is abundant evidence that this river has captured its tributaries by head erosion.

The Chindwin river rises at latitude 25° 40′ N. and longitude 97° E. first flowing northwards and then north-westward through the Hukawng valley and turning southward. In the Hukawng valley its tributaries are the Taron and Tawan Hka. It then flows through a rocky gorge and joins the Irrawaddy near Pakokku. The Uru river which flows through the jade mines tract is also a tributary of the Chindwin. It is interesting to note that the Lower Irrawaddy is the direct continuation of the valley of the Chindwin and that the former inherited this portion from the latter.

The Sittang rises in the Yamethin district and flows north for some distance before taking on its southerly course. There appears to be some support for the view that this river course was formerly that of the Lower Irrawaddy. As the greater part of the course is a low plain, the river meanders a good deal.

The Salween rises in the Tibetan mountains to the west of the head-waters of the Mekong and Yang-tse-Kiang all of which have parallel courses there in proximity to each other. The Salween is a wild river, for its course through the Shan States is marked by gorges. In the early part of its course it runs parallel to the Irrawaddy and the Mekong. It receives several tributaries in Yunnan and in the Shan States. The river seems to traverse Archæan and Palæozoic rocks throughout its course. It joins the sea through two branches, one to the west of Moulmein and the other several miles south of Moulmein.

The narrowness of the drainage basin of the Salween is noteworthy. It is probable that some of its tributaries have been captured by the other parallel rivers. Throughout its course, this river shows extraordinary vitality which has helped to carve its deep gorges.

GEOLOGICAL ACTION OF THE RIVERS.

The Peninsular rivers are entirely rain-fed so that they are full only during and immediately after the south-west monsoon, *i.e.*, from June to October. They are fairly active in their upper reaches where they generally flow over a rocky bed and actively erode the bed and banks. They have built deltas near their mouths where they deposit the load of silt carried from above. The delta regions are frequently liable to floods where the distributaries are silted up and are not kept in trim for carrying away the surplus waters. The deltas of the Godavari, Kistna, Mahanadi and Cauvery are rich agricultural tracts and they are gradually reclaiming land from the sea as is proved by the fact that places which were used as ports for sailing ships a few centuries ago are now some distance inland. The Narbada and Tapti have, however, not built up extensive deltas, the reason being that their deposits are moved away by sea-currents especially with the aid of the monsoon winds.

Compared to the Peninsular rivers, the three main Himalayan river systems are mighty giants. The Indus carries to the sea an average of about a million tons of silt per day, the Ganges a little less and the Brahmaputra a little more. The Irrawaddy has been estimated to transport about two-third million tons of silt per day. The Himalayan rivers are fed both by rain and snow, by rain during June to September and by snow during the warmer half of the year. In their courses through the mountains they have good gradients and carry much coarse materials including pebbles and boulders, brought in by glaciers and also torn off from the beds and banks. Much of the coarse material is deposited near their debouchure into the plains. They carry enormous quantities of fine sand and silt in their course through the plains, derived from the Himalayas as well as from the higher peninsular up-lands. The aggrading action is confined mostly to the lower reaches of the rivers and the deltas.

The Himalayan rivers are liable to big floods not only in the upper mountainous part of their courses, but also in the deltas. In the hills, barriers are often formed across the channels by the deposition of rocky matter or by landslides of hills which dam up large amounts of water until the barrier is burst when the pressure of the upstream side is able to overcome the obstacle. Such dams are known to have impounded huge bodies of water, several square miles in extent and hundreds of feet deep, in mountain valleys. Instances of disastrous floods of this character have been recorded in the case of the larger rivers—Indus (1841, 1858), Shyok (1924, 1930), Sutlej (1819), Alaknanda (1893), etc.

The floods in the lower reaches are brought about by exceptional rainfall in a short period of time when the river channel is unable to cope with the enormous run-off and spills over the banks, flooding the whole countryside with a huge sheet of water. With the steady deforestation of the river basin, percolation through the soil is diminished and run-off increases, establishing conditions favourable for floods. Such floods are of so frequent occurrence in various parts of India that special mention of individual floods is scarcely necessary.

LAKES.

Peninsula.

For a country of the dimensions of India, lakes are of infrequent occurrence and are of no great importance in the drainage system.

In the Peninsula there are a few lakes which represent natural depressions in the surface or obstructed drainage courses. The Malabar Coast contains several bodies of sea water more or less cut off from the sea by bars or spits. Similar in origin are the Pulicat lake near Madras and the Chilka lake on the Ganjam Coast.

Ponds of various dimensions, all of which have been artificially dammed up for water supply and irrigation are found all over the Peninsula but they are of no interest to geologists.

Rajputana Lakes.—There are three or four salt lakes in Rajputana typified by the Sambhar lake. They represent depressions in an arid country, receiving inland drainage, the outlet having been obliterated by advancing desert sands. The saline character of the Sambhar lake is not only due to excessive evaporation but also to the particles of salt and saline mud blown into Rajputana from the Rann of Cutch by the monsoon winds, as pointed out by Holland and Christie (*Rec.* 38, 154-186, 1909). This windborne saline matter is dissolved by the scanty rainfall and concentrated in the lakes. From experimental data, Holland and Christie have calculated the amount of salt brought into Rajputana along a front 300 km. broad and 100 metres high, during the four hot weather months as about 130,000 tons. The Sambhar lake when 'flooded' during the monsoon is a shallow sheet of water covering an area of 90 square miles. Most of this is evaporated during the dry months and the saline efflorescence in the bed is collected and purified. The mud of the lake bed is known to be highly saline for a depth of several feet from the surface.

Dhands.—There are several small alkaline lakes in Sind, called 'Dhands,' occurring in depressions amidst sand hills. Their waters contain different sodium salts.

Lonar Lake.—A great circular depression amidst the Deccan traps of the Buldana district in Berar is occupied by a shallow lake. It is about a mile in diameter and nearly 300 feet deep below the level of the surrounding country. In the hot weather the water in the lake practically disappears and yields encrustations of sodium carbonate (urao) with some sodium chloride. The mud at the bottom is also heavily impregnated with salt.

This circular depression is either a crater-lake or more probably represents a subsidence of a tract along circular fractures due to the emptying of lava and gases below, at a late stage of the Deccan trap activity.

The Kallar Kahar on the northern slopes of the Salt Range in Jhelum district, the *Khabaki Kahar*, *Khotaka*

Kahar, *Son-Sakesar* and *Jalar kahar* in the Shahpur district are all saline lakes apparently of tectonic origin.

EXTRA-PENINSULA.

Tibet.—The Tibetan basin amidst the high mountains of Asia contains a large number of lakes of which the largest is the Issik Kol (2,000 square miles) in the Tien Shan area, while the largest in Tibet is Koko Nor (1,630 square miles). The Tibetan and Tarim basins are now areas of inland drainage. The Tsaidam depression in Tibet is a dry lake basin having an area of 12,000 square miles at an elevation of 9,000 feet. It is now really a salt desert. It is thought that many of the Tibetan lakes have been formed by obstruction to river valleys by moraine material or in some cases possibly by earth movements. The desiccation dates from the time of conversion of the Tethys into a mountainous region. Lake terraces are often found in Tibet some hundreds of feet above the present water level.

The Tibetan region is now completely cut off on all sides from moisture-bearing winds so that its interior is becoming steadily arid. In the mountains on its borders, however, rise the great rivers of Eastern and Southern Asia.

In southern Tibet are the Manasarowar (200 square miles) Rakas Tal (140 square miles) and Gunchu (40 square miles); in south-eastern Tibet, south of the Tsangpo, are Yam drok (340 square miles), Trigu (51 square miles) and others. In the Himalayas there are many lakes of comparatively small dimensions, such as Khewan Tal, Naini Tal, Bhim Tal, Wular, Dal, Tso Morari, etc. The Himalayan lakes are probably attributable to different causes such as the damming up of the valleys by moraines or tributary streams, scooping out of part of the basin by glaciers, or the rise of parts of the river bed. Some of the Kumaon lakes are said to be due to the subsidence of the floor by the solution of underlying rock.

The Wular lake through which the Jhelum flows and the Dal lake near Srinagar, in Kashmir, are remnants of much larger lakes formed by the deposition of alluvial dams across their outlets. Of perhaps similar nature is the Manchhar lake near Sehwan in Sind, which is shallow and attains an area of 200 square miles during the monsoon. The lakes in Baluchistan and Mekran exhibit the characters of bodies of water in arid and desiccating regions.

LAKES IN BURMA.

As in India, there are very few lakes of importance in Burma. These include the Indawgyi and Indaw in the Katha and Myitkyina districts, some crater lakes in the Chindwin district, and ponds of various sizes in the alluvial area.

The Indawgyi lake in Myitkyina is 16 miles long and 7 miles broad with a superficial area of about 80 square miles. It has an outlet to the north in the Indaw stream, and occupies a depression amidst the hills which may be of tectonic origin. The Indaw lake in Katha district is probably also of tectonic origin.

The Inle lake in Shan States lies at an altitude of 3,000 feet between two ranges of hills. It has considerably silted up in historic times, as have several other lakes in the Shan plateau. It is 14 miles long and 4 miles broad but even when full is only about 20 feet deep. In the dry season the depth is on an average 7 feet, and the bottom is overgrown with weeds. Its margin is marshy and full of vegetation. Its origin is attributed to the sinking of land by the solution of limestone below the bed. Several other areas in the Shan States, now covered with thick alluvial deposits, point to the fact that they were all once lakes.

In the dry zone of Burma, particularly in the Sagaing and Shwebo districts, there are several saline lakes, all of small extent and a few which could yield brine for the manufacture of common salt, sodium sulphate, etc., during the dry season.

There are some 7 or 8 craters or hollows formed by volcanic explosion along both sides of the Chindwin river near Shwezaye. Some of these contain permanent water, while others are dry and may be cultivated for part of the year. In the Twindaung crater, two miles N. E. of Shwezaye, the water-level is over 300 feet below the rim of the crater and the water is said to be about 70 feet deep. The Taungbyauk crater is half a mile in diameter and 200 feet deep, and the bottom is only partly covered with water derived from springs at the sides. The Twin lake is the southern-most of the group. The crater is three-quarters of a mile in diameter, 150 feet deep and has a shallow lake at the bottom, the body of water being about half a mile across.

In Lower Burma the lakes are mainly depressions in the alluvium, or obstructed drainage channels. The Daga lake in Bassein is an elliptical lake 2$\frac{3}{4}$ miles long, 1 mile wide and 20 to 45 feet deep. It is considered to be an unfilled bend of the Irrawaddy river. The Imma (Engma) lake in Prome and the Htoo and Doora lakes in Henzada occupy abandoned courses of the rivers. These attain their largest extent during the rains and become mere marshes in the dry weather. There are several other, similar, but less important lakes in the delta region of the Burmese rivers.

EARTHQUAKES.

Earthquakes occur in regions of marked instability, such as orogenic zones. Such a region, *par excellence*, is the zone of the Himalayan and connected arcs around India's northern borders, which have been, during the Tertiary times, folded, faulted and overthrust. The instability appears to be greatest in the Tertiary belt and at the junction of the Tertiaries with the older rocks, for this belt has yet to attain complete equilibrium. It is also interesting to note that seismicity is marked where wedge-like masses of the old rocks have opposed the advance of the folds towards the shield area. Such areas are the syntaxial bends of the arcs in the north-east beyond the Sadiya region on the Chinese border ; in the north-west in the Kashmir—Gilgit—Pamir region ; near Quetta ; near the northern end of the Sulaiman Mountains in Waziristan.

The Assam plateau is of the nature of a block uplifted between two opposing movements, one from the north from the Himalayas and the other from the east and south-east from the Patkoi and Naga hills. The southern border of this block is marked by the composite Haflong-Disang fault along which the Tura Range region has been over-thrust southwards and the Patkoi region overthrust north-westwards, the intervening portion being a normal fault or a fold. The northern border is also apparently faulted. In addition there is a series of well-marked cross-faults trending in a N.—S. direction which have cut up the plateau into slices arranged *en echelon*. These various faults are the loci of seismic disturbances at the present day.

The Indo-Gangetic alluvial tract is one of occasional seismicity. As it is a depression filled up by soft unconsolidated alluvium it suffers from excessive vibrations set up by every strong earthquake on its borders. Secondly, it is not unlikely that its floor, which represents a sag in the crust of the earth, is fractured and movements are taking place therein. Though we do not know the structure of the alluvial tract in detail, the Bihar earthquake of 1934 and the Cutch earthquake of 1819 had their foci in the alluvial tract, and the Bihar earthquake has been attributed to possible movement connected with fractures in the floor of the valley beneath Motihari and Monghyr.

The Peninsular block is a region of comparative stability, as may be expected from its great geological antiquity. But it is known to be cut up by a large number of faults resulting from tension in the crust. The earthquake shocks experienced in the Peninsula are generally quite feeble. Sometimes when severe earthquakes occur in northern India, sympathetic shocks are felt in some places in the Peninsula ; for example the Bihar earthquake of 15th January, 1934, gave rise to a minor shock on the south-west coast at the same time. The reason for this sympathetic behaviour between these is, however, obscure. For a recent discussion of the structure of India with reference to seismic phenomena, the reader is referred to W.D. West's address to the Geology section of the twenty-fourth Indian Science Congress. A good summary of an earlier date is to be found in the monograph by Count Montessus de Ballore in the Memoirs of the Geological Survey of India (Vol. 35) and a descriptive catalogue of early earthquakes by Dr. T. Oldham in the same series (Vol. 19). Individual earthquakes of recent times are described in memoirs and papers published by the Geological Survey of India of which a selection will be found in the bibliography at the end of the Chapter.

VOLCANOES.

Though Tertiary volcanism has been fairly widespread in the Himalayas, Burma and Baluchistan, recent volcanic activity is known only in the Barren Island and Narcondam in the Burmese arc and in the Nushki desert in Baluchistan.

Barren Island has the shape of a cone which is surrounded by an encircling ring of a former crater. It occupies an area of a little over 3 square miles and the ridge is 600 to 1,100 feet high, the central cone rising to 1,015 feet above sea-level. The lava-flows consist mainly of basalt and augite-andesite, with intercalations of ash and pyroclastic materials. It was seen in actual eruption in 1789, 1795 and 1803 ; since then it has been dormant.

Narcondam (Naraka-Kundam) on the same alignment, is apparently an extinct volcano, which was probably active in the Pleistocene. Its crater has been worn down and its lavas are hornblende-andesites and dacites.

Barren Island and Narcondam are the crests of a deeply submerged ridge lying east of and parallel to the Arakan—Andaman—Sumatra arc. This ridge is bordered by deep troughs on both sides.

Further north in the Central belt of Burma there is evidence of Pliocene and Pleistocene activity in Mount Popa, Shwebo, Mandalay and Lower Chindwin districts, Jade Mines area and South Yunnam. It is not known whether any of these were active during historic times.

At the other end of India, in the Baluchistan desert, is the Koh-i-Sultan which is also an extinct volcano. Further along the same alignment is the Koh-i-Taftan in Iran which is said to be still active. The lavas are of andesitic type and intercalated with ash-beds. The Solfataras of Koh-i-Sultan deposit sulphur as do those in the Barren Island.

MUD VOLCANOES.

Mud volcanoes are not volcanoes in the true sense but are merely accumulations of mud in the form of crater and cone due to the eruptive power of hydrocarbon gases in petroliferous strata They vary in size from small mounds to hillocks 30 or 40 feet high, and rarely much larger. Some have the shape of basins with a central vent while others are like volcanic cones. They usually erupt soft liquid mud gently, but in rare cases rather violent eruptions of thick mud and fragments of rocks are known. Mud volcanoes seem to be more active during the rains, perhaps because rain-water helps to soften the mud and thus lessens the pressure on the imprisoned gases. A small difference in temperature between the atmosphere and erupted mud is sometimes recorded. This may be due merely to the depth from which the mud comes or to oxidation of the hydrocarbons escaping to the surface. The ordinary temperatures observed are between 85° and 100° F.

Mud volcanoes occur in Burma on either side of the Arakan Yoma. The eastern group comprises those in Minbu, Prome and Henzada districts and the western group those on the Arakan coast and especially in the Ramri and Cheduba and other islands and near Cape Negrais. They grade from *basins* on the one hand to *cones* on the other, the type being apparently controlled by the viscosity of the mud and the energy of eruption. In the basin type the gas escapes as bubbles from a muddy pool, which may have various degrees of permanence. The type which produces cones ejects thick mud and the ejection of gas is much more forceful than in the other type. The cones are often perfect miniatures of volcanic cones, and attain heights of 40 or 50 feet. Parasitic cones, craters, mud flows, explosions, intermittent activity, rumbling sounds, etc., are all phenomena which have parallels in true volcanism.

In the Arakan group, the mud volcanoes of Ramri are the best known. The diameter of the cones varies widely, up to 200 or 250 yards. The eruptions consist of methane and other hydrocarbon gas, petroleum, saline matter (sodium chloride and sodium and calcium sulphates), mud and fragments of rock from the strata underlying the locality. The more violent eruptions tend to be periodical as in the case of geysers. The gases evolved sometimes burn spontaneously. The Cheduba eruption of January 21st, 1904, had a duration of 45 minutes and is said to have been the most violent known in recent times. Submarine eruptions of the same type are known along the Arakan coast, these occasionally producing mud banks.

Mud volcanoes are known to erupt at times of earthquakes if they happen to be in the affected zone. The disturbance in the crust producing earthquakes should naturally be expected to favour the eruption of gases in mud volcanoes.

In and around the oil fields of Burma there are mud volcanoes, which are undoubtedly related to the occurrence of petroliferous strata, and occur on the anticlinal structures. In some of the oil fields, fissures in the sandstones are noticed to have been filled with clay. These fissure-fillings are of all dimensions, with thickness ranging up to about 10 inches, and running in all directions. These are to be explained as due to the liquid mud forced out from beneath, filling up joints and fractures in the dominant sandstone strata of the oil fields.

Mud volcanoes are also seen at the other end of the Himalayan mountain arcs, in the Mekran coast of Baluchistan. The region being dry, the cones attain much greater heights (200 to 250 feet) than in Burma, where they tend to be destroyed by rain.

SELECTED BIBLIOGRAPHY.

GENERAL REFERENCES

Medlicott, H B. and Blanford, W T. Manual of the Geology of India, 4 Vols Calcutta, 1879-1887

Oldham, R.D. Manual of the Geology of India (Second edition) Calcutta, 1893.

Wadia, D.N. Geology of India for students. London, 1939.

Fox, C.S. Physical geography for Indian students. London, 1938.

Holland, T H. Geology of India (Imperial Gazetteer of India, Vol. I, Ch 2), 1904.

Chhibber, H.L Geology of Burma. London, 1934.

Vredenburg, E. Summary of the Geology of India. Calcutta, 1910.

Burrard, S G., Hayden, H.H. and Heron, A.M. Geography and geology of the Himalaya Mountains and Tibet (2nd edition) Dehra Dun, 1932

GLACIERS.

Grinlinton, J.L. Glaciers of the Dhauli and Lissar valleys. *Rec 44*, 289-335, 1914.

Grinlinton, J L. Former glaciation of the E Lidar valley. *Mem 49*, Pt 2, 1928.

Hayden, H H. *et al.* Notes on certain glaciers in Kashmir, Lahaul and Kumaon *Rec.* 35, 123-148, 1907.

La Touche, T.D. Notes on certain glaciers in Sikkim. *Rec. 40*, 52-62, 1909.

RIVERS.

Medlicott, H.B. Sketch of the Geology of the N.W. Provinces (now U.P.) *Rec. 6*, 9-17, 1873.

Carless, T.G. Memoir to accompany the survey of the delta of the Indus. *Jour. Roy. Geog. Soc. 8*, 328-366, 1838.

Cunningham, A. Memorandum on the Irawadi River. *Jour As. Soc. Beng. 29*, 175-183, 1860.

Cunningham, A. Ancient geography of India. London, 1871.

Ferguson, J. Delta of the Ganges. *Q.J.G.S.* (London) *19*, 321-354, 1863.

Krishnan, M.S. and Aiyengar, N K.N. Did the Indobrahm or Siwalik river exist? *Rec. 75*, paper 6, 1940.

Oldham, C.F. The Saraswati and the lost river of the Indian desert. *Jour. Roy. As. Soc. N.S. 25*, 49-76, 1893.

Oldham, C.F. Notes on the lost river of the Indian desert. *Cal. Rev. 59*, 1-27, 1874.

Oldham, R.D. On probable changes in the geography of the Punjab and its rivers. *J. A. S.B. 55*, 322-343, 1886.

Pascoe, E.H. The early history of the Indus, Ganges and the Brahmaputra. *Q J.G.S.* (London) *75*, 138-155, 1919.

Pilgrim, G.E. Suggestions concerning the history of the drainage of Northern India, arising out of a study of the Siwalik Boulder Conglomerate. *J.A.S.B., N.S 15*, 81-101, 1919.

Rennell, J. An account of the Ganges and Burrampooter Rivers. *Phil. Trans. Roy. Soc.* (London) *71*, 87-114, 1781.

Rennell, J. Memoir of a map of Hindoostan. London, 1788 (3rd edn. 1793).

——Physical geography of Bengal, from maps and writings of Major J. Rennell. Calcutta (Bengal Govt.) 1926.

LAKES

Holland, T.H. and Christie, W.A.K. Origin of the salt deposits of Rajputana. *Rec. 38*, 154-186, 1909.

La Touche, T.D. Lakes of the Salt Range, Punjab, *Rec. 40*, 36-51, 1909.

La Touche, T. D. Geology of the Lonar Lake. *Rec. 41*, 266-285, 1910.

EARTHQUAKES, VOLCANOES, MUD VOLCANOES

Auden, J.B. and Ghosh, A.M.N. Preliminary account of the earthquake of 15th January, 1934, in Bihar and Nepal. *Rec. 68*, 177-239, 1935.

Ballore, M. De. Seismic phenomena in British India and their connection with geology. *Mem. 35*, Pt. 3, 1904

Brown, J.C. Burma earthquakes of May, 1912. *Mem* *42*, Pt. 1, 1914.

Brown, J.C. The Pyu earthquake of 3rd and 4th December, 1930. *Mem.* *62*, Pt. 1, 1933.

Brown, J.C. *et al.* Pegu earthquake of May 5th, 1930. *Rec.* *65*, 221-270, 1932.

Gee, E.R. Dhubri earthquake of 3rd July, 1930 *Mem*, *65*, Pt 1, 1934.

Heron, A.M. Baluchistan earthquake of 21st October, 1909. *Rec.* *41*, 22-35, 1911.

Middlemiss, C S. Kangra earthquake of 4th April, 1905. *Mem.* *38*, 1910.

Oldham, R.D. Assam earthquake of 12th June, 1897. *Mem.* *29*, 1900.

Oldham, R.D. Cutch earthquake of 16th June, 1819, with a revision of the Great Earthquake of 12th June, 1897. *Mem.* *46*, Pt. 2, 1926.

Oldham, T. Catalogue of Indian earthquakes from the earliest times to the end of A D. 1869 *Mem.* *19*, Pt. 3, 1883.

Stuart, M. Srimangal earthquake of 8th July, 1918. *Mem.* *46*, Pt. 1, 1920

West W D. Baluchistan earthquakes of August 25th and 27th, 1931. *Mem* *67*, Pt. 1, 1934.

West, W.D. Baluchistan earthquake of May 31st, 1935. *Rec.* *69*, 203-240, 1936

West, W.D. Presidential address to the section of Geology, 24th (Hyderabad) session of the Indian Science Congress. *Proc. Ind. Sci. Congr.*, 1937.

Hobday, J.R. and Mallet, F.R. Volcanoes of Barren Island and Narcondam. *Mem.* *21*, Pt 4, 1885

Brown, J.C. Mud Volcanoes of the Arakan coast, *Rec.* *37*, 264-279, 1909.

Brown, J.C Submarine mud eruptions of the Arakan coast. *Rec.* *56*, 250-256, 1926.

Mallet, F R. Mud volcanoes of Ramri and Cheduba. *Rec.* *11*, 188-207, 1878; *12*, 70-72, 1879; *14*, 196-197, 1881; *15*, 141-142, 1882; *18*, 124-125, 1885.

Noetling, F. Occurrence of petroleum in Burma and its technical exploitation. *Mem* *27*, 35-49, 80-85, 1897.

Pascoe, E.H. The oil fields of Burma. *Mem.* *40*, 211-215, 1912.

——The Bihar-Nepal Earthquake of 1934. *Mem* *73*, 1939.

CHAPTER II.

STRUCTURE AND TECTONICS OF INDIA.

PENINSULA.

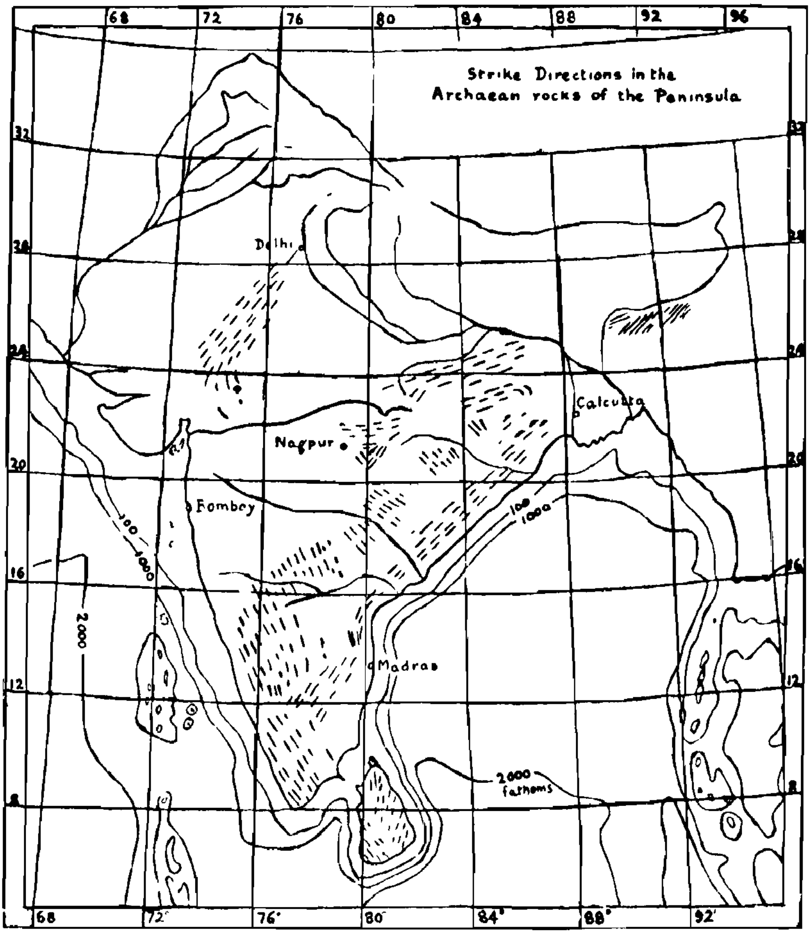
In this chapter are described the general structural features of India which will explain to some extent the present configuration of the country. For understanding the discussion, a knowledge of the stratigraphical geology of India is essential, but it is thought that a preliminary reading of this chapter at the commencement will be useful, for the structure and geological history are intimately connected with each other.

As already mentioned, the Peninsula consists largely of Archæan formations, parts of which are covered over by the Deccan trap lavas, Cuddapah and Vindhyan basins and faulted blocks of the Gondwanas. The Archæans, on examination in a broad way, are found to reveal certain general regional strikes over large stretches of country as explained below :—

The *Aravalli strike* has a N.E.—S.W. trend which can be seen over the whole of the region from Delhi to Gujarat, across Rajputana. This strike continues into parts of the Sub-Himalayan zone of Tehri—Garhwal. In the south, towards Gujarat, this strike splays out, the western part pointing straight to the Gulf of Cambay and the eastern part gradually changing to N.—S. and then N.N.W.—S.S.E. It will be noticed that the latter trend is characteristic of the Dharwarian rocks of Mysore, Hyderabad and Southern Bombay as will be referred to later. It is a noteworthy fact that there is a ridge underneath the sands and alluvium of the Punjab, trending north-west from Delhi. Evidence of its presence is furnished by the Kirana and Sangla hills, and by geodetic evidence of 'upwarp' along this region. Whether this is connected with the Aravallis or whether it has something to do with the earth movements which lifted up the Himalaya and formed a parallel sag in the Punjab plains is, however, a debatable and speculative question.

The several bands of Dharwarian rocks in Southern Bombay (Dharwar and Belgaum districts) and adjacent parts of Mysore and Hyderabad form deep synclinal basins whose axes and the strike of foliation trend N.N.W.—S.S.E. This *Dharwarian trend* extends to at least as far south as Mysore city.

MAP III.



In the southernmost part of the Peninsula the strike seems to spread out and is referable to three main directions, *viz.*, N.N.W.—S.S.E. in the Western Ghats; N.W.—

S.E. (to W.N.W.—E.S.E.) in Madura and Tinnevelly which apparently continues into Ceylon ; and E.N.E.—W.S.W. (to N.E.—S.W.) in Salem and Arcot, which very probably continues towards Madras and the Eastern Ghats.

The *Eastern Ghats strike* (N.E.—S.W.) is seen all over the Eastern Ghats region from near Bezwada in Madras to Balasore in Orissa. Parts of Hyderabad also show this strike while the crescentic basin of the Cuddapah rocks in the Madras Presidency has been influenced and more or less moulded on this structure. This same strike is conspicuously displayed in the Khasi and Jaintia hills of the Assam plateau and in the Mikir hills of Upper Assam.

The strike in the Western part of the Assam plateau may be the continuation of the Satpura strike of Bihar.

In the Bastar and Orissa region, particularly for instance in the lower Mahanadi valley up to Sambalpur, the trend is N.W.—S.E., the *Mahanadi strike*. How much of this region follows the grain of the Eastern Ghats and how much that of the Mahanadi, is not known as large tracts still remain to be surveyed.

Over the whole of the region from near the Rajmahal Hills on the east through the Chota Nagpur plateau and Balaghat to Chhindwara, a distinct strike persists which is called the *Satpura strike*. Southwards, this extends to Singhbhum and Gangpur ; the southern parts of these and the adjoining Orissa States show, however, the Eastern Ghats and Mahanadi strikes. A similar interference of three regional strikes with the same general directions is also seen in the Bhandara region of the Central Provinces, according to Mr. D. S. Bhattacharjee.

One interesting feature may be emphasised in this connection. The Aravalli and Eastern Ghats strikes exhibit a rough parallelism ; so also the Dharwarian and Mahanadi strikes ; these two sets are more or less perpendicular to each other. The Satpura strike is quite distinct from these. This reticulate structure is perhaps a factor which may account for the great stability of the Peninsula, as pointed out by Col. E. A. Glennie in another connection. Further, it is noteworthy that the ranges which these trends characterise form the edges of the Peninsular mass beyond which are sunken areas filled either by ocean waters or by thick alluvium.

Cuddapah Basins.—Lying over the Archæan mass are basins of Cuddapah and Vindhyan rocks referable mainly to the Pre-Cambrian, and perhaps partly to the Cambrian. The Cuddapah basin in Madras is crescentic in outline, the convexity facing the west or northwest and the greatest disturbance of the rocks being found along its eastern margin. The Cuddapah basin of Bastar and Chhattisgarh is similar but the structure is not so well seen because it has been split up into separate areas with Archæans intervening between them.

The great basin of Vindhyans around Bundelkhand, occupying the Son valley and parts of Eastern Rajputana and Central India, has a complicated structure, its western margin being marked by a great thrust zone in which the older rocks are brought against the youngest Vindhyans, the direction of the thrust being from north-west to south-east. The southern and eastern portions, however, seem to have been thrust from the south-west or south.

It is not known when the post-Vindhyan movements took place. They may be Palæozoic and probably connected with the Hercynian movements, which also initiated geosynclinal marine sedimentation in the Tibetan Zone of the Himalaya.

Faults.—The north-eastern part of the Peninsula has, since then, been subjected to block faulting. The coal fields of the Damodar—Son valley, the Mahanadi valley, Chhattisgarh, and the Godavari valley are all bounded by faults which have helped to preserve the Gondwana strata. There are several faults which traverse the Peninsula, in addition to those which are found in and around the coal fields. It is now well recognised that the western coast of India has been formed by faulting. Along this coast, from Ratnagiri to north of Bombay there is a series of hot springs arranged along a straight line which strongly suggests that they are situated on a line of fracture. Additional evidence is afforded by the Deccan traps which are several thousand feet thick near the Bombay coast and gradually thin down eastwards. It is thought that their abrupt stoppage at the Bombay coast is due to the breaking off of the portion of land which originally lay to the west of Bombay. The age of this faulting is post-Deccan trap and may be as late as Pliocene at which time a fault developed also along the Mekran coast of Baluchistan.

Western Coast.—There seems to have been some irregularity in the region of the Gulf of Cambay for we find Cretaceous and Eocene strata in the region of the Narbada valley. This may have been an arm of the Arabian Sea stretching into this area from Sind and southern Rajputana through northern Gujrat, which were occupied by a sea in the Upper Mesozoic and Tertiary. There must have been a considerable gap here in the Aravallis, for there is evidence of the continuation of the same range further south into the Arabian Sea, though this is now submerged. There is evidence that this region has been raised in very recent geological times. The continental shelf on the western coast is generally about 100 fathoms deep, but it suddenly slopes down to 1,000 or 1,100 fathoms, which is the depth of the trough lying between the coast and the ridge, part of which forms the Laccadives. The continental shelf, even more than the coast line, is remarkably straight from Cape Comorin to the mouths of the Indus.

Laccadives and Maldives.—There is evidence that the Aravallis continue, after the gap in Gujarat, into the ridge found alongside the western coast. In the gulf of Cambay is the Direction Bank which is continuous southward with the Angria and Adas Banks west of Goa, which form the connecting link. The Laccadives lie west of the

Malabar Coast and rise from a depth of about 1,100 fathoms. At the southern end of this ridge there is a curvature pointing to the east. This ridge apparently dies down, a deep channel intervening between the Laccadives and Maldives at about latitude 8° N. The Maldives rise as a ridge from the sea bottom with the same direction but slightly to the east of the Laccadive alignment. There is another gap at about latitude 2° S., after which rises the Chagos Archipe'ago

The eastern slopes of the Laccadive and Maldive ridges are steeper than the western, so that this slope may indicate a fault similar to the 'Boundary Fault' of Rajputana. But whereas the trough on the east is 1,100 fathoms deep, the floor on the west rapidly deepens to about 2,000 fathoms. It we assume that the ocean floor on both sides of this ridge was originally level with the western coast of India, then the subsidence due to the Tertiary faulting should have a minimum value of 6,000 to 7,000 feet. This, it will be seen, will bring the ridge to a height of 3,000 to 7,000 feet above sea level which fits in well with the idea that the ridge originally formed the watershed in the existing land mass.

Eastern Coast.—The continental shelf broadens at Cape Comorin and includes the island of Ceylon, with however an indentation pointing towards the Gulf of Manar. The eastern coast is irregular, for there have been marine transgressions and regressions since the Jurassic, the chief transgressions being of Upper Gondwana (Jurassic), Cenomanian and Miocene ages. The present configuration of the Bay of Bengal dates roughly from the Jurassic whereas the Arabian Sea coast is definitely of post-Deccan trap age and possibly as late as Miocene or Pliocene.

EXTRA-PENINSULA.

Himalayas.

It has already been mentioned that the Extra-Peninsula is characterised by arcuate disposition of the mountains. The convexity of the arcs is in every case turned towards the stable and comparatively rigid block of the Peninsula. The areas now occupied by these mountain arcs were once large basins of sedimentation, of geosynclinal dimensions. These have been intensely folded and corrugated and overthrust, large slices having been sometimes carried forward for long distances. Such masses are called *nappes*. Because of the overthrusts, nappes and recumbent folds, the beds generally seem to dip towards the interior (*i.e.*, the direction from which the thrusts are thought to have acted).

Four parallel Zones.—The four zones into which the Himalayas can be divided, *viz.*, (1) the foot-hills zone, (2) the Lesser Himalaya or Sub-Himalayan zone, (3) the Central or Great Himalaya and (4) the Trans-Himalaya or Tibetan zone, have each certain distinguishing geological features. The foot-hills zone consists of Tertiary sediments including Eocene, Murree and Siwalik strata. Of these, only the Siwaliks seem to be persistent throughout the length of the Himalayas, except for two or three small gaps. The Murrees are apparently absent east of Dehra Dun whereas the Eocene seems to be unknown east of Naini Tal, and even there very thin. The Siwaliks are sometimes folded, faulted and even overthrust. This zone is often separated from the inner zone by the 'Main Boundary Fault.'

The Lesser Himalayas contain various stratigraphical units ranging in age from Pre-Cambrian to Tertiary, and intrusive igneous rocks of different types. The rocks are generally of the peninsular facies—*i.e.*, large thickness of unfossiliferous slates and quartzites, Gondwanas and Mesozoic rocks. It is only in Kashmir that the Tibetan marine facies transgresses into this zone. This zone is highly complicated in structure, since two or more overthrusts and nappes have been deciphered, and recumbent folds and inverted sequences are common.

The Central Himalayan Zone consists of rocks of the Lesser Himalayas together with much gneissic and granitic rocks of different ages.

The Trans-Himalayan or Tibetan zone shows a complete sequence of marine fossiliferous strata formed in a geosyncline, ranging in age from the Cambrian to the Eocene. There are, however, certain well-marked stratigraphical gaps such as the one at the base of the Permian (which is probably to be attributed to the Hercynian disturbance) ; and the Callovian unconformity which is overlain by the Spiti Shales (Upper Jurassic) in Western Himalaya, and by Neocomian beds in the Baluchistan area. These two types of succession are found along two contiguous and parallel zones in Hazara, the strikes coinciding with the later fold axes. It seems that in the Himalayan area the structure of the older (Pre-Cambrian and Purana) rocks has influenced the later structures imposed on them during the Tertiary era.

The trend lines of the Himalaya are seen as far north as the Karakoram-Hindu Kush system of mountains. This leads to the plausibility of the hypothesis of the Karakoram mountains being of the same age as the Himalayas. It is however held by Trinkler and De Terra[1] that the Karakoram system is of Hercynian age and thus related to the Kun Lun and Tien Shan ranges which are included in the 'Altaides' by E. Suess in his great work 'Das Antlitz der Erde.' The core of the Karakoram mountains consists of granitic rocks. De Terra attributes the present features of these mountains to later faulting and movements.

Recent work in the Himalayas has been concentrated in the Kashmir-Hazara, Simla and Garhwal areas. These areas have not yet been mapped continuously. There is a very large gap in the Nepal region, while the Darjeeling

[1] Geologische Forschungen in Westlichen Kun Lun und Karakoram Himalaya, 1932.

area has been mapped only in a general way. Short descriptions follow.

KASHMIR HIMALAYA.

In the Kashmir area D.N. Wadia[1] has recognised three tectonic elements :—

1. A northward projecting wedge of the Gondwana *foreland* covered by Murree sediments.

2. An *Autochthonous zone* consisting of sediments of various ages ranging from Carboniferous to Eocene, and often highly folded and inverted, which has been overthrust (*Murree thrust*) against the foreland.

3. A *Nappe zone* of two successive nappes which is thrust over the other two. These nappes include rocks of the Salkhala series (Pre-Cambrian) and Dogra Slates with infolded synclines of Palæozoic and Triassic rocks which constitute areas such as the Kashmir basin and the Shamsh Abari mountains. The thrusts have been called *Panjal thrusts*.

4. Beyond these is the Central Himalayan zone wherein lie the 'roots' of the nappes intruded by granite of presumably different ages, the latest being distinctly Tertiary. Patches of the Tibetan marine zone of sedimentaries, Palæozoic and Mesozoic in age, are found in this zone.

SIMLA HIMALAYA.

G. E. Pilgrim and W.D. West have mapped the Simla neighbourhood and published the results in Memoirs of the Geological Survey of India, volume 53. This work has been continued since by West. Here the younger and older Tertiaries are separated by a 'boundary fault.' The Tertiaries are separated from the Pre-Tertiary, autochthonous, Krol belt rocks by the *Krol thrust* which apparently corresponds to the Murree thrust of Kashmir. This

[1] Presidential address, Geology section, Twenty-fifth Indian Science Congress, 1938.

thrust zone is itself folded and highly compressed and can be followed for a long distance to the south-east where it even overlaps the Tertiaries near Nahan. Beyond the Krol belt is the zone of nappes, containing Pre-Cambrian Jutogh and Chail series, with the *Jutogh* and *Giri thrusts*—which correspond to the Panjal thrusts. To the north is the great *Chail thrust* which exposes a tectonic ' window ' of Shali limestone, Madhan States and Tertiaries near the Shali peak.[1] The trace of the Chail thrust marks a great discordance as, in following it north-east and north across the Sutlej, the Tertiaries gradually disappear and the Chails rest on the Shali limestone. Granitic intrusives are found both in the nappe zone and further north.

GARHWAL HIMALAYA.[2]

Here also there is the outer Siwalik zone separated by a reversed fault (Main Boundary Fault) from the autochthonous zone consisting of Simla Slates overlain by Nummulitics and younger Tertiary rocks. This unit is seen in a series of "windows" along anticlines formed after the thrusting had taken place. The Tertiaries of the autochthonous unit are overlain by the *Krol nappe* consisting of a thick (20,000 feet) succession of rocks ranging in age from Pre-Cambrian to Tertiary. The *Krol thrust* is continuous with the Giri thrust of the Simla region and has been followed eastwards to beyond Naini Tal. The *Garhwal nappe* overlies the rocks of the Krol nappe and consists of Pre-Cambrian schists and older Palæozoics which are distinctly more metamorphosed that the rocks on which they lie. At the base of the main Himalayan range occur the schists of the Garhwal nappe. There is an important overthrust here, under which are found rocks of the Barahat series in a ' window.' This overthrust has been traced from Dutatoli to Tehri and has been recognised near Almora. Beyond these is the Central

---

[1] W.D West, The Shali Window, *Rec G.S I* LXXIV, 1939.

[2] J B. Auden, The Geology of the Krol Belt, *Rec G S I.* LXVII, 1933.

Himalayan zone with its granitic intrusives and crystalline schists.

NEPAL HIMALAYA.

In the foot-hill zone the Upper Siwaliks are separated from the Nahans by a thrust fault. The Nahans are separated from the Pre-Tertiaries by the so-called ' Main Boundary Fault.' The Pre-Tertiaries overlie the Nahans and consist of Krols, some fossiliferous Lower Palæozoics and Gondwanas, together with schistose rocks. The ' Main Boundary Fault ' passes north of Sanotar and Udaipur Garhi and probably continues through Dharan Bazar to Tindharia in the Darjeeling area. This Pre-Tertiary belt is separated from the Darjeeling gneisses and Daling schists by another thrust. In this area the schistose Dalings seem to pass upward into the gneissose Darjeelings and the two may represent merely different metamorphic facies of the same formations.[1]

SIKKIM HIMALAYA.[2]

The Siwalik zone is narrow and shows two gaps, occupied by Gondwanas and Dalings which belong to the autochthonous zone the latter being comparatively narrower than further west. Darjeeling, Daling and Buxa rocks are thrust over the autochthonous belt ; the nappe zone is extensive and may contain more than one important thrust. Kanchenjunga lies in this nappe zone whereas Mt. Everest lies on the margin between the Central Himalayan and Tibetan zones containing metamorphosed sediments intruded by granite. The peak of Mt. Everest consists of metamorphosed Permo-Carboniferous limestone while the northern flanks show sediments of Permian to Jurassic age.

Little is known of the geology and structure of the Eastern Himalayas but there is every probability that they

[1] J B. Auden. Traverses in the Himalaya, *Rec G S I* LXIX, pp 136-147, 1935

[2] L R Wager, 'Everest, 1933,' pp 312-336, 1934.

are similarly constituted. There is a fringe of Siwaliks in the outer hills, and Gondwanas and various metamorphosed rocks further in. The E.-W. strike of the Darjeeling area gradually becomes N.E.-S.W. in the region of the Brahmaputra and beyond. In the extreme north-east of Assam N.W.-S.E. strikes are known, apparently where the structure turns round with a sharp bend to the south and becomes the Burmese arc.

BURMA.

It was formerly thought, more on geographical rather than geological grounds, that the Himalayas of Assam continued north-eastward into China. Geological evidence, however, shows that there must be a sharp bend of the formations of the Himalayas to the south into Burma. The analogy between the Burmese and Baluchistan arcs would also lend support to this conclusion.

In the north-easternmost corner of Assam and beyond there is a series of close-set parallel ranges, composed of crystalline schists and igneous intrusives. The Central Himalayan zone apparently continues through this into the Mishmi hills and then southward into the Shan plateau, the Sittang valley and Tenasserim

THE ARAKAN BELT.

There are three parallel N.-S. belts in Burma, *viz.*, the Arakan Belt, the Central or Tertiary belt and the Shan-Tenasserim belt. The Arakan Yomas and their extension northward through the Manipur and Patkoi hills consist of a series of rocks called the 'Axial group' including Cretaceous and Pre-Cretaceous rocks which form a highly folded geo-anticline. The Cretaceous rocks of the Arakan belt are similar to those of Baluchistan rather than to the Assam Cretaceous. The rocks continue southwards as a well-marked arcuate ridge comprising the Andamans and Nicobars, and Sumatra and Java further south. They were probably uplifted during the early Eocene period into a long narrow island ridge in the Arakan area which served to separate the basins of Tertiary deposition on either side.

The Tertiaries of Assam to the west of this important divide include strata up to the Pontian age. The earlier, *i.e.*, Cretaceous and Eocene, rocks are found along the southern border of the Assam plateau. The Barail, Surma and Tipam series of Oligo-Miocene age are the equivalents of the Murrees and Pegus ; the Dihing series represents the Siwaliks and the Irrawaddians. Within this Tertiary area occurs the Haflong-Disang thrust fault trending N.E.-S.W. in Upper Assam and gradually changing its direction to E.-W. along the southern part of the Assam plateau. The strike of the Tertiary rocks is in general N.E.-S.W. in north-eastern Assam. But N.W.-S.E. strikes are known in the extreme north-east which accord well with the belief of the existence of a sharp syntaxial bend in this region.

THE CENTRAL BELT.

The Arakan belt is fringed on its east by Eocene rocks and is also faulted against the rocks of the Central or Tertiary zone. This Central zone consists mainly of Pegus and Irrawaddies, exposed in the Pegu Yomas and the hills further north, which have been folded and uplifted by compression at the end of the Pegu times and also later. To one of the ridges on the border of the Arakan and Tertiary belts must be assigned the Barren Island and Narcondam which represent peaks on a submerged ridge in the Andaman Sea. This belt now contains the chief rivers of Burma, at least the greater part of their courses.

THE EASTERN BELT.

The eastern belt, comprising the Shan Plateau and the Tenasserim Yomas, continues northwards into the region of tangled mountains north of Burma. It consists of

Archæan, Palæozoic and Mesozoic rocks intruded extensively by granitic rocks. This belt is highly folded and marked off from the Tertiary belt by overthrust faults. The junction zone between the two is well known to be seismic. The western margin of the Shan plateau is generally a well-marked scarp. Followed southward, the plateau gives place to the mountain ridges of Tenasserim which continue into the Malay Peninsula. This part of the belt is characterised by granite containing deposits of tin and tungsten. The Shan-Tenasserim belt was also finally uplifted probably in late Cretaceous or early Eocene times, for the youngest rocks involved in the earth movements are Cretaceous in age. It is evident that this belt corresponds to the Central and Sub-Himalayan zones in orogenic history, though they may not agree in the details of their stratigraphical history.

THE BAY OF BENGAL.

As already pointed out, the Bay of Bengal began to have its present configuration from about the Upper Jurassic. It had a gulf extending into Assam and Burma in Jurassic and Cretaceous times. The eastern portion became separated into an Assam gulf and a Burma gulf in Upper Cretaceous or early Eocene times by the formation of a great north to south ridge now seen as the Arakan mountains, with their continuation into Upper Assam on the one hand and into the Andamans, Nicobars, Sumatra, Java, etc., on the other. The western coast of this ridge (of Andamans and Nicobars) deepens westwards gradually, though rapidly, to about 2,000 fathoms. Barren Island and Narcondam are separated from the main ridge by a deep irregular valley but east of the volcanic islands the sea deepens abruptly to 1,500 to 2,000 fathoms. The basin of the Andaman sea has a straight eastern margin and a very irregular western margin and its deepest part (2,100 fathoms) lies a little east of Kar

Nicobar.[1] The Gulf of Martaban is less than 100 fathoms deep, the 100 fathom line running E.-W. slightly to the north of Narcondam. The eastern side is a gradual slope from the Tenasserim Coast to the trough bordering on the Barren Island-Narcondam sub-ridge. The continuation of the Andaman ridge is in the mountainous region of the southern edge of Sumatra and Java whereas the Barren Island-Narcondam ridge will continue into the northern margin of the same mountain belt, as will be seen from the position of Krakatoa in the Sunda Strait. The configuration and topography of the Andaman Sea would suggest that the Andaman ridge system is faulted certainly on its eastern side, and possibly on its western side. The faulting down of the Andaman Sea is probably of Pliocene age. The very gradual westerly slope of the Tenasserim Coast would suggest that there is no deep faulting here though there may be thrusts with low dipping thrust planes.

The Sunda Sea (north of the Dutch East Indies) was formed in post-Pliocene times, and the sea level first sank in the Pleistocene (during the glaciation) and later rose (during the post-glacial time).

There are two parallel ridges west of the Andaman ridge. The first one is a submerged line of peaks west of the Andaman ridge, continuing into the Nias and the Mentawai islands. The second is separated from this by a deep trough (the Investigator Deep) and is called Carpenter's ridge, which has also been recognised south of Sumatra and Java.

Igneous Belts of Burma.—H. L. Chhibber distinguishes five igneous belts in Burma (Geology of Burma, London, 1934, p. 286 ff.) :—

(1) The Arakan Yoma continuing into the Andamans, Nicobars, Sumatra and Java. In this are serpentines of Cretaceous age.

---

[1] R B.S Sewell, Geographic and Oceanographic Researches in Indian waters—1. Geography of the Andaman Basin *Mem Asiat Soc. Bengal*, IX, No 1, 1925

(2) The fold-belt of the Pegu Yoma including the Jade-Mines area, Wuntho area in Katha, Lower Chindwin, Shinmadaung, Mount Popa, Prome and Tharrawaddy districts and the recent volcanoes of Barren Island and Narcondam. These are of Tertiary, mainly Upper Tertiary, volcanic rocks.

(3) The lavas and dolerites of Kabwet, Mandalay and Shwebo districts and the rhyolites of Thaton district. This belt is along the edge of the Shan plateau.

(4) An older (Palæozoic) line of igneous rocks in the Shan plateau, which includes the Lagwe Pass in the north-east of Burma, Bardwin area and perhaps the outer islands of the Mergui Archipelago.

(5) A younger line of volcanoes connected with the folding of the Shan plateau zone, and containing the volcanoes of Teng Yueh in Yunnan, Loi Han Hun in Northern Shan States and some in the Mergui Archipelago.

All the above mentioned are prominent zones of warping and often of fracture and faulting and are therefore of significance in the structure of Burma.

Orogenic periods in Burma.—Burma was apparently subjected to an early Palæozoic orogeny involving the Chaung Magyi and Mergui sediments and older rocks. These were again depressed beneath the sea. The Arakan area and the Shan-Tenasserim belt seem to have been compressed and raised up about the end of the Cretaceous, accompanied by intrusions of peridotites, gabbros, etc., along the Andaman-Arakan Yoma belt which continues northward into the Manipur hills, the Hukawng valley and the Jade Mines area. To the same period of igneous activity may be attributed some of the granites of the main Burma-Malay arc.

The next upheaval is dated between the Eocene and Miocene. Since undoubtedly the orogenic history of the Himalayan and connected arcs is intimately related, this may perhaps be put down to the upheaval at the close of the Eocene. This was accompanied by some igneous activity as in the Kamaing area of the Myitkyina district and the Wuntho area of the Katha district.

An important upheaval and folding occurred at the close of the Pegu epoch, which corresponds to the close of the Murree epoch in India. This raised up the Pegus of the Central Tertiary belt of Burma and was also accompanied by some igneous activity in the Kabwet, Mount Popa and other areas.

The next period of orogenesis was at the close of the Irrawaddian period which lifted up the central basin almost entirely. Igneous activity accompanying this diastrophism is to be found in the Central belt (Jade Mines area, Lower Chindwin, Mount Popa, Mandalay, Shwebo) and also Teng Yueh in Yunnan and in Loi Han Hun in the Northern Shan States.

The orogenic activity has persisted down to sub-recent times. The Pleistocene gravels have been folded and tilted in the Irrawaddy valley and further north. The volcanoes of the Central belt of Burma have apparently been active in Pleistocene and sub-recent times, because of these crustal disturbances. There are also evidences of raised beaches on the Arakan coast.

TREND LINES IN THE NORTH-WESTERN ARC.

The geological formations of the main Himalayan arc bend round to the south at the western extremity of the Himalaya near Nanga Parbat, just as they do at the eastern extremity some distance beyond the peak of Namcha Barwa. The Himalayan trend in Kashmir, east of the sharp bend (syntaxis), is N.W.-S.E. but when followed through beyond the syntaxis, it exhibits a broad curve, the trend changing from N.-S. through N E.-S.W. to E.-W. in the Hazara mountains The Siwalik zone of Jammu and the Murree zone to its north can be followed in the Potwar plateau. The Upper Mesozoic and Eocene zone of Hazara forms an inner belt which can be followed westward into the Samana Range.

Further to the interior is a slate zone with Palæozoic rocks and then a crystalline zone with ancient slates and schists and granitic intrusives which latter are apparently continued westward into the Safed Koh. The southern and south-eastern edge of this group is the faulted thrust scarp of the Salt Range which exposes a sequence comprising various strata from the Cambrian to Eocene, and which is covered on top and on its northern slopes by the Siwaliks underlain by the Murrees.

This remarkable syntaxis is due to the north-westerly projection of a wedge of the old Peninsula across Kashmir. It is however covered by Siwalik and Murree sediments. The influence of this wedge is seen not only in the moulding of the Himalayan system around it, but also further north in the Karakoram-Hindu Kush system and up to the mountain knot of the Pamir plateau. The structure is highly constricted at the bend and spreads out in sheaf-like fashion on both sides and away from the bend. West of the Punjab Salt Range and in the Region of the Kurram river basin, there is another sharp bend of the formations from an E.-W. direction to a N.-S. (or N.N.E.-S.S.W.) direction. Though this region has not been mapped, there is little doubt of the presence of another wedge here. The formations then continue into the Sulaiman Range and Bugti hills, with another very sharp loop near Quetta. The southerly trend of the Sulaiman range becomes westerly in the Dera Bugti area and north-westerly when followed further towards Quetta. Near Quetta they turn again sharply southward, continuing into the Kirthar ranges. The sheaf-like arrangement is excellently displayed in a geological map of this area, for the constricted formations around Quetta spread out and occupy a large area in Baluchistan, Mekran and Southern Sind. The above mentioned structure is due to another wedge of the Peninsula projecting into the region of Jacobabad-Sibi-Quetta, though the basement is entirely covered by the alluvium of the Indus.

Hazara and North-West Frontier Province.—As mentioned in the previous paragraphs, the different zones of the Punjab-Himalaya can be followed into this region. Here also the older rocks of the interior zones are thrust over the younger rocks of the outer zones facing the Indian Peninsula. Thus the "scaly" or "imbricate" structure of the Himalayas is repeated here also.

There is an interesting fact to be noticed here. In Hazara, the geosynclinal facies of Mesozoic and Eocene rocks of the Tibetan zone appears and lies in Juxta-position with the Calcareous facies of Baluchistan comprising rocks of Jurassic, Upper Cretaceous and Eocene age, including the well-marked Callovian unconformity. There is a sharp line of junction between these two facies, the Tibetan facies appearing to the north-west of the junction and the Calcareous facies to its south-east. The Tibetan facies comprises rocks of the Spiti Shales type, while the Baluchistan facies shows Neocomian limestones and flysch-like shales and sandstones of the Giumal type. In the Transition zone are Upper Cretaceous rocks which are absent in Baluchistan but well known in Kashmir.

Further in, there is a vast development of Attock Slates with intercalations of limestones. The latter sometimes resemble the pisolitic limestones of the Vindhyans of Tirhowan in Bundelkhand. The Attock Slates are overlain in places by the Infra-Trias with boulder-bed, sandstones and shales at the bottom and limestones at the top. This slate zone is succeeded by the crystalline zone comprising schists, gneisses and granites as in the Central Himalayan zone. The Safed Koh proper represent mainly the crystalline zone, while the mountains of Tirah show the Jurassic, Upper Cretaceous and Eocene rocks of the Calcareous zone. The Slate zone may probably be present in the unmapped regions lying between the Samana Range and the Safed Koh.

Baluchistan.—The Baluchistan ranges show three zones :—The outermost, bordering on India, is the Calcareous zone consisting mainly of rocks of Liassic to Oligocene age ; the second or middle zone consists mainly of the ‘ flysch ’ facies of rocks of Oligocene age ; the third or inner zone comprises rocks of various ages from Archæan to Tertiary, including intrusives and constituting the desert regions of Baluchistan and part of Afghanistan.

The Calcareous zone consists of a succession of folds with the anticlines having their steeper limbs on the side of India. The anticlines are also found standing out as ridges and forming all the higher peaks, *e. g.*, Takht-i-Sulaiman (11,070 feet), Kaliphat (11,440 feet) north of the Harnai valley, and Takatu (11,390 feet) and Chehiltan (10,880 feet) near Quetta. The Kirthar range consists of Eocene and Oligocene limestones. The Siwaliks occur in the synclines and also on the outer border where they attain considerable thickness.

The flysch zone consists of more closely folded rocks. It includes the mountains of the Zhob valley, the Toba plateau, the Khwaja Amran and Sarlat range, the western border of Sarawan, Jhalawan and Las Bela, and the greater part of the Mekran province, and consists of monotonous folded sandstones and shales of greenish colour known as the Khojak shales forming close-set parallel ridges. They are mostly of Oligocene age. Near the Mekran Coast they consist of friable clays overlain by white sandstones constituting the peninsula of Ormara and the Hinglaj mountains, the sandstone group being probably of Miocene age. In the Mekran region it is usually the synclines which form the hills, probably because it receives more rain than the arid region of Baluchistan where much of the Calcareous zone is found. The sandstones form grand hills in the Mekran region. Mud volcanoes are sometimes found in the crest of anticlines which are often formed of shales and clays.

The inner zone comprises rocks of different ages. The ridges here are separated by desert plains, the edges of the ridges being often thrust planes. Both intrusive rocks and volcanics occur in this zone.

Mekran Coast.—The Baluchistan ranges are continued westward into Iran not only through land but also through the submerged region of the Arabian Sea for some distance from the coast. This strip adjoining the Mekran coast is streaked with a series of straight parallel ridges. There is a gradual deepening to about 1,800 fathoms at which depth there is a wide level floor which narrows towards Karachi, and broadens towards the Gulf of Oman. The submerged ridges are 2,500 to 3,000 feet high above the adjacent troughs. The ridges of the Zagros mountain system are at a distance of some 60 miles from the Mekran coast and their tops rise to within 3,000 feet. of (beneath) the sea-level.

The Kirthar range, which reaches the sea at Cape Monze, apparently continues in a south-west direction underneath the waters as a double ridge. The northern ridge is the Murray ridge which has a N.E.-S.W. trend in the eastern portion and gradually turns southwards further west. The highest peak in the ridge which occurs about the middle region is only 480 fathoms below the sea level. The floor to its north is 1,750 fathoms deep, while the gully to its east is 2,100 fathoms deep. When followed to the south-west, the latter shallows to 1,600 fathoms and after a few miles is continued by a wider gully 2,000 fathoms deep.

South of the Murray ridge is another more or less parallel ridge, about 1° distant from it. A peak on this, which is only 440 fathoms deep, appears at 20° 20′ N. and 64° E. The general depth of the greater part of the ridge is about 1,500 fathoms and this can be traced as far as 20° N. and 61° E. It is not known where the continuation of these ridges is to be looked for on the Arabian Coast or elsewhere but it is not unlikely that the region may be near Ras Madraka, for the south-eastern coast of Arabia is known to contain Cretaceous and Eocene rocks.

Since the Kirthar range contains rocks of the Nari and Gaj series (Miocene) it must have been raised up in post-Gaj age and faulted down at a still later date, perhaps in the Pliocene. The Mekran coast of Baluchistan is therefore of Pliocene age as pointed out by Blanford. Whether the western coast of the Indian Peninsula is also of the same age is difficult to decide, but it seems probable that faulting took place in the Miocene or somewhat earlier for there are marine deposits of Miocene age on the Travancore coast.

THE ARABIAN SEA.

The East coast of Africa from Cape Guardafui to Mombasa is faulted. From Socotra runs the Carlsberg ridge south-eastward to the Equator and then seems to turn southward to Rodriguez. This forms a grand arc convex to the east, comprising parallel ridges. One of the parallel ridges of the Carlsberg system may probably run on to join the Chagos Archipelago. Parallel and concentric to this ridge system is another on which are situated the Seychelles, Saya de Malha, Nazareth Bank and Mauritius. To the interior of this lies the island of Madagascar which is separated from the African mainland by a shallow sea. Sewell and Wiseman opine that there is a great similarity between the floor of the Arabian Sea and the Rift valley region of Africa, and that the two form a mirror image of each other along the meridian 50°. G.M. Lees however thinks it possible that the ridges in the Arabian Sea may indicate folded mountains. The Gulf of Aden shows a series of parallel ridges which join Arabia and Africa slantwise and have a N.E.-S.W. direction. In all cases these ridges are steep on the south-east side.

THE POTWAR AND THE ASSAM PLATEAUX.

The two spectacular bends of the geological formations and structures at either end of the Himalayas are, as already mentioned, due to the presence of wedges of the

Peninsular mass, one projecting north-west into Kashmir and the other north-east into Upper Assam. In both cases the ancient rocks are partly or entirely covered by the Tertiaries. The general direction of pressure in the Himalayan area is from north to south, but in the Baluchistan and Burma arcs it is from the west and east respectively. But whereas the Burma arc takes a broad sweep with only a slight concavity in the Arakan coast, the Baluchistan arc shows the presence of two prominent north-westerly projections or wedges in the region of Jacobabad and of Dera Ismail Khan which have split it up into three well marked festoons. The Dera Ismail Khan wedge is indeed double, one directed north-west from this place and the other parallel to it through Mianwali. But for these projections, the Baluchistan arc should also have been a single broad arc from Nanga Parbat to Karachi.

The Arakan range in the east has its counterpart in the Sulaiman-Kirthar range on the west. The Central belt of Burma Tertiaries is represented in the Baluchistan arc by the Mekran belt, the southern part of both these having foundered beneath the sea. Other structural and geological parallelism will be evident on examining the geological maps of both the regions.

The two regions of the Peninsula bordering the two ends of the Himalayas are of particular interest because of their structure and stratigraphy. At the western end is the Potwar plateau and the Salt Range, while at the eastern end is the Assam plateau and Mikir hills.

The Potwar plateau is structurally a folded synclinal trough (Soan syncline) lying between the Hazara mountains and the Salt Range, and occupying an area 150 miles long and 60 miles broad, the axial direction being E.N.E.-W.S.W. To its north this basin is closely folded into isoclines and recumbent folds in the Kala Chitta and Margala hills, apparently thrust from the north-west. In the basin itself are some subsidiary open folds and strike faults hading to the north. It has an average elevation of 1,500 feet and exposes sandstones and clays of Murree and Siwalik ages but the basin probably includes also Mesozoic and Palaeozoic rocks, the whole resting on an ancient foundation which is a westerly continuation of the Rajputana massif.

The Salt Range consitutes the southern border of the Potwar plateau and has a general E.-W. trend, turning north-west at its western end. The southern flank is a well marked escarpment overlooking the alluvial plains of the Jhelum while the northern gradually and gently grades into the Potwar plateau. Over a substratum of Cambrian rocks, there are rocks of all ages ranging from Carboniferous to Pliocene. The Pre-Eocene beds are exposed on the scarp, those from Permian to Eocene being composed of limestones in the main. The highest point in the range is the Sakesar peak (5,010 feet). The plateau portion of the range shows Eocene limestones almost continuously throughout its length, but the Productus limestone is also sometimes seen especially in the south-east. In the Permian-Cretaceous sequence, the oldest beds commence in the east and the succession becomes more and more complete when followed westwards.

The calcareous plateau, which attains its greatest development in the Central part of the Salt Range, consists of nearly horizontal rocks and shows several lakes which are generally saltish, the salinity in some instances being connected with salt springs on lines of faulting. Deep glens intersect this plateau.

Along the northern border of the calcareous plateau Lower Siwalik rocks dip rather steeply (30 to 50°) beneath the Potwar plateau where again the dips become gentle. This northern border constitutes a watershed between the northerly and southerly drainage. North of Sakesar, the drainage flows into the Vihi (or Wahi) river which flows around and cuts across the Salt Range between the

Chidru and Tredian hills through a narrow and deep cleft known as the Bakh ravine. The remainder of the drainage flows mainly into the Soan river which joins the Indus a short distance above Kalabagh, the Indus cutting through the Salt Range at Kalabagh. The southerly drainage, flowing through a number of channels is generally lost in the plains, before reaching the Jhelum. The slopes leading to the Potwar plateau and a large part of the Potwar plateau itself are intersected by deep, labyrinthine, narrow and often vertical sided ravines, attributable to the joints in the Siwalik sandstones. This type of country is known as 'Kuddera.'

The Salt Range proper (*i.e.*, the portion east of the Indus) shows a faulted flexure, the sequence being inverted in places. The N.W.-S.E. strike near the Indus becomes E.-W. in the central part and N..E.-S.W. in the eastern part. The fault zone in the east also breaks up into parallel lines of fracture producing three parallel ridges. In the western portion the structure is that of close-set anticlines and synclines more or less fractured by overthrusts. The range crosses the Indus at Kalabagh and continues into the Surghar range. To the north of the latter is the Kohat region which is similar in stratigraphy and structure to the Punjab salt Range though the overfold and thrust are less pronounced and the southern limb frequently visible. The broad Siwalik zone of the Potwar is constricted in the Kohat region but apparently expands further west, being however hidden and covered over by alluvium or Pleistocene formations in the Bannu plain. The Kohat anticlines do not expose any rocks older than the Eocene, the intervening areas being occupied by Murree beds.

The Surghar range constitutes an overfold divided into two ridges by denudation. The northern one is the Shingarh range or Green Mountain, so called from the greenish colour of the Siwaliks constituting them, while the southern is the Chichali or Surghar range consisting of

Eocene and Mesozoic rocks and reproducing many of the features of the Salt Range proper. These ridges are over 20 miles long east to west from the Indus, and then turn sharply south forming the Maidan range which is cut across by the Kurram river. To the south of this river, the strike gradually veers round to the west and an anticline of Siwalik rocks is seen forming the Marwat range (or Nila Roh) up to the Sheikh Budin hills in which Mesozoic rocks are exposed for a short distance. These continue north-west under the name Bhattani ridge which finally turn southwards to join the Siwaliks of the Sulaiman range.

To the south-east of, and parallel to, the Marwat range is a ridge known as the Khasor range in which also Siwaliks and pre-Tertiary rocks are exposed. The pre-Tertiary rocks, best seen near Saiduwali, consist of maroon sandstones, shales, dolomites and gypseous rocks (all probably Cambrian), Talchir boulder-bed, Speckled sandstone, and Mesozoics so that much of the succession of the Salt Range is reproduced here.

Tht Potwar-Bannu area is really an outpost of the Himalaya but it is evidently underlain by a corner of the Peninsula which has produced the syntaxial bends on either side of this area, as mentioned before.

The Assam wedge in the north-eastern corner of India is the counterpart of the Potwar and the Punjab wedge and plays much the same role with regard to the structure of the north-eastern tract. It includes the Shillong plateau and the Mikir hills separated by a stretch of alluvium through which the Kopili river flows. This area consists of gneisses and schists (Shillong series) and granitic intrusives and is thus a part of the Peninsula which here apparently extends further to the north-east under the alluvium of the Brahmaputra. The southern flank of the Shillong plateau shows Upper Cretaceous and Tertiary rocks, the latter being extensively developed in the Patkoi, Naga, Barail, Manipur, Lushai and Arakan ranges.

The regional strike over the greater part of Assam is N.E.-S.W. but in the Western part of the Shillong Plateau E.-W. strikes are seen. In the extreme corner of Upper Assam, in the Mishmi hills, the strike is N.W.-S.E. which shows that the Himalayan formations turn here and continue to the south.

The southern border of the Shillong plateau shows Upper Cretaceous and Tertiary rocks overthrust by older formations. Followed eastwards, this fault (the Haflong-Disang fault) becomes a monocline, whose southern limb dips steeply into the plains of the Surma valley. Further east this fault has a north-easterly trend, but the overthrust is from the opposite direction, *i.e.*, from the Patkoi and Naga hills.

The Assam wedge is therefore a block of ancient rocks between two opposing thrusts, one directed southward from the Himalaya and the other north-westward from the Patkoi-Naga hills. Because of these opposing forces, this wedge has been cut up by transverse faults which run approximately N.-S., all with a westerly down-throw, According to Dr. C.S. Fox[1] the fault blocks have been arranged *en echelon*, each block having been shifted slightly south of the one to its west. The northern border of the Shillong plateau also shows a fault and it is supposed that the Brahmaputra valley in Upper Assam lies in a 'ramp valley' or a sag in the crust.

The southern border of the plateau thus shows a resemblance to the southern border of the Potwar plateau (*i.e.*, Salt Range). Though there is a general structural similarity, the stratigraphy is different which tends to obscure the parallelism.

ORIGIN OF THE HIMALAYAS AND THE GANGETIC PLAINS.

It is generally assumed, following the ideas of Eduard Suess, that the Gondwanaland (*i.e.*, the Peninsular mass) remained passive while the country to its north was thrust

[1] *Rec. G.S.I.*, LXXII, pp. 91-92, 1937

against and over its edges. Along its borders, fragments of Gondwanaland have been broken off and carried along the thrusts. Fragments of Gondwanaland are recognisable in parts of the Sub-Himalayan zone, including Peninsular facies of rocks such as Cuddapahs, Vindhyans and Gondwanas. The Aravalli strike is, for instance, seen continued into some parts of Garhwal while the Satpura or Eastern Ghats strike has been noted in parts of the Eastern Himalaya. The main mass of the overriding rocks are the soft sediments formed in the seas surrounding Northern India. To the front of the thrust region is the 'fore-deep', or a sag in the crust, obviously formed by a slight buckling down of the crust in obedience to the pressure exerted on the edges of the Peninsular mass.

There is, however, one anomaly to be explained in this conception of Central Asia moving towards India. The Pacific Coast of Asia also shows convex arcs of Tertiary age facing the ocean, which would mean that Central Asia moved towards the east at the same time as it moved southwards. P. Lake[1], who has discussed this question, points out the difficulty of explaining how a single mass could move in different directions at the same time and suggests that the Pacific region and the Indian region have been underthrust towards Asia, which is a plausible explanation. Moreover, Central Asia is a region of great excess of matter which could only be explained as due to compression *towards* it. The Baluchistan arc and the Himalayan arc appear as if they were compressing the area of N.W. India intervening between them. Burrard points out that, if this were the case, an excess of mass should be found in this region (N.W. Punjab), but the reverse is the case. The explanation would seem to be that the mountains are being pushed back by the borders of the Peninsula, rather than the reverse.

---

[1] *Geogr. Jour*, 78, p. 149, 1931.

It would appear therefore that, relatively speaking, the Indian shield has been moving northward by under-thrusting, allowing the comparatively soft sediments in the basin around the northern border to glide over it and to adjust themselves to some extent to the shape of the ancient mass. It is this adjustment which now gives the appearance of an easterly movement of the Baluchistan arc and westerly movement of the Burma arc. According to this explanation, India should have moved northward (or north-eastward, since that is the general direction perpendicular to the Himalayan arc) a considerable distance, pushing back all the while the sediments deposited in the northern sea. The borders of the comparatively rigid mass of the Peninsula have apparently suffered a downward buckling or warp at the same time, forming the 'fore-deep' bordering the Indian side of the mountain arcs, which has since been filled up by thick sediments. Before following up this line of thought further, it would be well to examine the evidence obtained by geodetic observations in India.

Geodetic observations.—The making of accurate maps necessitates the fundamental assumption of a standard form of spheroid for the shape of the earth. This would be given by the sea-level surface if we imagine that surface to be continued through the continental masses as well. This sea-level surface (computed mean sea-level from tidal observations), would give the 'geoid' which is an oblate spheroid. The Survey of India has used, for this purpose, a spheroid (usually called Everest's spheroid)[1] whose equatorial semi-axis is 6,377.3 kilometres with an ellipticity[2] of 1/300·8. The modern value is however very slightly different, the major semi-axis being 6,378.4 kilometres and the ellipticity 1/295.

---

[1] H J Couchman, Progress of Geodesy in India. *Proc Nat Acad Sci. India* III, p 23, 1937.

[2] Ellipticity $= \frac{a-b}{a}$ where a and b are the equatorial and polar semi-axes respectively.

If we have a homogeneous sphere it will have the same force of gravity at every point on its surface, *i.e.*, the geopotential will be the same at every point. But the geopotential will vary according to height (*i.e.*, vertical distance from the level surface of reference) and also according to variation in the distribution of matter. Any extra mass as that which forms a plateau or mountain will give an extra value of gravity over it which can be measured. As a general rule[1] we can state that if we have a thickness of 1 km. of rock of average density 2.5 per unit area (1 square cm.) it increases the gravity by 0.105 cm./sec.^{2} This extra thickness of 1 km. therefore gives roughly an extra value of 100 milligals (1 milligal=0.001 cm./sec.^{2}).

There is another type of effect. This extra mass possesses gravitative attraction, which will be seen as a deflection, from the vertical, of a plumb-line placed at the side of the mass. This deflection, when measured, can give us a measure of the mass which produces it.

The attraction due to gravity is, as we have seen, dependent on the height above the spheroid at which the measurements are taken. It will be different and smaller if we could take it *in free air* at the same height (*i.e.*, allow for the fact that the place of observation is some distance above the geoid surface and so from the centre of the earth). This gives the 'free air' value. We can calculate this from the observed gravity by allowing for the height above the mean sea-level. The difference is the 'free air anomaly.'

It is an observational fact that most mountains produce much less disturbance on gravity than what we should expect if they were merely added matter of standard density. This anomalous difference is called the 'Bouguer anomaly.'

---

[1] H Jeffreys, Earthquakes and Mountains, London, 1935, Chapter, III

[2] Ellipticity $= \frac{a-b}{a}$ where a and b are the equatorial and polar semi-axes respectively

Isostasy.—It is also known that gravity does not vary in accordance with the height of solid matter above sea-level or depth below sea-level. In the Alps, for instance, the observed gravity is something like 100 milligals less than what would be the normal. In the 'deep' off the coast of California we should expect gravity anomalies of—300 milligals if the 4-mile depth meant merely replacing normal rock by water. But in many parts of the oceans the anomalies are systematically positive. These observations prove that, in and below mountains, there is matter of lower density than normal,and in ocean basins there is matter of higher density. Thus Nature seems to try to compensate the visible inequalities cf matter by density, so that excess of matter is compensated for by lack of density and defect of matter by an excess of density. This relationship between mass and density is called *Isostasy.* The subterranean variation of mass is called *compensation* ; if there is too much, it is over-compensation, and if too little under-compensation. If our calculated value of gravity is also corrected for the disturbance due to any type of assumed compensation, we get the *isostatic anomaly.* The free-air anomaly gives us the earth's external gravitational field. The Bouguer anomaly gives us the sum total of all the information about the distribution of density. Isostatic anomaly is only of interest to test any particular theory of compensation.

It is an interesting fact that it was in India that the theory of mountain compensation was first propounded by Archdeacon Pratt of Calcutta, an eminent mathematician to whom Sir Andrew Waugh (Surveyor General of India) referred certain gravitational anomalies for solution. When the deflections of the plumb line were measured at some localities near the foot of the Himalayas, it was found that the observed deflection was much less than the result obtained by calculation from the visible excess of matter of the Himalayas. At Dehra Dun the calculated and observed deflections are 86 seconds of arc and 36 seconds of arc respectively ; at Murree they are 45 seconds and 12 seconds respectively.

According to one view of isostasy adopted by Hayford and Bowie of the United States Coast and Geodetic Survey, different vertical sections or blocks of the crust may be thought of as being completely compensated at a certain uniform depth, called the *depth of compensation.* This can be illustrated by an experiment in which blocks of various substances, of equal cross section and of equal weight, are resting on a heavy liquid, say mercury. Here they all sink to the same depth but rise to various heights above the liquid in inverse relation to density. On the Hayford principle, the depth of compensation in the earth's crust is generally taken as 60 miles below sea-level. According to another interpretation, blocks of one substance having the same cross section but different weights can be thought of as resting on mercury. Here they sink to various depths and also have their top surface at various heights. The latter view, allowing for variations in the depths of compensation of different segments of the earth's crust, is perhaps more in consonance with the evidence of seismology. Below a mountain range, the surface of contact between the lighter upper layer and the heavier bottom layer would be at a lower level than elsewhere. Under a low plain, the lower heavy layer of the crust would reach up to a comparatively higher level than under a mountain. Under an ocean floor, the lower heavy layer will rise still nearer to the surface of the crust.

Both the views, however, agree that there is a natural tendency for compensation of mass against density. On the whole, the second view (favourd by Heiskanen and others) seems to give better agreement with the observed values of gravity in addition to agreeing with seismological evidence. It is also to be noted that the underground compensation is more likely to be spread out over a larger area than that indicated by the surface inequality. Heiskanen's estimate of the depth of compensation is about 40 km.

It is well known that continental masses are built up, to a large extent, of granite. Granite and large masses of sediments also form the mountain ranges of Tertiary age. In contrast with this, heavier rocks like basalt are found in regions which have been rent by tensional cracks. The ocean basins are also supposed to have basic rocks at shallow depths. These facts and suppositions are in accord with the principles of isostasy.

This theory can also be used to explain partially the conditions observed in the Himalayas and the Gangetic plains. The Himalayas are built up of huge masses of sediments estimated to have an aggregate thickness of over 30,000 feet, with a granitic core in places. The plains bordering these are deep troughs filled with alluvium, which are also to some extent compensated. There are, however, large anomalies which could not be explained by isostasy. It happens that there is a great deal more agreement between the theory and the actuality in the U.S.A. than in India. The gravity data in India show that there is a major belt of high gravity running through Sambalpur-Jubbulpore-Jodhpur called ' Burrard's Hidden Range ' which is explained by the geodesists of the Survey of India as a region in which heavy sub-crustal rocks have risen fairly close to the surface. A parallel hidden trough exists under a zone connecting Belgaum-Bellary-Nellore.

Glennie's Explanation.—Several local anomalies are also found throughout India, to explain which, Col. E.A. Glennie of the Survey of India has advanced his hypothesis of *crustal warp.* After allowing for isostatic compensation and the major features of the Hidden Range and Trough, the residual anomalies are explained by certain postulated upwarps and downwarps in which the sub-crustal dense layer is considered to rise towards, and recede from, the surface. This seems to give a satisfactory explanation of the anomalies.

Col. Glennie's deductions are described and figured in the successive Geodetic Reports of the Survey of India.

The major upwarps are, according to Col. Glennie :—

(1) From the laccadives along the western coast and the Aravallis to Dehra Dun.

(2) Along the eastern coast of Ceylon, Madras and Orissa.

(3) Shillong Plateau and the southern border of the Gangetic alluvium and from Delhi to the eastern end of the Salt Range.

(4) Karachi to the Sulaiman Range.

Minor lines include the belt of Dharwarian rocks of Mysore, from the mouth of the Kistna to Chhindwara in the Central Provinces, and between and parallel to the Narbada and the Tapti.

The major downwarps are :—

(1) The Maldives and along the Western Ghats up to the Tapti.

(2) Ceylon, and the Cuddapah basins of Madras and Bastar-Chhattisgarh.

(3) The Vindhyan basin of Gwalior.

(4) The Ganges valley and Upper Punjab plains.

(5) The Indus valley down to the junction with the Sutlej and straight on to the Rann of Cutch.

In the Peninsula, the fair coincidence of the upwarps with the compressed synclinals of Dharwarian age and that of some of the downwarps with the Cuddapah and Vindhyan basins is quite interesting. It is also rather remarkable that the Himalayas, the Gangetic trough and the Hidden Range and Trough exhibit parallel disposition. If the Gangetic trough has been formed by the buckling down of the Peninsula a little behind where its edges are overthrust by the Himalayas, it is an interesting speculation whether the Hidden Range and Trough cannot also be attributed to the same movements. The sub-crust under the comparatively rigid crust of the Peninsula may be expected to accommodate itself in this way to the stupendous stresses set up by the opposition of the Peninsula and the Tethyan sediments. It will be noticed that these structures (Hidden Range and Trough) have apparently no connection whatever with any previous structural lines and traverse India across the whole range of geological formations. This indicates that this feature is later than the other major geological and geographical features of India and the parallelism with the trend of the Himalaya is apparently significant.

SELECTED BIBLIOGRAPHY.

Auden, J.B. Geology of the Krol belt. *Rec.* *67*, Pt. 4, 1934.

Auden, J.B. Structure of the Himalayas in Garhwal. *Rec* *71*, 407-433, 1936.

Burrard, S.G. Origin of the Himalaya Mountains—a consideration of the geodetic evidence. *Surv. of Ind. Prof. Paper*, *12*, 1912.

Burrard, S.G. (Presidential address to the Indian Science Congress). *Proc. As. Soc. Beng. N.S.* *12* (2), 1916.

Burrard, S.G. Origin of the gangetic trough, commonly called the Himalayan fore-deep. *Proc. Roy. Soc.* (London) *91-A*, 220-238, 1915.

Burrard, S.G. Attraction of the Himalaya Mountains on the plumb line. *Surv. of Ind., Prof. Paper* *5*, 1901.

Burrard, S.G., Hayden, H.H. and Heron, A.M. Geography and Geology of the Himalaya Mountains and Tibet. (2nd edition). Dehra Dun. 1932.

Crosthwaite, H.L. Investigation of the theory of Isostasy in India. *Surv. of Ind., Prof. Paper* *13*, 1912.

Couchman, H.J. Progress of Geodesy in India. *Proc. Nat. Inst. Sci. Ind.* III, 1937.

Du Toit, A.L. Our wandering continents. London, 1937.

Glennie, E A. Gravity anomalies and the structure of the earth's crust. *Surv. of Ind. Prof. Paper* *27*, 1932.

Hayden, H.H. Relationship of the Himalaya to the Indo-gangetic plain and the Indian Peninsula. *Rec.* *43*, 138-157, 1913.

Krishnan, M.S. The Structure of India. *Ind. Geogr. Jour.* XVIII, 137-155, 1943.

Oldham, R.D. Structure of the Himalayas and the Gangetic plain. *Mem.* *42*, (2), 1917.

Oldham, R.D. Support of the Mountains of Central Asia. *Rec.* *49*, 117-135, 1918.

Oldham, R.D. The geological interpretation of some recent geodetic investigations. *Rec.* *55*, 78-94, 1923.

Sewell, R.B.S. Geographic and oceanographic researches in Indian waters. *Mem As. Soc. Beng. IX*, Parts 1-8, 1925-1938, 10.

Wadia, D.N. Syntaxis of the N.W. Himalayas—their rocks, tectonics and orogeny. *Rec.* *65*, 189-220, 1932.

Wadia, D.N. Structure of the Himalaya and the North Indian foreland. *Proc. 25th Ind Sci. Congress*, 1938, Pt. II, p. 91-118.

Wadia, D.N. The making of India. *Proc. Ind. Sci. Cong.* 29th session, Baroda (Presidential Address). Part II, 3-23, 1942.

Pilgrim, G.E. and West, W.D. Structure and correlation of the Simla rocks. *Mem.* *53*, 1928.

West, W.D. Structure of the Shali window. *Rec.* *74*, 133-163, 1939.

Wiseman, J.D.H. and Sewell, R.B.S. The floor of the Arabian Sea. *Geol. Mag.* *74*, 219-230, 1937; *75*, 143-144, 239-240, 1938.

——Geodetic Reports (annual). Survey of India, Dehra Dun.

——John Murray Expedition, Scientific Reports, I, 1936.

CHAPTER III.

GENERAL REVIEW OF INDIAN STRATIGRAPHY.

Stratigraphical or historical geology has, as its aim, the description and classification of rocks with a view to arranging them in the order in which they were laid down on the surface of the earth. Of the three great groups of rocks—sedimentary, igneous and metamorphic—only the sedimentary rocks are easily amenable to such an arrangement, since they have been deposited bed by bed and contain the remains of organisms which flourished while they were formed. The lithological characters of the units or formations and their fossil contents have been invaluable for determining the chronology of the materials of the earth's crust, as will be explained below.

Lithology.—The lithological characters of the different groups of rocks are persistent through their thickness and over the area in which they are exposed, though there may be minor variations from bed to bed. Each lithological type comprises a number of individual beds having more or less the same characters and is spoken of as a formation and given a local or specific name to distinguish it from a similar formation of a different age or belonging to another area. We have thus the Barakar sandstone, Kamthi sandstone, Bhander sandstone; the Attock slate and Cumbum slate; the Daonella limestone and Megalodon limestone, etc. The lithology is often of help in correlation as in the case of the Spiti shales of various parts of the Himalayas or the Purple sandstone of the Salt Range and the similar Upper Vindhyan sandstone of Central India.

Fossil content.—Each formation has not only distinct petrological characters but also encloses a fossil assemblage which is characteristic and different from that of the underlying and overlying formations. Animal and vegetable organisms of each particular geological age bear special characters not found in those of other ages. Though some species are long-lived and have a long range in time, there are others which have a very short range, and each assemblage contains a mixture of many different species and groups of animals. Some species, for example of graptolites and ammonites, are so highly specialised in morphological characters and so restricted in range of time that they are highly valuable indicators of very small sub-divisions of geological time.

Fossil assemblages of the same age are not necessarily identical, for the species in them will depend on the conditions of environment. If the environment was the same or similar, the species may be identical or closely allied, as in the case of marine fauna ; if different, as in the case of estuarine and lacustrine deposits, the elements of the fauna will be different but will show the same stage of evolution or development in respect of each other and in comparison with the parallel faunas of another age. The conditions which control sedimentation and life give rise, therefore, to different *facies*, such as the deep sea, coastal, estuarine, fluviatile, etc.; and also, depending on lithology, to shale, limestone or sandstone facies. Hence, in comparing the faunas or floras of two areas, the lithological as well as environmental facies will have to be fully taken into account.

Order of superposition.—Every geological formation rests on another and is superposed by a third. The formation at the bottom is naturally older than the one at the top, and when we deal with several, the upper ones are successively younger than those below. This sequence is the same wherever the same formations are met with.

If the formations have been laid down continuously, each of them grades perfectly into the succeeding one. They are then said to be *conformable.* The gradation is not only lithological but also faunistic. It often happens however that, owing to local upheavals, some formations are locally missing. In this case, the transition from the underlying to the overlying beds will be abrupt, such a break in continuity being called an *unconformity*. The unconformity is marked by a change in rock type, by the different disposition of the overlying beds, by the intervention of a horizon of conglomerate containing pebbles from the underlying formation, and by other features. The overlying formation may spread over and transgress the limits of the lower one, thereby showing the phenomenon of *overlap*. Or, there may be regressive overlap or gap. Yet these phenomena do not affect the order of superposition of the strata.

The earth's crust is the scene of constant changes and the rocks are affected by them in various ways. They may be tilted, folded, and faulted. They may be intruded by igneous rocks, or metamorphosed as a result of earth movements. The final result of these changes, as seen at the present day, is often very complex but the geologist should observe all the facts carefully and unravel the history of the formations after weighing all the available evidence.

TABLE 2—THE GEOLOGICAL SYSTEMS.

Groups.	Systems.
Quaternary	Recent Pleistocene
Tertiary or Kainozoic or Cenozoic	Pliocene Miocene Oligocene Eocene
Secondary or Mesozoic	Cretaceous Jurassic Triassic
Primary or Palæozoic	Permian Carboniferous Devonian Silurian Ordovician Cambrian
Archæan or Azoic	Pre-Cambrian Archæan

TABLE 3—THE STANDARD FORMATIONS AND STAGES.

Recent		Present day alluvium			
Pleistocene		Younger alluvium			
		Older alluvium			
Pliocene		Villefranchian (Arno beds)			
		Astian			
		Plaisancian			
		Pontian			
Miocene		Sarmatian			
		Tortonian		Vindobonian	
		Helvetian		Vindobonian	
		Burdigalian			
		Aquitanian			
Oligocene		Chattian			
		Rupelian (Stampian)			
		Lattorfian (Sannoisian)			
Eocene		Ludian		Priabonian	
		Bartonian		Priabonian	
		Auversian			
		Lutetian (Parisian)			
		Ypresian (Cuisian)		Londinian	
		Sparnacian		Londinian	
		Thanetian			
		Montian			
Cretaceous		Danian			Chalk
		Mæstrichtian			Chalk
		Campanian			Chalk
		Senonian	Santonian		Chalk
		Senonian	Coniacian (Emscherian)		Chalk
		Turonian			Chalk
		Cenomanian			Chalk
		Albian (Gault & Upper Greensand)			
		Aptian (Lower Greensand)			
		Barremian			Wealden.
		Hauterivian		Neocomian	Wealden.
		Valanginian		Neocomian	Wealden.
Jurassic		Tithonian (Purbeck)			White Jura or Malm
		Portlandian			White Jura or Malm
	Oolite	Kimmeridgian	Bononian		White Jura or Malm
	Oolite	Kimmeridgian	Havrian		White Jura or Malm
	Oolite	Sequanian (Lusitanian)			White Jura or Malm
	Oolite	Oxfordian	Argovian		White Jura or Malm
	Oolite	Oxfordian	Divesian		White Jura or Malm
	Oolite	Callovian			Brown Jura or Dogger.
	Oolite	Bathonian			Brown Jura or Dogger.
	Oolite	Bajocian			Brown Jura or Dogger.
	Oolite	Aalenian			Brown Jura or Dogger.

Jurassic	Lias	Toarcian		Black Jura.
		Charmouthian		
		Sinemurian		
		Hettangian		
Triassic	..	Rhætic		Keuper
		Noric		
		Carnic	Tuvalic, Julic	
		Ladinic		Muschel-kalk
		Virgloric (Anisic)		
		Werfenic (Scythian)		Bunter
Permian	..	Thuringian		Zechstein
		Saxonian (Punjabian)		Rotlie-gendes
		Artinskian		
Carboniferous	..	Stephanian	Uralian	Pennsyl-vanian
		Westphalian	Moscovian	
		Namurian		Mississi-pian.
		Dinantian	Culm	
Devonian	..	Famennian		
		Frasnian		
		Givetian		
		Eifelian		
		Coblentzian		
		Gedinnian		
Silurian	..	Downton (Downtonian)		
		Ludlow (Clunian)		
		Wenlock (Salopian)		
		Llandovery (Valentian)		
Ordovician	..	Bala (Caradocian)		
		Llandeilo (Llandeilian)		
		Arenig (Llanvirnian)		
Cambrian	.	Potsdamian (Olenus)		
		Acadian (Paradoxides)		
		Georgian (Olenellus)		

After careful study, the geological formations have been arranged into a few major groups. These are shown in Table 2 in the order of increasing antiquity. The latter terms in these groups indicate the stage of development of the organisms. The Azoic is either entirely devoid of organisms or contains only traces of the most primitive life; the Palæozoic contains the remains of ancient animals and plants, and so on to Recent times.

The major groups are divided into Systems; each System into Series; each Series into Stages; each Stage into Zones. Corresponding to these divisions of formations there are divisions of geological time, as shown below:

Formations.		Time.
Group (*e.g.* Mesozoic)		Era.
System (*e.g.* Triassic)	.	Epoch.
Series (*e.g.* Upper Triassic)	..	Period.
Stage (*e.g.* Carnic)	.	Age
Zone (*e.g.* *Tropites subbullatus*)		

As the geological formations were first studied in Western Europe, the names of formations in the European region are now universally used as standards of reference to facilitate the correlation and comparison of formations of all parts of the world. Table 3 gives the names of the chief divisions in usage, and many of them will be frequently referred to in the following pages.

GENERAL REVIEW OF INDIAN STRATIGRAPHY.

Before commencing the description of the stratigraphical units of India, a general summary might prove useful so that the subject can be viewed in the roughest outline.

More than half of the Peninsula is occupied by the Archæan rocks, including schistose rocks which are generally referred to as the Dharwarian group. The Cuddapah, Vindhyan and Gondwana systems and the Deccan Traps occupy the rest of the area, except parts of the coastal regions. In the Extra-Peninsula, marine sedimentary systems predominate, though parts of the sub-Himalaya and the main axis of the Himalaya are occupied by ancient metamorphic rocks and intrusive igneous rocks. A full succession of fossiliferous sedimentary systems, extending from the Cambrian to Eocene, is met with on the Tibetan side of the Himalaya, while the southern or Sub-Himalayan zone contains a different facies which is practically unfossiliferous. These two facies are, however, found in juxtaposition in Kashmir.

Beyond the sharp syntaxial bend of the North-western Himalaya near the Nanga Parbat, the Hazara area shows unfossiliferous Palæozoics and fossiliferous later formations ; but further south, the Baluchistan arc is built up mainly of post-Carboniferous systems which sweep down in a broad arc to the Mekran region where the Tertiaries predominate. To the east and south of the north-eastern Syntaxis of Assam, in the Burmese arc, Tertiary rocks form a broad zone with a core of Upper Mesozoic rocks which constitute the Arakan Yomas. To their east is the Shan-Tenasserim belt of pre-Tertiary rocks which corresponds roughly to the Himalayan belt.

The major stratigraphical divisions of India are shown in Table 4 together with their standard European equivalents, these being arranged, as usual, in the order of increasing antiquity.

TABLE 4—GEOLOGICAL FORMATIONS OF INDIA.

Recent	Recent alluvia.	
Pleistocene	Older alluvia and Pleistocene.	
Mio-Pliocene	Siwalik and Irrawaddy systems.	
Oligo-Miocene	Murree and Pegu systems.	
Eocene	Ranikot-Laki-Kirthar-Chharat series.	
Cretaceo-Eocene	Deccan Trap and Inter-trappeans.	
Cretaceous	Upper Cretaceous of South India, Assam, Narbada valley ; Giumal and Chikkim series (Himalaya)	
Jurassic	Spiti shales; Upper Kioto Limestone	Gondwana system (Lower Cretaceous to Upper Carboniferous.)
Triassic	Lilang system	
Permian	Kuling system	
Carboniferous	Lipak and Po series	
Devonian	Muth quartzite	
Silurian	Silurian	
Ordovician	Ordovician	
Cambrian	Cambrian	Vindhyan system.
Algonkian	Dogra and Simla slates	Cuddapah system.
Archæan	Salkhala, Jutogh and Chail series	Dharwar system etc. and gneisses.

In 1904, in an article in the Imperial Gazetteer of India, Sir T. H. Holland proposed a new classification of the Indian strata in which the Cuddapah and Vindhyan systems were grouped together under the name of *Purana group*, corresponding to the Algonkian of America. The strata from the base of the Cambrian to Middle Carboniferous were put together under the *Dravidian group*. At the top of this group and below the Talchir boulder bed there is a well marked and universal unconformity. All the rocks from the Talchir boulder beds upwards were placed under the *Aryan group* which therefore includes everything from the Upper Carboniferous to the Pleistocene. Of these, only the term ' Purana ' is sometimes used in geological writings and the other two have not gained any currency.

The main divisions enumerated in the Table above have representatives in different areas, varying in facies, lithology and succession. Besides deep-sea and coastal marine, we have also estuarine, fluviatile and continental facies of different ages. It is fairly easy to correlate the marine systems of the Extra-peninsula with those of the coastal regions of the Peninsula because of the contained fauna. But in the case of the fluviatile and continental deposits, the faunas are of local distribution and have special characters for which there are few helpful parallels in other parts of the world. Their age can be settled with confidence if they are in some way connected with marine beds or if the age of any similar formations in other parts of the world is known.

There are several stratigraphical problems in this sub-continent which await solution. The regional peculiarities of strata have necessitated the growth of a considerable number of local names which have only a limited application. Moreover, geological work was originally done in a series of detached areas which have compelled the adoption of local nomenclature. As these areas were connected up by the mapping of the intervening tracts, some of the local formation names have become superfluous. But, in a large number of cases, even though the general equivalence or homotaxis could be recognised, the local nomenclature persists because of the lack of identity of characters or of complete parallelism.

By far the greater part of India has been mapped in a general way but there are still some blanks in Orissa, in the Central Provinces, parts of Assam and in the Himalaya. These are gradually being filled up while several of the more important areas have been undergoing revision. Hence the stratigraphic information available on different parts of the country is of varying degrees of modernity, detail and precision. Among the best known areas at present are Mysore, the Cuddapah basin of Madras, Chota Nagpur, the Nagpur-Chhindwara area of the Central Provinces, Rajputana, Salt Range, Kashmir, the Sub-Himalaya of Simla-Garhwal and parts of the Tertiary belt of Burma.

A generalised picture of the geological succession in different areas is presented in Table 5 which may be useful for reference purposes. Further details about individual areas will be found in the relevant chapters in which each geological system is described in detail.

TABLE 5—GENERAL GEOLOGICAL SUCCESSION IN DIFFERENT PARTS OF INDIA AND BURMA.

(Sy.=System ; S.=Series ; B.=Beds ; Sst.=Sandstone ; Lst.=Limestone.)

Standard scale	Northern Himalaya	Baluchistan arc	Salt Range & Potwar	Kashmir-Hazara	Simla-Garhwal	Assam	Burma	Peninsula	Coastal areas
RECENT	Alluvium	Sands, Loess	Alluvium, Loess	Alluvium &c.	Alluvium &c	Alluvium, River gravels	Alluvium, River gravels	Alluvium Khadar	Alluvium sands
PLEISTOCENE	Older alluvium, gravels, moraines	Older alluvium, sands	Older alluvium, etc	Older alluvium, moraines, Upper Karewa	Older alluvium, moraines	Older alluvium, gravels	Older alluvium, river terraces	Older alluvium, Bhangar, cave deposits, river terraces	Raised beaches Porbander stone etc
PLIOCENE UPPER MIOCENE	—	Siwalik Sy Manchhar Sy	Siwalik Sy.	Lower Karewa Siwalik Sy	Siwalik Sy	Dihing S	Irrawaddy Sy.	—	Siwalik Sy Karaikal B Quilon B Cuddalore Sst etc
MIDDLE MIOCENE LOWER MIOCENE	—	Mekran Sy. *Flysch*, Bugti B. Gaj S	Murree S.	Murree S *Fatehjang* zone	Kasauli B *Dagshai B*	Tipam S Surma S.	Upper Pegu S	—	Gaj S
OLIGOCENE	—	Nari S, Khojak shales	—	—	—	Barail S. (in part)	Lower Pegu S.	—	Nari S. Dwarka B.

equivalence or homotaxis could be recognised, the local nomenclature persists because of the lack of identity of characters or of complete parallelism.

By far the greater part of India has been mapped in a general way but there are still some blanks in Orissa, in the Central Provinces, parts of Assam and in the Himalaya. These are gradually being filled up while several of the more important areas have been undergoing revision. Hence the stratigraphic information available on different parts of the country is of varying degrees of modernity, detail and precision. Among the best known areas at present are Mysore, the Cuddapah basin of Madras, Chota Nagpur, the Nagpur-Chhindwara area of the Central Provinces, Rajputana, Salt Range, Kashmir, the Sub-Himalaya of Simla-Garhwal and parts of the Tertiary belt of Burma.

A generalised picture of the geological succession in different areas is presented in Table 5 which may be useful for reference purposes. Further details about individual areas will be found in the relevant chapters in which each geological system is described in detail.

TABLE 5—GENERAL GEOLOGICAL SUCCESSION IN DIFFERENT PARTS OF INDIA AND BURMA.

(Sy.=System ; S.=Series ; B.=Beds ; Sst.=Sandstone ; Lst.=Limestone.)

Standard scale	Northern Himalaya	Baluchistan arc	Salt Range & Potwar	Kashmir-Hazara	Simla-Garhwal	Assam	Burma	Peninsula	Coastal areas.
RECENT	Alluvium	Sands, Loess	Alluvium, Loess	Alluvium &c.	Alluvium &c.	Alluvium, River gravels	Alluvium, River gravels	Alluvium Khadar	Alluvium sands
PLEISTOCENE	Older alluvium, gravels, moraines	Older alluvium, sands	Older alluvium, etc	Older alluvium, moraines, Upper Karewa	Older alluvium, moraines	Older alluvium, gravels	Older alluvium, river terraces	Older alluvium, Bhangar, cave deposits, river terraces	Raised beache Porbander stone etc
PLIOCENE UPPER MIOCENE	—	Siwalik Sy. Manchhar Sy.	Siwalik Sy.	Lower Karewa Siwalik Sy	Siwalik Sy.	Dihing S	Irrawaddy Sy	—	Siwalik Sy. Karaikal B Quilon B Cuddalore Sst. etc
MIDDLE MIOCENE LOWER MIOCENE	—	Mekran Sy. Flysch, Bugti B. Gaj S	Murree S.	Murree S. Fatehjang zone	Kasauli B Dagshai B	Tipam S Surma S.	Upper Pegu S	—	Gaj S
OLIGOCENE	—	Nari S., Khojak shales	—	—	—	Barail S. (in part)	Lower Pegu S.	—	Nari S Dwarka B

TABLE 5—*Contd.*

Standard scale	Northern Himalaya	Baluchistan arc	Salt Range & Potwar	Kashmir-Hazara	Simla-Garhwal	Assam	Burma	Peninsula	Coastal areas.
EOCENE	Eocene	Kirthar S. Laki S. Ranikot S.	Chharat S. Kirthar S. Laki S. Ranikot S.	Chharat S. Hill Lst. Ranikot S	Subathu B.	Barail S. Jaintia S. Sylhet Lst. Disang S. Cherra Sst.	Yaw and Pondaung Stages. Tabyin, Tilin, and Laungshe stages.	—	Kirthar S. Laki S. Ranikot S.
UP. CRETACEOUS	Up. Cretaceous Chikkim S.	Cardita Beaumonti B, Pab Sst.	Up. Cretaceous	Up. Cretaceous	—	Disang S. (in part) Up. Cretaceous	Axial S. (in part) Negrais S.	Deccan Trap and Intertrappeans Lametas	Bagh B. Trichinopoly Cretaceous
L. CRETACEOUS	Giumal Sst.	Parh Lst.	L. Cretaceous	Giumal S. Orbitolina Lst.	—	—	L. Cretaceous	Umia B	Umia B.
JURASSIC	Spiti Shales Kioto Lst.	Massive Lst. Crinoidal Lst.	Jurassic	Spiti shales Jurassic	? Tal. S.	—	Namyau B. ? Loi-an B.	Jubbulpore Kota Rajmahal	Katrol Chari Patcham
TRIASSIC	Triassic	U. Triassic	Triassic	Triassic	? Shali Lst. ? Krol S.	—	Napeng B.	Maleri Pachmarhi Panchet	—
PERMIAN	Productus B. Syringothyris Lst.	Permo-Carboniferous	Productus Lst. Speckled Sst	Agglomeratic slates, Zewan B.	? Infra-krol	—	Up Plateau Lst. Moulmein Lst	Raniganj S Barren Measures, Barakar S.	—

UP. CARBONIFEROUS	—	—	Conularia and Eurydesma B. Boulder bed	Agglomeratic sh. Gangamopteris B. Tanakki Boulder B.	? Blaini boulder Bed	Subansiri B.	?	Umaria B. Talchir boulder B.	—
MIDDLE & L. CARBONIFEROUS	Po series Fenestella sh.	—	—	Fenestella sh.	—	—	L. Plateau Lst.	—	—
DEVONIAN	Muth Qtzt.		—	Muth qtzt. Devonian (Chitral)	? Jaunsar S.	—	Padaukpin Lst. Wetwin sh.	—	—
SILURIAN	Silurian	—	—	Silurian	—	—	Zebingyi S. Namshim S	—	—
ORDOVICIAN	Ordovician	—	—	Ordovician	—	—	Naungkangyi S, Mawson S.	—	—
CAMBRIAN	Cambrian	—	Cambrian	Cambrian	? Deoban Lst.	—	Bawdwin volcanics ? Mergui S	Vindhyan Sy.	—
ALGONKIAN	Haimanta Sy	—	Attock slates	Dogra slates	Simla slates	Buxa S Daling S. Darjeeling S	Chaung Magyi S	Cuddapah Sy. Delhi Sy.	—
ARCHAEAN	Vaikrita Sy.	—	?	Salkhala S. Gneisses	Chail S. Jotogh S.	Shillong S, Gneisses	Mogok S. Gneisses	Dharwar Sy. Aravalli Sy etc Gneisses.	—

CHAPTER IV.

THE ARCHAEAN GROUP—PENINSULA.

INTRODUCTION.

The term *Archæan* was introduced by J. D. Dana[1] in 1872 to designate the formations older than the Cambrian. In America it is now restricted to the highly metamorphosed schistose, gneissic and granitic rocks, while the term *Algonkian* includes undoubted original sediments lying below the base of the Cambrians. In India, the formations below the Eparchæan (epi-archæan) unconformity, *i.e.*, the unconformity at the base of the Cuddapah system and its equivalents, have been included under the Archæan by Sir T.H. Holland,[2] with which view Sir L.L. Fermor[3] agrees. Within the Archæans are included certain sedimentary rocks or mixtures of sediments and igneous rocks, these being generally separated into the *Lower Transition System* in order to differentiate them from the Upper Transition systems which appear above the Eparchæan unconformity. The Lower Transition rocks which occur in compressed and partly buried synclinoria in South India were included by R. Bruce Foote[4] in his Dharwar System, named after the District of Dharwar in Southern Bombay. This term has since acquired a wider significance than that given by Foote through the work of several geologists among whom are W. King, J. M. Maclaren and L. L. Fermor, so that it is now often used as a general term for similar formations in other parts of India. Though objections have recently been raised to such a general usage, the term has become so well

---

[1] *Amer. Journ Sci* 3, p. 253, 1872.

[2] *Trans. Min Geol. Inst. India*, I, p. 47, 1907.

[3] *Mem. G.S.I.*, XXXVII, p. 236-238, 1909.

[4] *Rec. G.S.I.* XIX, p. 98, 1886.

entrenched in Indian geological nomenclature that it is scarcely possible to discard it. Used in this broad sense, it serves to designate the schistose Archæans older than the Eparchæan unconformity and to indicate the approximate homotaxial relationship of these formations in various parts of India.

The Archæan rocks are unfossiliferous as they were formed at a time when the conditions for the existence of life were unfavourable. For this reason they are referred to as the Azoic group. We find however that, at the beginning of the Cambrian, a rich fauna appears all over the world. This leads us to infer that there was a long period of evolution when very primitive organisms such as skeleton-less soft-bodied animals and plants of the type of algæ flourished. It is unlikely that such organisms could have left any recognisable impressions or relics, and that they could have survived the repeated and intense changes to which the earth's crust was subjected in Archæan times.

The Archæans form the basement or foundation of all the sedimentary systems. Because of this and their complex constitution, they are referred to as the 'basement complex', 'gneissic complex' or 'fundamental gneiss.' The areas in which they occur are called 'shields' because of their great resistance to later earth movements which have left them practically unaffected. It was at one time believed that some of the Archæan gneisses represented the primordial or first crust formed on a cooling globe. We now know that the Archæans have been affected by at least three, if not more, periods of diastrophism and large scale igneous activity. Though some undoubtedly very ancient gneisses do underlie the oldest schistose members of sedimentary origin, they are so complex in nature and must have had so varied a history that they could scarcely be regarded as representing the original crust.

From what has been said above, it will be apparent that the division of the Archæan group into an Archæan System and a Dharwar System should not be carried to the extent of describing each as a separate unit, since the two are very closely associated and since the granites and gneisses may merely represent certain horizons within the schistose members. Hence the formations are described regionally in the following pages.

DISTRIBUTION.

The Archæans occupy about two-thirds of Peninsular India and the greater part of the island of Ceylon which is but a fragment of the former, now separated by a shallow strait. They stretch continuously from Cape Comorin to the Central Provinces and Bihar and continue apparently underneath the Ganges alluvium into the Assam plateau; the Mysore area is also presumably connected with that of Gujarat and Rajputana beneath the Deccan Traps. This vast stretch includes parts of the Provinces of Madras, Orissa, Bihar, Assam and the States of Travancore, Mysore, Hyderabad, Western India and Rajputana.

In the Extra-peninsular area the Archæans are found in the Lesser Himalaya and also in the Shan States-Tenasserim belt of Burma.

MYSORE—SOUTHERN BOMBAY.

This constitutes the type region of the Dharwar system studied by R. Bruce Foote in the eighteen-eighties. Since then a considerable amount of work has been done by the geologists of the Mysore Geological Department. This region (including the adjoining part of Hyderabad State) is occupied by gneisses and granites which are traversed by a number of bands of schistose rocks, these being named after the places lying on them:

1. Castle rock.
2. Dharwar-Shimoga.
3. Gadag-Dambal (Chitaldrug)-Seringapatam.

4. Sandur-Copper mountain.
5. Bellary-Kushtagi.
6. Penner-Huggari.
7. Maski-Hatti.
8. Bomanhal.
9. Kolar.
10 Raichur.
11. Gadwal.

Besides these there are several small strips scattered over this and the neighbouring regions. These are all thought to be remnants of a great formation which formerly covered a large part of Southern India and which have escaped denudation because they form synclinal strips folded in with the gneisses. The larger ones are evidently closely folded synclinoria in which some members are repeated by folding. For example, Bruce Foote noted about 36 beds across a section in the Sandur band which he believed to form a simple syncline with an overturned easterly limb; since the total thickness, on this interpretation, would amount to 6 miles, it is very likely that this is a synclinorium in which some part of the section is repeated by folding.

The Dharwarian rocks have a regional strike of N.N.W.-S.S.E. which becomes N.-S. at the southern end of Mysore and even veers to a N.E.-S.W. direction.

The Archæan succession of Mysore was described by W.F. Smeeth in 1915. This has since been revised by B. Rama Rao, the latest ideas being given in Bulletin 17 of the Mysore Geological Department. These two classifications are given in Table 6 for comparison. It may be added that Rama Rao's ideas conform in a large measure to those of geologists working in other parts of India.

In Smeeth's classification, the Dharwars, the oldest formations in Mysore, were held to be entirely of igneous origin and divided into a lower Hornblendic division and an upper Chloritic division. This lithological classification has been found defective for it depends more on the regional metamorphic grade than on the age and stratigraphical relationships of the constituent members. In the northern parts of the State, where the Dharwars form wide bands, the chloritic types predominate in the green-stones, while normal limestones, argillites and quartzites are also seen. In the central region, amphibolites begin to develop while the sedimentary types become schistose, recrystallised and silicified. The southern tract contains only comparatively small lenses and stringers amidst the gneisses and they are conspicuously hornblendic, coarsely recrystallised, granulitic and fresh-looking because of the higher grade of metamorphism. Here the argillaceous sediments have been reconstituted into schists and granulites with garnet, staurolite, kyanite, etc., while the ferruginous quartzites are dominantly magnetitic.

Formerly, all the Dharwarian types were regarded as of igneous origin ; the conglomerates as autoclastic and derived from felsites and porphyries ; the hæmatite-quartzites as altered and silicified amphibole rocks and so on. This view has changed in recent years and a considerable part of the Dharwars is now shown to be of sedimentary origin. The conglomerates and grits are found to exhibit ripple-marks and current-bedding. The banded ferruginous rocks are recognised as original sediments with alternating bands of cherty or chalcedonic silica and iron-rich jasper or hæmatite, the nature of the iron oxide having been determined by the degree of metamorphism. The limestones and calc-granulites, which were regarded as products of metasomatism of igneous rocks, are in part at least sedimentary. Some of the conglomerates which were first described as autoclastic, *i.e.*, as pseudo-conglomerates whose structures were produced by shearing and rolling, are now regarded as sedimentary in origin. There are, of course, metamorphosed igneous rocks such as amphibolites, amphibole-schists, talc-tremolite-schists, serpentines, sheared porphyries, felsites, etc. Amongst the mixed types are various gneisses containing

TABLE 6—THE ARCHAEAN SUCCESSION IN MYSORE.

Smeeth (1915)	B. Rama Rao (1940):	Original formations	Probable alterations
Pre-Cambrian— Basic dykes		Basic dykes, chiefly dolerites	
Eparchæan interval—			
Felsite and Porphyry dykes		Felsites nad Porphyry dykes	
Closepet Granite (coarse pink or grey biotite-granite rarely slightly foliated)		Closepet granite	Slightly foliated.
Charnockite massifs and later dykes		Recrystallisation and reconstitution of older rocks into complex types of the charnockite series.	
Hornblende and Pyroxene granulite dykes		Norite dykes Hornblendic dykes	Slightly crushed and granulitic
Peninsular Gneiss (Biotite-granite and gneiss with inclusions of schists).		Peninsular Gneiss Complex granite gneisses.	
Champion Gneiss (crushed granitic gneiss with zones of autoclastic conglomerate)		—Eruptive unconformity.—	
Eruptive unconformity—	Dharwar system: Upper	Some cherty and ferruginous silts, clays, calcareous silts and clays, impure quartzites and conglomerates forming in part the G.R. formation (Local)	Somewhat altered but easily recognisable
Dharwar system: Upper Dharwars (Chloritic Division), Chloritic schists and greenstones, mica-schists, conglomerates, quartzites, crystalline limestones and banded ferruginous quartzites. Also schists with kyanite, staurolite, etc.	Dharwar system: Middle	Granite porphyry and granitic rocks, fine and coarse.	Micaceous granitic gneisses and crushed and foliated gneissic granites.
Dharwar system: Lower Dharwars (Hornblendic division) schistose hornblendic rocks with subordinate magnetite—and hæmatite-quartzites, some calc-granulites etc	Dharwar system: Middle	Basic and ultrabasic intrusives. Ironstones limestones, argillites, quartzites and conglomerates, also ashes, tuffs and other volcanic products.	Banded ironstones with amphibole, etc., granular crystalline limestones, micaceous gneisses with cordierite, sillimanite, etc., schistose conglomerates — all highly crushed and crystalline
	Dharwar system: Lower	Rhyolites, felsites and quartz-porphyry and other acid volcanics with opalescent quartz	Quartz-schists, micaceous quartz-schists and gneisses with opalescent quartz—highly crushed.
	Dharwar system: Lower	Basic volcanic dykes and flows.	Greenstones, hornblende-schists etc.
		—Original basement not recognised—	

biotite, hornblende and garnet, pyroxene-bearing granulites and calc-granulites.

Rama Rao has divided the Mysore occurrences into five geographical groups from west to east. The westernmost contains mainly hornblendic schists and thin bands of hæmatite-quartzites. The west-central group, comprising the Shimoga and Bababudan belts, shows a fairly full succession, banded ferruginous rocks and manganiferous rocks occurring in force in the Bababudan hills. The central group, comprising the Chitaldrug, Chiknayakanhalli and Nagamangala belts, shows much igneous material and also banded ferruginous rocks and limestones. The east-central group includes various small occurrences in which both regional and thermal metamorphic effects are discernible which have produced several interesting rock types—quartz-magnetite-granulites, garnetiferous quartzites, garnet-quartz-pyroxene-granulites, sillimanite-cordierite-gneisses, sillimanite-quartzites, cordierite-hypersthene gneisses, cordierite-mica gneisses, cummingtonite-schists, pyroxene-gneisses, etc. The easternmost is the Kolar schist-belt which is of great economic importance because of the rich gold-bearing vein quartz in it. It is 40 miles long and 4 miles broad at its widest and is composed of hornblendic rocks believed to be of igneous origin, with a band of autoclastic conglomerate at its eastern border.

According to Rama Rao, the Shimoga schist-belt in the west-central area exposes one of the best developed sections of Dharwars. Typical current-bedding and ripple marks, indicating undoubted features of sedimentary origin, have been found at several places in this belt in recent years. The oldest rocks are basic volcanics overlain by rhyolitic flows and tuffs and intruded by sills of felsite and porphyry. With these are intercalated bands of chert and halleflinta. They are succeeded by thick beds of conglomerate containing pebbles of felsite, quartz-porphyry and quartzite. Above these are micaceous quartzites showing current-bedding in the upper layers. These are the earliest undoubted sediments in the Dharwars. The quartzites are succeeded by slaty schists, limestones and banded ferruginous quartzites, intruded by bosses of granite-porphyry. This series is followed by a bed of conglomerate indicating a period of uplift and denudation. Further sedimentation laid down a series of silts and ferruginous quartzites above these rocks. The succession in the Shimoga belt, as worked out from several sections, is shown in Table 7.

TABLE 7—DHARWARIAN SUCCESSION IN THE SHIMOGA BELT.

(After B. Rama Rao, *Mysore Geol. Dept. Bull. 17*, p. 36).

Upper Dharwars (Sulekere series)	(e) Ferruginous quartzites and cherty ferruginous slates with thin intercalations of argillitic layers and probably of ash beds. (Rain-prints and sun-cracks in some sections). (d) Friable ferruginous silts and micaceous ferruginous grits intercalated with thin bands of limestone towards the top Basic hornblendic sills. (c) Argillitic and calcareous silts and fine grained quartzites with minute grains of opalescent quartz. (b) Quartzites. (a) Jandimatti and Kaldurga conglomerates containing pebbles of granitic rocks, ferruginous quartzites, schists, etc.

Granite-porphyry masses of Rangandurga, Balekal and probably granites of Honnali, Shimoga and adjacent parts.

Middle Dharwars (Hosur series)	(e) Banded hæmatite-quartzites (Chandigudda outcrops). (d) Limestones, dolomites and siliceous limestones. (c) Phyllitic and chloritic schists, grey or greenish. (b) Sericitic grits and quartzites with coarse grains of opalescent quartz. (a) Conglomerates (showing pebbles of 'quartzites' and quartz-porphyries), felspathic grits and greywackes.

Lower Dharwars (Igneous Complex) ..	(c) Sills of quartz-porphyry, felsite and other types of acid intrusives and their schistose phases. (b) Acid and intermediate flows—rhyolites, keratophyres, etc., with intercalated tuffs and ash-beds now seen as dark grey or bluish argillitic layers and beds, altered in places into compact hornstones in contact with (c). (a) Compact greenstone and greenstone-schists, micaceous or calciferous chlorite-schists, etc. (Basic and intermediate lava flows probably with admixed ash beds.)

Before leaving the Dharwars it may be mentioned that there are amongst them certain special rock types, usually occupying small areas. Among these are included :

(1) SAKARSANITE SERIES developed as lenses amidst gneisses near Sakarsanhalli, Kolar district, and consisting of calc-granulites, hornblende-granulites, sillimanite quartzites, manganiferous limestones and cummingtonite schists.

(2) BANDITE SERIES near Bandihalli, Bangalore district, comprising garnetiferous hornblende-granulites, cordierite-sillimanite gneisses, quartz-magnetite granulites, etc.

(3) KODAMITE SERIES seen around Kodamhalli, Bangalore district, and consisting of cordierite-biotite gneisses with sillimanite and garnet, garnetiferous quartzites, quartz-magnetite-pyroxene granulites, etc.

(4) BIDALOTI SERIES named after Bidaloti near Koratgere, Tumkur district, and including diopside-granulites, cordierite-hypersthene-rock, sillimanite-quartzites and quartz-magnetite granulites.

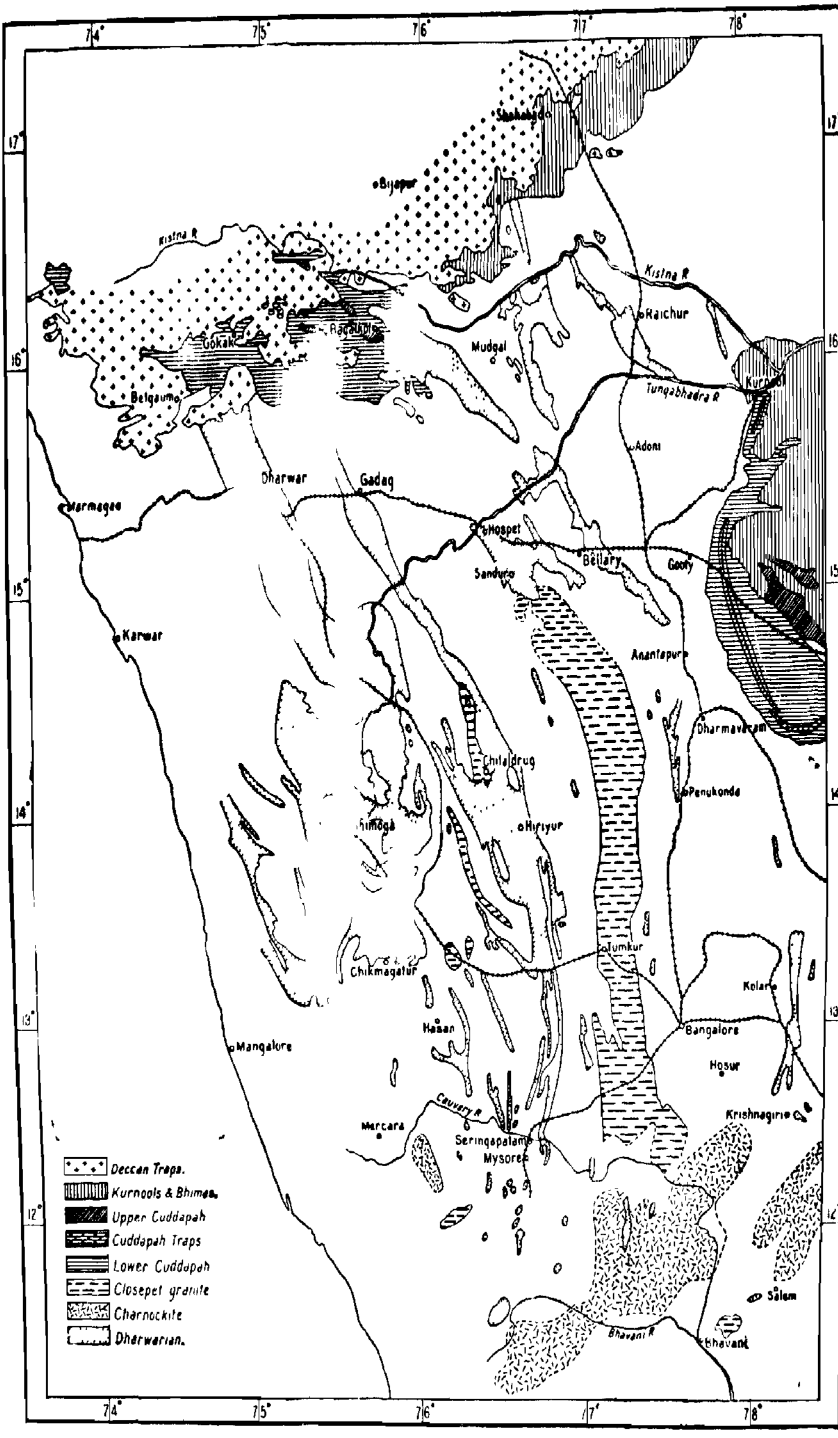
The stratigraphical relationships of these rocks are far from clear. They appear, however, to be mainly of sedimentary origin and resemble in some measure the rocks found in the Sausar series of the Central Provinces which are referred by Fermor to a lower division of the Dharwars.

The Dharwars appear to rest on gneisses and granites and it seems certain that their base has been stoped out by igneous intrusions of a later age. It is doubtful if any original Archæan basement still remains as such under the schistose rocks.

MAP IV

THE DHARWARS OF SOUTH INDIA

To Face P. 103



Champion gneiss.—Succeeding the Dharwars is the Champion gneiss which is a sheared, grey, micaceous gneiss whose type area is the eastern edge of the Kolar schist belt. It contains blebs of opalescent, grey-coloured quartz. Some other types like keratophyres, rhyolites, quartz-porphyries and some granites, which also contain the same opalescent quartz, are included with the Champion gneiss group, but it is not always easy to distinguish some of them from the types belonging to the Peninsular gneiss group. It appears desirable to restrict the use of the name Champion gneiss to the stocks and bosses of granite and granite-porphyry which are older than the Peninsular gneiss.

Peninsular gneiss.—This is the most widespread group of rocks in Mysore and in many parts of Southern India. They consist of a very heterogeneous mixture of different types of granites intrusive into the schistose rocks after the latter were folded, crumpled and metamorphosed. They include granites, granodiorites, gneissic granites and banded or composite gneisses, the granitic constituents of which show distinct signs of intrusion. The banded gneisses consist of white bands of quartz-felspar alternating with dark bands containing hornblende, biotite and minor accessories. The gneissic types are due to the intensive granitisation of older schistose rocks and show streaky and contorted bands some of which are granitoid to porphyritic and others granulitic. The granitic group ranges in composition from granite, through granodiorite to adamellite, augite-diorite, monzonite, etc., and contains inclusions of hornblendic rocks. To what extent they represent intrusives of different ages it is difficult to say, but their very complex nature is unquestionable since they include composite gneisses, migmatites, granitised older crystalline rocks and true granites with their aplitic and quartz vein systems.

Charnockites.—The next younger group of rocks is the Charnockite series whose characters seem to show that they are igneous in origin, and which were originally named the 'Mountain gneiss' or 'Nilgiri gneiss' by W. King as they constitute the Nilgiris and other hills in South India. They comprise a whole series of rocks ranging in composition from acid to ultrabasic, the intermediate (syeno-dioritic) type being the most common. The acid type was called charnockite by Sir Thomas H. Holland (after Job Charnock, the founder of Calcutta, whose tombstone is made of this rock) and the name was extended to cover the whole series.

The rocks are all characterised by the presence of the ortho-rhombic pyroxene hypersthene. They are bluish grey to dark grey in colour, granitoid and massive. The acid and intermediate members contain bluish-grey, waxy looking quartz with a greyish to brownish turbidity, containing acicular inclusions of rutile, and perthitic microcline (less frequently orthoclase) and plagioclase. Garnet is fairly common while zircon, magnetite and ilmenite are the usual accessories. The chief ferromagnesian mineral is enstatite-hypersthene, but augite and hornblende are also found, while biotite is not common. The basic varieties are noritic and rich in hypersthene. The ultrabasic ones are pyroxenites and hypersthenites which occur as lenses and segregated patches. Some related acid varieties rich in garnet are classed under leptynites. The density of the types varies from 2.67 (acid, with 75 per cent. silica) to 3.37 (very basic, with 52 per cent. silica).

The charnockites include porphyritic types in which large crystals of orthoclase or microcline are developed. In parts of the Eastern Ghats there are evidences of the action of later magmatic solutions producing albitisation and myrmekitisation. The felspars are usually micro-perthitic, and quartz may show graphic intergrowth with felspar. The hypersthene is pleochroic and is often highly schillerized. Augite, often titaniferous, is fairly common while hornblende, though frequently present, is distinctly subordinate in quantity.

The charnockites are widely distributed in Peninsular India and in the Island of Ceylon which is geologically a part of it. They enter largely into the constitution of the south-western part of Ceylon and the mountains of South India including the Nilgiris, Palnis, Shevaroys, Anaimalais and Cardamom hills ; and parts of the Eastern Ghats from north of Nellore to the Mahanadi valley.

Sir T. H. Holland adduced evidence to show that they have the characters of plutonic igneous rocks. They give out tongues, apophyses and veins into the surrounding masses and have sometimes produced mineralogical changes at their contact with other rocks. They show the phenomena of segregation and differentiation. F.L. Stillwell, who found similar rocks in the Antarctic region near Australia thought that the characters are to be ascribed to high grade or plutonic metamorphism at high temperatures and pressures. The chief minerals of the charnockites are devoid of the hydroxyl molecule and indicate high pressure conditions and it is therefore likely that they were formed as comparatively 'dry' magmas originating under kata-zone (hypo-zone) conditions.

Pyroxene granulites similar to or identical wth the charnockites have been found in other areas under specially severe metamorphic conditions, *e.g.*, Central Provinces, Bastar State, Bamra State and Mogok tract in Burma. P. K. Ghosh has described rocks from Bastar State identical in characters with charnockites which he regards as due to the metamorphism of calc-granulites intruded into, and hybridised by, granitic rocks. Vredenburg suggested in 1918 that the charnockites might represent highly metamorphosed representatives of the Dharwars. The trend of opinion at present seems to be that the charnockites are products of plutonic metamorphism showing some of the characters of intrusive rocks.

B. Rama Rao has described the charnockitic and quasi-charnockitic rocks of Mysore as having been formed by different ways from pre-existing rocks under varying conditions. These include recrystallised siliceous, argillaceous and ferruginous sediments which have become granulites with hypersthene ; dykes and sheets of norites and basic rocks, the original amphiboles having been mostly converted to pyroxene ; magnesia- and iron-rich rocks silicified by acid and intermediate igneous rocks. In most cases there is no clear evidence of any intrusive relationships of these 'charnockites' ; indeed they seem to be older than the Peninsular gneisses, according to this authority.

Closepet Granites.—These form a well marked band about 10 miles wide running north to south through Closepet and Channapatna. A few other granites in the State (*e.g.*, Chitaldrug, Hosdurga, Arsikere and Chamundi granites) are also probably of the same age. They are coarse-grained, porphyritic, grey to pink biotite-granites containing inclusions of various types of older schists and granulites. Some of the inclusions have been granitised and modified in composition to diorites. The granites are occasionally foliated in the marginal portions, while the adjacent rocks are in many cases contract-altered. A series of porphyries, felsites and other differentiates traverse the Closepet granites.

This same type of granite has been described as Bellary gneiss, Hosur gneiss and Balaghat gneiss outside Mysore in Southern India. The Dome gneiss of Bihar and the Bundelkhand gneiss of Bundelkhand and Rajputana are also similar though the last is regarded as pre-Aravalli (pre-Dharwar) in age by A.M. Heron. For this type, in South India, the general term 'Bellary gneiss' has been suggested by L.L. Fermor.

HYDERABAD.

The Dharwars are well displayed in the south-western parts of Hyderabad State. A few outlying bands are seen further east in Karimnagar and Warangal districts. They consist, as in Mysore, of hornblende-, talc-, chlorite- and mica-schists, quartzites, ferruginous quartzites, etc., having the same (N.N.W.-S.S.E.) direction of strike. The rest of the country is occupied by gneisses of which there are *two types, a Grey gneiss and a Pink gneiss. The Grey gneiss*, which corresponds to the Peninsular gneiss, is conspicuously banded, the light bands containing quartz and felspar and the dark bands containing mica and hornblende. The Pink gneiss is granitoid, though occasionally gneissic, and intrusive into the Dharwars and into the Grey gneiss, and therefore referable to the Bellary gneiss. It consists of quartz, microcline, orthoclase, acid plagioclase, some hornblende, mica and epidote. Phases of the Pink gneiss are red syenitic rocks and porphyritic pink granites. They are cut up by later felsite and porphyry dykes. Gold-bearing quartz veins occur in shear zones in the schistose Dharwars and near the margin of the Dharwars and gneisses.

EASTERN MADRAS.

W. King distinguished four types of gneisses in the Nellore region, two being schistose and two massive. The schistose gneisses are referable to the Dharwarian and include quartz-, mica-, hornblende- and talc-schists, and quartz-magnetite rocks, while the massive gneisses include a grey, sometimes porphyritic, gneiss and a red granitoid gneiss. The grey gneiss is banded and very variable in composition and contains streaks and bands of micaceous gneisses and charnockites; it is also called by King the Carnatic gneiss, and belongs undoubtedly to the Peninsular gneiss group. The red gneiss is mainly granitic and corresponds to the Bellary gneiss and Closepet granite. The granitic gneisses and granites are associated with pegmatites and quartz veins and are often quite rich in fluorine-bearing minerals, especially fluorite, apatite and topaz. The north-western portion of the Dharwarian belt is practically devoid of pegmatite intrusions but the south-eastern portion is rich in them including numerous lenses and veins containing workable deposits of muscovite mica. The Dharwarian rocks have here the same strike—(N.N.W. or N.W.) as in Hyderabad and Mysore.

SOUTHERN MADRAS.

In the districts of Coimbatore, Salem and Arcot which lie to the south-east of Mysore, there are several synclinal strips of Dharwars amidst the Peninsular gneisses, charnockites and granites. Ferruginous quartz-schists (hæmatite and magnetite-schists with quartz) are particularly abundant in Salem and form several hills of rather low grade iron ores. The strike direction of the gneisses in this region is N.E-.S.W.

In Southern Mysore the Dharwars thin down and are shredded out by intrusive rocks, and only the lower and middle divisions are present in a highly metamorphosed form. These continue into Malabar and are represented by mica-gneisses, garnetiferous gneisses, quartz-schists, quartz-hæmatite- and quartz-magnetite-schists. Further south there are Peninsular gneisses and massive granitoid rocks which latter may be the same as the Bellary gneiss. It is known that in the southernmost districts of the Peninsula there are quartz-schists, crystalline limestones, garnetiferous mica-gneisses and schists, biotite-cordierite-gneisses etc. which are referable to the Dharwars ; there are also the Peninsular gneisses, charnockites and granites.

The areas above described contain a few interesting types of rocks. Alkali rocks including nepheline-, augite- and corundum-syenites occur in the Sivamalai in Coimbatore district. Anorthosite and anorthite-corundum rocks occur at Sithampundi in Salem to which special interest attaches as this anorthite was originally described by Count de Bournon in 1802 under the name *Indianite.* In the same area there are also pyroxene-chromite and pyroxene-chromite-corundum rocks, the pyroxene being largely altered to amphibole. Lenses of orthoclase-corundum rocks occur at Palakod and other places in the

Salem district in a biotite-hypersthene granulitic gneiss. Olivine-rocks, in which magnesite is developed, are found in several places in Salem and Mysore, the best known being the "Chalk Hills" and the surrounding tract near the foot of the Shevaroys a few miles from Salem town. The ultrabasic rock is highly altered and replaced by abundant veins of magnesite.

CEYLON.

The island of Ceylon is geologically continuous with the adjacent part of Southern India. Physiographically it consists of three peneplains, the lowest forming the general plain country, the highest the mountainous uplands and the middle one a unit of intermediate altitude. According to Dr. D. N. Wadia,[1] the two upper units are the result of uplift of fault blocks. The intermediate peneplain is considered to be post-Jurassic while the upper one may be of late Tertiary age. Dr. Wadia has also recognised similar units in Southern India. Ceylon is built up of Archæan rocks except for a narrow coastal strip in the north-western part where Miocene rocks occur. A belt of khondalites and charnockites forms a central synclinorium and traverses the island from north to south separating the south-eastern area of the Bintenne gneiss from the north-western area of Wanni gneisses. The regional strike of the rocks is N.-S. in the northern part, N.E.-S.W. in the north-east and east and N.N.W.-S.S.E. to N.W.-S.E. in the southern and south-western part. The disposition of the khondalites suggests that i is a southerly continuation of the Eastern Ghats of north-eastern Madras while the southern portion of the island is a continuation of the rocks of Travancore and the southernmost districts of Madras. The trend of the rocks follows the configuration of the coast especially in the south-west, south and south-east of the island.

[1] Wadia, D.N , The three superposed peneplains of Ceylon. *Rec Dept. Min. Ceylon*, Prof Paper 1, 25-32, 1943.

The sequence of rock formations, as deduced by J.S. Coates, is shown below :—

5. Younger Pegmatites and basic dykes.
4. Wanni gneiss of northern and north-western Ceylon.
3. Charnockites.
2. Khondalites and associated rocks.
1. Bintenne gneiss (biotite-gneiss).

Bintenne Gneiss.—This is well developed in the south-east extending from the sea to a line drawn from Batticola through Badulla to Hambantota. It is a banded gneiss consisting of alternating white and dark bands, the former composed of quartz and felspar and the latter rich in biotite. Granulites, garnetiferous gneisses, crystalline dolomites and porphyritic granitic gneisses are closely associated with the banded types. The Bintenne gneiss is found to dip invariably under the Khondalites and is thought to form the basement on which the Archæan sediments (which have since been converted into Khondalites) were laid down. But the descriptions rather suggest that these rocks are the equivalents of the Peninsular gneiss group and thus to a large extent younger than the Dharwars of which the khondalites (quartz-sillimanite-garnet-gneisses with graphite and sometimes felspar) would seem to form a part.

Khondalites.—These garnet-sillimanite-schists occupy the central hilly portion of Ceylon around Nuwara Eliya and are found in a belt extending to Trincomalee. They are often banded and contain appreciable amounts of micro-perthite and microcline. They are associated with hornblende-gneiss, calc-gneiss, corundum sillimanite rock, quartzites and some marbles. These rocks are regarded as metamorphosed sediments, as in India.

Charnockites.—Rocks having some resemblance to the South Indian charnockites occur mainly in the south-west of Ceylon though smaller exposures may also be seen in other areas, especially in a band running N.E.-S.W. through the centre of the island. They are rather rich in micaceous types and interbanded with garnetiferous leptynite, while microcline is rare or absent, and calcite is frequently present.

Wanni Gneisses.—These rocks are to be seen in a belt running N.E.-S.W. from a short distance north of Colombo to Trincomalee. They occupy the north-western third of the island except the coastal strip between Puttalam and Elephant Pass which is covered by Miocene rocks. They include both granites and gneisses, the latter especially towards their borders. The principal type is apparently to be correlated with the Bellary gneiss of Southern India.

The gneisses as well as the khondalites are intruded profusely by veins of granite and pegmatite. But it is only the khondalites that contain useful mineral deposits—e.g. graphite, phlogopite, sillimanite, apatite. The white pegmatite intrusives contain several interesting minerals among which thorianite, thorite, fergusonite, monazite, zircon xenotime, columbite- tantalite, etc. may be mentioned. The felspars in some of the pegmatites have given rise to moonstone.

The latest rocks of the igneous and metamorphic suite are dykes of dolerite and lenses and dykes of ultrabasic rocks.

The Archæan geology of Ceylon bears much resemblance to that of the Eastern Ghats region, Travancore and the adjoining parts of Madras. It may, in fact, be regarded as a continuation of India southward, the continuity being interrupted by the sea encroaching on and covering the shallow intervening portion.

METAMORPHISM OF THE SOUTH INDIAN DHARWARS.

It has already been noticed that there is progressive metamorphism as we follow the Dharwars from Southern Bombay to Southern Mysore. The metamorphism is mainly of the epi-grade in Bombay while it is of the meso-grade in Central Mysore and of the hypo-grade in Southern Mysore where pyroxenes, garnets, cordierite and sillimanite have been developed. The metamorphism is mainly regional, though locally the effects of igneous contacts are observable.

Detailed knowledge of the rocks in most of the areas except Mysore is lacking, as the regional mapping of South India was done before the petrographic microscope came into general use in this country. It is however known that the Dharwars include both epi-and meso-grade rocks in Nellore where garnet, kyanite and staurolite bearing schists are found. In the southern districts of Madras there are tremolite and pyroxene bearing crystalline limestones and different types of schists including garnetiferous ones.

The following general sequence of rocks in South Indian Archæans may be taken as established (*Mem. G.S.I.* LXX, (2), p. 110) :—

5 Bellary gneiss (Closepet granite, etc.)

4 Charnockites

3. Peninsular gneiss

2. Champion gneiss

1. Upper Dharwars (sediments with some ferruginous rocks)
   Middle Dharwars (sediments with important ferruginous quartzites and iron ores).
   Lower Dharwars (mainly metamorphosed igneous rocks).

EASTERN GHATS.

The Eastern Ghats region between Bezwada and Cuttack, which attains the greatest width in the Ganjam tract, is composed of ridges trending in a N.E.-S.W. direction which is also the regional strike of the rocks. The hills are made up of gneisses, charnockites and khondalites (quartz-garnet-sillimanite-graphite schists occasionally with felspar). To their west lies a great basin of Cuddapah rocks which is highly disturbed and faulted on its eastern side, and which might have originally extended further to the east. The folding and uplift of the Eastern Ghats in post-Cuddapah times has been responsible for the removal, by denudation, of the Cuddapah rocks which might have covered them at one time.

The Eastern Ghats is a region of high grade metamorphism as evidenced by the abundance of garnet and sillimanite. The charnockite shows intrusive relationship towards the khondalite and has itself undergone post-magmatic changes such as albitisation and myrmekitisation as described by H. Crookshank. There are, in parts of this area, some metamorphosed manganiferous rocks which have formed hybrid mixtures with igneous rocks. The *kodurites*, as these have been called by Fermor, consist of spessartite-andradite (contracted to *spandite*), orthoclase, apatite and manganese-pyroxene in varying proportions. Associated with these rocks there are also crystalline limestones, cordierite-gneisses, sapphirine-bearing rocks, nepheline-syenites, etc.

The khondalites are para-schists, the varieties rich in felspar being probably attributable to admixture with granitic material. On weathering, they give rise to laterite and bauxite. Fermor believes that the khondalites were metamorphosed under deepseated (*i.e*, katamorphic or hypomorphic) conditions but owe their present position to regional uplift and that the western margin of the Ghats must be a faulted zone. Crookshank states that this postulated fault is not identifiable, but it is not improbable that it is obscured by intrusions of granite and charnockite.

It is interesting to note that the Eastern Ghats have a strike parallel to that of the Aravallis in Rajputana, and that the same strike is found in the Shillong plateau of Assam which is directly in line with the trend of Eastern Ghats.

JEYPORE-BASTAR-CHANDA.

The structure, and to certain extent also the lithology, of Southern India is continued beyond the faulted trough of the Godavari valley into the districts and States of the eastern and southern parts of the Central Provinces. The Dharwarian strike persists over a large part of this area in the Archæans. A considerable tract here is occupied by the rocks of the younger Cuddapah system which must formerly have covered the whole of the region now marked by a series of detached patches of the same rocks. The eastern margin of the Cuddapah basin is faulted against the Archæans. There is little doubt that the main period of folding and faulting of this region was of post-Cuddapah and pre-Gondwana age. The southern part of this region is occupied by gneissic granites and mica-schists, quartz-schists, hornblende-schists and other types. There are also granites which occupy the eastern part of Chanda and probably the western part of Bastar and Khairagarh. Granites, banded and foliated gneisses, and mica-, hornblende- and talc-schists occupy the region from eastern Bastar to Sambalpur. West of the Eastern Ghats, the general strike of foliation is N.W.-S.E. though traces of the effects of the Eastern Ghats strike are discernible in places.

The recent work of H. Crookshank and P.K. Ghosh has established the presence of sedimentary series of Dharwarian affinities here, the rocks being classified as shown below.

TABLE 8—ARCHAEAN SUCCESSION IN BASTAR STATE.

Intrusive rocks ..	Pegmatites, dolerites and basalts; Granites, injection-gneisses, aplites, charnockites.
Kopayi stage ..	Quartzites
Bailadila Iron-ore series.	Calc-schists, amphibolites, zoisite-quartz-granulites. Banded ferruginous quartzites and grunerite and magnetite-quartz-schists.
Bengpal series ..	Andalusite-gneiss, anthophyllite-cordierite-gneiss, biotite- and garnetiferous schists.
Pendulner stage .	Quartzites with intercalations of andalusite- and cordierite-gneiss.

A large part of the above succession is of sedimentary origin. The ferruginous quartzites resemble those of Singhbhum and adjoining Orissa States and may be of the same age. By metamorphism they have been converted into magnetite and grunerite bearing schists. The andalusite and cordierite bearing rocks represent aluminous sediments metamorphosed by pressure and by the effect of granitic intrusives. The granites have to some extent been modified in composition by differentiation and assimilation of sedimentary rocks. According to P.K. Ghosh, the charnockites (pyroxene-granulites) of Bastar owe their origin to hybridism between granites and calc-schists.

SAMBALPUR.

In Sambalpur, in the Mahanadi drainage, there are biotite- and hornblende-gneisses, schists and granites. The town of Sambalpur is situated on a ridge of quartzite and quartz-schist of Dharwarian aspect.

To the west and north of the Sambalpur area there is a group of rocks, typically developed in the Sonakhan hills and called the Sonakhan beds[1] by F.H. Smith, strikingly similar to the Chilpi Ghat and Sakoli series. They are steep-dipping, highly crushed and schistose rocks which pass under the Cuddapahs to the north. They comprise quartzites, conglomerates, slates, phyllites, hornfelses, quartz-magnetite-schists, garnetiferous gneiss, etc. The regional strike of foliation is N.E.-S.W. There are also interbedded traps and hornblende-schists, and intrusive basic dykes of a comparatively late age. These schistose rocks are intruded by a coarse porphyritic pink granite with a little biotite and hornblende. The granite and the schistose series of rocks are overlaid by horizontal or gently dipping Cuddapahs consisting of quartzites, shales and limestones, and occupying a large area in Chhattisgarh.[2]

[1] General Report of the G.S.I. for 1898-99, pp. 39-42, 1899.
[2] The Raipur-Bilaspur-Raigarh area is called Chhattisgarh.

RAIPUR-DRUG.

Immediately to the south and south-west of the Cuddapah basin of Raipur there is a large tract occupied by granites. Dharwarian rocks occur in the adjoining parts of Kanker and Bastar States, their strike being N.W.-S.E. The rock types include quartzites, phyllites, mica-schists and banded hæmatite-quartzites (*e.g.*, those of the Dhalli-Rajhara ridges). These schistose rocks in the Drug district are overlain by volcanic agglomerates and epidiorites and intruded by granites which occasionally show quartz-porphyries along their margin.

BILASPUR-BALAGHAT.

The Dharwarian rocks north and north-west of the Chhattisgarh Cuddapah basin have been designated the *Chilpi beds* by W. King and the *Chilpi Ghat series* by R.C. Burton. The rocks wedge in at the eastern end between the Cuddapahs and granitic gneisses but expand westwards into two strips, the northern one going into Nagpur and Chhindwara and the southern one into Nagpur and Bhandara.

The rocks of the Chilpi Ghat series strike roughly N.E. and have a straight northern margin and a sinuous and irregular southern margin. They comprise quartzites, felspathic grits, shales and slates with intercalations of trap. The basal conglomerate contains pebbles of rocks which appear to have been originally sedimentary. The following is the succession according to Burton.

		Feet.
Chilpi Ghat series ..	Phyllites, sericite-schists and felspathic tuffs ..	2500
	Blue slates and slaty quartzites ..	10-1800
	Phyllites .	3500-5000
	Manganese-ore ..	0-50
	Phyllites and jasperoid quartzites ..	200
	Basal conglomerates and grits	0-900

The Chilpi Ghat series rests on a group of rocks which includes composite gneisses, mica-schists, quartzites, epidotic gneisses, hornblende-schists, etc., which represent older rocks intruded into and shredded out by younger granites.

In northern Balaghat there is another group of Dharwarian rocks to which Burton has given the name of *Sonawani series.* The sequence of beds in this is as follows :

Sonawani series ..	Phyllitic schists and quartz-muscovite-schists. Felspathic quartzites. Quartz-muscovite-schists. Calc-gneiss and crystalline limestone with manganese-ore. (Base not seen).

The Sonawani series is supposed to represent an older series than the Chilpi Ghats. It may be noted that each of these contains a manganese-ore horizon.

Fermor has critically reviewed the reports of King and Burton and given the following section at Chilpi Ghat, based on King's descriptions :—

(Top)

- Greenstones.
- Dark green clay-slates weathering buff with subordinate claystones and hard sandstones.
- Green and white speckled grits and slates.
- Coarse conglomerate.
- Massive slaty beds and grits.
- Slaty quartzose rocks.
- Massive traps and trappoids.

(Bottom)

In this interpretation there are no conglomerates at the base but they are assigned a position about the middle of the series. They contain pebbles of quartzites, red silicified gneiss, red jasper, tourmaline-quartz rock, etc., some of which are distinctly older in age than the Chilpis. The traps may be younger than, and intrusive into, the Chilpis. The Chilpi Ghat series is separated from the overlying Cuddapahs by a well-marked unconformity.

In this region there are three groups of granitic rocks. The oldest are fine-grained schistose biotite-gneisses ; the next one is a streaky augen-gneiss ; the youngest is a granite called the Amla granite.

There are uncertainties regarding the relationship between the Sonawani series and the Chilpi Ghat series.

At present, however, the general succession of rocks of this region may be given as below :

5. Granite.
4. Porphyritic and augen gneiss.
3. Schistose biotite-gneiss.
2. Chilpi Ghat series.
1. Sonawani series.

NAGPUR-BHANDARA.

The Chilpi rocks continue westwards and bifurcate, the southern strip occupying parts of the Nagpur and Bhandara districts, and the northern strip going into Chhindwara. There is no distinct stratigraphical unconformity between the rocks of these two areas, which are called the Sakoli (southern) series and Sausar (northern) series respectively. It appears likely that the Sakoli series may be an upward continuation of the Sausar series since there is not much lithological resemblance between the two, even allowing for the different metamorphic grades. The rocks of the northern belt dip to the S.S.E. and those of the southern to the N.N.W., while the middle or axial region may be a zone of faulting. The southern belt (Sakoli series) contains chlorite and sericite schists and hæmatitic iron ore of a low grade of metamorphism, in contrast with the northern belt (Sausar series) which is characterised by calc-granulites, marbles, garnetiferous schists and manganese-silicates.

The sequence in the Sakoli tract is as follows :

Quartz-dolerite
Tourmaline-muscovite granite and pegmatite

<table>
<tr><td rowspan="7">Sausar series.</td><td rowspan="4">Sakoli series.</td><td>Crushed albite-microcline-quartzite</td></tr>
<tr><td>Phyllite and slate.</td></tr>
<tr><td>Hæmatite-sericite-quartzite.</td></tr>
<tr><td>Chlorite-muscovite schist with chloritoid epidote-chlorite-schist, jaspilite, phyllite, chloritic-hornblende-schist.</td></tr>
<tr><td colspan="2">Amphibolite and garnet-amphibolite.</td></tr>
<tr><td colspan="2">Dolomites, crystalline limestones, calciphyre and chlorite-tremolite-schist.</td></tr>
<tr><td colspan="2">Microcline-muscovite-quartzite.</td></tr>
</table>

The lower part of this succession seems to contain recognisable equivalents of the Sausars ; the amphibolites may be referred to the Sitapar stage, the dolomites, etc. to the Bichua stage and the muscovite-quartzites to the Chorbaoli stage, all these stages being parts of the Sausar series (see below). The upper part constitutes the Sakoli series, the rocks of which sometimes show evidences of regressive metamorphism such as the conversion of sillimanite to muscovite, and garnet and biotite to chlorite. Local patches contain sillimanite, kyanite and dumortierite, which are attributed by S.K. Chatterjee to the effects of hydrothermal metamorphism.

NAGPUR-CHHINDWARA.

As one passes from the Chilpi Ghat area (Balaghat district) to the west (Chhindwara district) one notices that calcareous rocks gradually attain importance while the phyllites give place to schists of a higher grade of metamorphism. Indeed, it becomes difficult to separate the original sediments from igneous materials in the western tract. The difference in the lithological and metamorphic facies makes it almost impossible to correlate the rocks of the two tracts.

TABLE 9—THE SAUSAR SERIES.

Stage.	Rock Types.
(N) Sapghota ..	Garnet-anthophyllite-schists, chlorite-schists, magnetite-quartz-rocks.
(C) Sitapar ..	Hornblende-schists, garnet-amphibolites, pyroxenites.
(C) Bichua ..	PURE FACIES : White dolomite marbles with serpentine, spinel, chondrodite, tremolite, diopside, forsterite
	IMPURE FACIES : Diopsidites, diopside-quartzites, actinolite-schists with wollastonite, grossularite, tremolite and anthophyllite.
(N) Junawani ..	Tabloid muscovite-biotite-schists.

(N) Chorbaoli ..	Felspathic muscovite-quartz-schists and quartzites (sometimes with muscovite and microcline).
(N) Mansar ..	Schistose micaceous gneisses and muscovite-biotite-sillimanite-schists, with gondites and manganese-ore bodies ; also some garnet-quartzites
(C) Lohangi	Pink calcite marbles and calciphyres, black manganiferous marbles, piedmontite-marbles and some manganese-ores.
(C) Utekata	Banded calc-granulites, sometimes scapolitic.
(N) Kadbikhera	Magnetite-biotite-granulites.

Note.—It is uncertain whether the Sapghota stage is a separate entity but it apparently contains more ferruginous matter than other stages, though by volume (extent and thickness) it is rather unimportant

The regional strike is E.S.E. east of the Maikal range ; it becomes E.N.E. and N.E. in the Balaghat district, and N.N.W. in the Sausar area of the Chhindwara district.

The Dharwars of the Nagpur-Chhindwara region, called the Sausar series, have been studied in considerable detail by Fermor, Bhattacharjee and West. The succession deciphered here is shown in Table 9. (*Mem. G.S.I.*, LXX (2), p. 270, 1940), the letters (N) and (C) indicating respectively the districts of Nagpur and Chhindwara in which the stages are well developed.

There are no conglomerates at the base of the Sausar series and it is not known whether there are any rocks older than and underlying these. Three series of ortho-gneisses younger than the Sausars have been recognised, *viz.*—

3. Later granite and pegmatite, including the Amla granite.
2. Streaky gneisses derived by the intrusion of aplitic material into (1) and into the schistose members of the Sausar series.
1. Granodioritic biotite-gneisses, porphyritic and augen gneisses.

The relationship between the Sausars and Chilpis is very obscure. The Chilpis may be regarded as either younger than the Sausar series or as a lateral variation of facies. In the former case, the manganiferous rocks of Balaghat and Ukua, which occur in the Chilpis, should be regarded as a much younger horizon than the Mansar stage. The absence of calcareous rocks in the Chilpis deprives us of a useful aid in correlation. In Fermor's opinion, the Chilpis may represent the upper portion of the Sausars and may even include beds higher in sequence than any found in the latter.

BENGAL.

The Midnapur area of Bengal is contiguous with Dhalbhum (Eastern Singhbhum) and contains gneisses and schists similar to those found in the latter. The gneissic rocks are of the type formerly known as the *Bengal gneiss*, closely akin to the Peninsular gneiss of South India.

A few miles to the south of the Raniganj coalfield there is exposed an interesting group of rocks comprising anorthosites, labradorite-pyroxene rocks, anorthosite-gabbro, norite, grano-diorite, granite and pegmatite. The anorthosite forms masses and dykes, the largest of which occupies an area 20 miles in length and 6 miles in width. The igneous suite is intrusive into the Dharwarian schists and is thought to be derived from the differentiation of a single magma, the anorthosite being regarded as a product of crystal settling. These rocks have been studied in some detail by S.C. Chatterjee.

SINGHBHUM.

Singhbhum in Southern Bihar is one of the regions which has been mapped in detail in recent years and information about which is of modern character. The rocks show two facies, an unmetamorphosed one in the south and a metamorphosed one in the north, separated by a major thrust zone.

This thrust zone extends from Porahat in western Singhbhum through Chakradharpur, Amda, Rakha Mines, Mushaboni and Sunrgi into Mayurbhanj State, over a distance of 100 miles. It has an E.-W. course in the western part and turns to the S.E. in the eastern part. The thrust zone marks the overfolded limb of a geanticline. Two lesser zones of thrust are found further north, one along the northern border of the Dalma lavas in Southern Manbhum and Midnapur, and the other still further north along the boundary of the granitic and schistose rocks. The three zones are parallel to each other and to the Satpura strike which prevails over Southern Bihar and parts of the Central Provinces. They converge in the neighbourhood of Goilkera (between Manoharpur and Chakradharpur) as a result of which the rocks are seen to be tightly folded.

South of the main thrust zone, the rocks are little metamorphosed, though affected by the disturbance of the Eastern Ghats movements. They have been thrown into folds whose axes are parallel to N.E.-S.W. (or N.N.E.-S.S.W.) which is the general trend of the Eastern Ghats. Since the rocks to the north of the thrust zone have been found to belong to the same series as to its south, and since the former frequently show relics of earth movements earlier than the Satpura disturbance, it may be inferred that the Eastern Ghats movements were earlier than the Satpura ones. H. C. Jones recognised the following succession in the Archæans of Southern Singhbhum.

	Newer Dolerite
	Granite
	Ultrabasic rocks.
Iron-ore series .	Basic lavas Upper shales. Banded hæmatite-quartzites. Lower Shales. Purple and grey limestones (local). Basal conglomerate and sandstone.
	Older Metamorphics-Quartzites, quartz-, mica-, hornblende- and chlorite-schists.

The Older Metamorphic Series consists of a group of metamorphic rocks including hornblende-schists, quartzites, quartz-schists, micaceous and chloritic schists which have been highly folded and eroded before the deposition of the Iron-ore Series. They are found as a series of small exposures isolated by the Singhbhum granite. Jones states that there is a profound unconformity between them and the overlying Iron-ore series, and that the base of the latter is marked by conglomerates and sandstones. These are overlain by purple, somewhat phyllitic, shales and beds of banded hæmatite-quartzites. The shales contain some deposits of manganese-ore, mainly pyrolusite, derived from the shales themselves by a process of concentration by meteoric waters. They are worked in the Koira valley in Keonjhar, South of Jamda. The hæmatite-quartzites, which have a thickness of well over 1000 ft., form prominent ridges capped by beds of very high grade hæmatite. They are composed of alternating layers of cherty silica, jasper and hæmatite, the individual layers varying in colour from white, through grey and brown to nearly black. These layers are from a tenth to a quarter of an inch in thickness but may sometimes be much thicker. They are intricately folded and contorted, the minor structures being apparently attributable to local adjustments during replacement and slumping. The iron-ore is thought to have been derived from the enrichment of the hæmatite-quartzites through solution and replacement of the silica by ferric oxide, though other modes of origin are attributed to some of the small and unimportant ore-bodies of Northern and Eastern Singhbhum.

There are some basic lavas in South Singhbhum which appear to be younger than the Iron-ore series. In North Singhbhum, however, the top of the Iron-ore series shows intercalations of contemporaneous lava flows, tuffs, and agglomerates which are known as the Dalma traps. The Iron-one series is intruded into by ultrabasic rocks—peridotites, saxonites and dunites—which have largely been serpentinised. Some of these occurrences near Chaibasa contain workable lodes of chromite. To a later date belongs the Singhbhum granite which is traversed by innumerable dykes of Newer Dolerite.

To the north of the main thrust-zone, in North Singhbhum, the Iron-ore series forms a geanticline composed of mica-, hornblende- and chlorite-schists. The schists contain garnet, staurolite and kyanite, the last forming large deposits in Lapsa Buru and other places in Singhbhum and along the same zone in Mayurbhanj. Banded hæmatite-quartzites are unimportant in North Singhbhum, being represented mainly by phyllitic rocks. The geanticline shows, just to its north, a syncline of Dalma traps which are silicified to some extent in the basal portion and also include sheared talcose and chloritic rocks.

North and north-west of these Dharwarian rocks there occurs a large spread of granite and gneiss—the Chota Nagpur granite-gneiss. It is conspicuously gneissose and banded especially in the vicinity of the schists and has assimilated the latter to an appreciable extent. Intrusions of soda-granite with granophyric structure (Arkasani granophyre) are seen along the main shear zone and also along the northern border of the geanticline.

J. A. Dunn has recently re-mapped part of the Iron-ore series of South Singhbhum and re-interpreted the succession (*Rec.* 74, p. 28, 1939 ; *Mem.* 62, *Pt.* 3, 1940; and *Mem.* 69, *Pt.* 2, 1942). He now considers the Older Metamorphics as part of the Iron-ore series. The conglomerates and sandstones are found to be younger than the Iron-ore series and are now assigned to the basal portion of a new *Kolhan series* in which are included the limestones and some of the shales. The Kolhan series is said to be quite undisturbed near the border of the granite but highly disturbed further west and north-west. The Kolhan series is correlated with the Dhanjori stage of Eastern Singhbhum. The basic lavas of South Singhbhum and Keonjhar are regarded as pre-Singhbhum granite in age. The new succession is compared below with the one originally adopted by Jones.

TABLE 10—ARCHAEAN SUCCESSION IN SINGHBHUM.

South Singhbhum		East Singhbhum.
Jones (1934)	Dunn (1939)	Dunn (1942)
Newer Dolerite Singhbhum granite *Iron-ore series* Older Metamorphics	Newer Dolerite Kolhan series *Iron-ore series* (?)	Newer Dolerite Kolhan series *Dhanjori sandstones and* Dalma lavas Iron-ore series.

In Eastern Singhbhum (Dhalbhum) the Iron-ore series is unconformably overlain by the Dhanjori stage of quartzites, sandstones and conglomerates, followed by lavas and phyllites occurring to the south of the main shear zone. The Iron-ore series contains ferruginous phyllites and poor iron-ores in Dhalbhum but good deposits occur in Mayurbhanj in the Gorumahisani, Sulaipat and Badampahar hills. The ferruginous rocks have been altered in places to grunerite bearing rocks, mainly perhaps by contact metamorphism. The Iron-ore series is intruded by dolerite, gabbro, picrite and anorthosite, which are often found altered to epidiorites, talc-schists, talc-chlorite-schists, tremolite-schists (with asbestos), etc., and contain lenses of titaniferous and vanadiferous magnetites. A few small occurrences of these magnetites are found around Dublabera in Dhalbhum, but larger ones are said to occur within the Mayurbhanj State, especially near the Simlipal hills.

Intrusive into the Iron-ore series there are : (1) ultrabasic rocks (2) Chota Nagpur granite and gneiss (3) Singhbhum granite (4) Arkasani soda-granite and granophyre and (5) Newer dolerite. These are briefly described below.

The Ultrabasic rocks are found as a series of lenses in South and East Singhbhum and in Mayurbhanj. Some occurrences a few miles S.W. and W.S.W. of Chaibasa comprise peridotites, dunites and saxonites which have been partly serpentinised and silicified, and contain veins of chromite up to a foot thick. These have been affected by folding and are therefore regarded as older than the Singhbhum granite which is unaffected. A few exposures of similar rocks, found in the Bonai State south-west of Singhbhum, are probably post-granite in age. As already mentioned, the occurrences in Dhalbhum and Mayurbhanj include dolerite, gabbro, pyroxenites and anorthosites. Tremolite and talc rocks have been derived from some of them, while in a few places they contain titaniferous and vanadiferous magnetites.

The Chota Nagpur granite-gneiss[1] occupies an immense tract to the north of the Dharwarian rocks of Singhbhum and Gangpur. The northern belt of this extends from Santhal Parganas through Hazaribagh to Palamau and the southern one from Bankura to Ranchi and Jashpur and further west. It is distinctly intrusive into the Iron-ore series and assumes a banded and composite aspect near the margins of the schistose rocks. It is generally coarse and porphyritic and contains quartz, microcline, orthoclase, oligoclase, biotite, a little apatite (and occasionally some green hornblende in Singhbhum). Tourmaline is frequently seen but especially abundant in the pegmatitic phase as in Southern Ranchi. In parts of Manbhum, Ranchi and Hazaribagh, it weathers into *tors* and is called the *Dome gneiss*. The composite form of the rock used to be referred to as *Bengal Gneiss* in earlier geological literature. It resembles the *Peninsular Gneiss* to a great extent. Its later phases are pegmatites, aplites and quartz veins, the last being often auriferous in

[1] Chota Nagpur is a term applied to the region comprising the Singhbhum and Ranchi districts and Gangpur and adjacent States. It is also the name of a Commissioner's division which includes the Ranchi, Hazaribagh, Palamau, Singhbhum and Manbhum districts.

Chota Nagpur. The pegmatites of Gaya, Hazaribagh and Monghyr contain important deposits of muscovite mica (the 'ruby mica' of commerce, so named because of its warm orangish red colour) and also pitchblende, monazite, columbite-tantalite, triplite, cassiterite, etc.

The Singhbhum granite occupies large areas in Singhbhum, Mayurbhanj, Keonjhar, Bonai, Bamra, Sambalpur, etc. It is a calc-alkali granite probably related to the Chota Nagpur granite or it may be later ; in composition it varies from a potash granite to granodiorite and contains orthoclase, microcline, acid plagioclase, biotite and some hornblende. It is generally granitoid in texture but occasionally becomes streaky when associated with schistose rocks.

The Arkasani soda-granite is seen in Kharsawan and Seraikela in Singhbhum, mainly along the major zone of thrust. The chief type is a granophyre with inter-growth of quartz and felspar, grading into a soda-granite. The granite around Chakradharpur in Singhbhum is probably a modified form resulting from contamination by schistose rocks. It seems to be slightly earlier than the Singhbhum granite in age.

The Newer Dolerite is the latest intrusive, appearing as dykes in the Singhbhum granite. The dykes have a major direction of N.N.E.-S.S.W. and a subsidiary one of N.N.W.-S.S.E. The dykes vary in width from a few feet to as much as 600 or 700 yards, and can often be seen standing out in the granite country as low ridges for miles. The rock is a dolerite or quartz-dolerite with granophyric structure. The thicker dykes are gabbroid or noritic. Dykes of augite-granophyre are also known among them, but these may be somewhat older.

GANGPUR.

To the west of the Singhbhum district, in Gangpur State, there is an anticlinorium (or geanticline) which has an E.N.E.-W.S.W. axial direction. The structure is closed towards the east but is obscured by granitic intrusives to the west. The strike becomes W.N.W.-E.S.E. in western Gangpur, apparently due to the influence of the Dharwar strike which persists along the Mahanadi and Brahmani valleys just to the south of this region.

The anticlinorium shows the following succession of rocks, deciphered by M. S. Krishnan, and named the Gangpur series. (Table 11).

TABLE 11—THE GANGPUR SERIES.

Iron-ore series .	Phyllites, slates and lavas.
	Raghunathpali conglomerate, with a shear zone.
Gangpur series ..	Phyllites and mica-schists.
	Upper carbonaceous phyllites.
	Calcitic marbles.
	Dolomitic marbles
	Mica-schists and phyllites.
	Lower carbonaceous quartzites and phyllites.
	Gondites with associated phyllites (Base not seen).

There is a general increase in the grade of metamorphism when the rocks are followed from the Singhbhum border on the east to the centre of the anticlinorium and towards the west. It may, however, be noted that some of the rocks, which have phyllitic appearance and characters, are really products of retrogressive metamorphism, containing relics of garnet, staurolite, biotite, etc. The Satpura strike (E.N.E.-W.S.W.) is found to be superimposed on an earlier, presumably Dharwarian, strike which is prominent south of this area.

The oldest rocks are gondites, found in the central or axial region of the anticlinorium. They contain, besides quartz-spessartite rocks, also those with rhodonite, blanfordite, winchite, etc., associated with workable bodies of manganese-ore. They are succeeded by carbonaceous quartzites and phyllites, dolomitic and calcitic marbles and carbonaceous phyllites, these being intercalated with phyllites and mica-schists. The carbonaceous phyllites form fairly good slates in certain places while the marbles contain very large reserves of limestone and dolomite which are now being used as fluxes in the iron-smelting furnaces of Bengal and Bihar. Large quantities of the limestone are also burnt into quick-lime, well known in the Calcutta market as Bisra lime, named after Bisra which is a railway station near the eastern border of Gangpur State. At the top of the succession is a shear zone in which the Raghunathpali conglomerate is involved. It is a sedimentary conglomerate which has suffered intense shearing as a result of which an autoclastic character is imposed on it. The overlying beds are phyllites and mica-schists belonging to some part of the Iron-ore series. The Gangpur series is intruded by basic sills (presumably of Dalma traps), and by bosses of the Chota Nagpur granite-gneiss.

The Gangpur series is deduced to be older than the Iron-ore series since it forms an anticlinorium surrounded by the Iron-ore series ; the lithology is different ; and the basic igneous rocks which occur as flows in the latter form sills and occasional dykes intrusive into the former.

Disregarding the Older Metamorphic Series, there are two groups of rocks in the Dharwars of Chota Nagpur —the Gangpur series characterised by manganiferous rocks and marbles, and the Iron-ore series containing iron-ores. These two show close affinities with the Sausar and Sakoli series of the Central Provinces respectively.

THE SON VALLEY AND ADJOINING AREAS.

North and north-west of Ranchi and Hazaribagh, schistose rocks are found in the Mirzapur district in the drainage basin of the Son river which is a tributary of the Ganges. Mallet found two series in this area, separated by an unconformity. The lower division, called the Agori stage, includes slates, chloritic schists, schistose quartzites, jaspers, thin limestones and basic igneous rocks. There are also some slates and porcellanoids which are thought to constitute the upper division. No marbles or gonditic rocks seem to have been found amongst these rocks. The sequence would therefore seem to be the equivalent of the Iron-ore series. It is intruded by gneissic granite which is evidently the same as the Chota Nagpur granite-gneiss.

In parts of the Gaya and Hazaribagh districts there are various types of schistose rocks—biotite-schists, sillimanite-gneisses, calc-granulites and epidiorites—which have been extensively granitised by the Dome gneiss intrusive into them. The Dome gneiss is here contaminated by the absorption of schists and is characterised by the presence of quartz, oligoclase, biotite and occasional hornblende, with fluorite as an important accessory. In this and other respects it resembles the granitic rocks of the Nellore region.

Further east, in the Rajgir, Kharakpur, Gidhaur, Shaikpura and other hills, there are quartzites, crush conglomerates, jaspery quartzites, slates, phyllites and mica-schists, having a general E.-W. or E.N.E.-W.S.W. strike. The quartzites are generally the most prominent members and form scarps. The schistose rocks have been highly disturbed and have an irregular boundary with the gneisses which are intrusive into them.

JUBBULPORE.

The rocks of the Son Valley are practically continuous with those in the Jubbulpore region of the Central Provinces. Here they comprise phyllites, mica-schists, calcitic and dolomitic marbles, banded ferruginous rocks associated with manganese and iron-ores, with sills of altered basic igneous rocks. The iron-ores and manganiferous iron-ores have been investigated by Prof. Henry Louis and by P. N. Bose. They are not of high grade but have supported a local indigenous industry. In the neighbourhood of Sleemanabad, the schistose rocks are traversed by veins containing copper-ores.

The above series of rocks was first referred to the Bijawar series (Cuddapah System) by C. A. Hacket and divided into four stages, named respectively the Majhauli, Bhitri, Lora and Chanderdip groups (from below upwards), but these are not definite stratigraphic units. The marbles occur in the lower beds and the iron-ores in the upper beds. The rocks bear an extraordinary resemblance to the Dharwars of Singhbhum and Gangpur and have been shown by Fermor to belong to the Dharwar system. (*Mem. G. S. I.* XXXVII, p. 805, 1909.)

BUNDELKHAND.

The Archæans of Bundelkhand are separated from those of the Central Provinces, Bihar and Rajputana by the Vindhyans and Deccan traps.

The greater part of Bundelkhand is occupied by the *Bundelkhand gneiss.* It is really a massive granite with rare and obscure banding or foliation, so that the term 'gneiss' is rather a misnomer as applied to the typical rock. It has the same characters here as in Rajputana (see below) and comprises fine to coarse grained as well as occasional porphyritic varieties. The mineral constituents are quartz, pink orthoclase, hornblende, and the micas. It forms a flat undulating country, to the south-west of which occur the 'Transition rocks' and Vindhyans which form a hilly country. The schistose rocks in the south include hornblendic, chloritic and talcose schists, but mica-schists seem to be practically absent. Where occasional foliation is developed in the Bundelkhand gneiss, it has a general E.N.E. direction.

The Bundelkhand gneiss is traversed by pegmatite veins and well marked quartz reefs of varying dimensions. These quarts reefs form a characteristic feature of the landscape in Lower Bundelkhand and trend in a N.E. or N.N.E. direction. They are up to 100 yards wide and can be traced for long distances. In some places they form dams across the courses of streams. They consist of bluish white quartz associated sometimes with a little serpentinous material.

There are also numerous trap dykes traversing the gneiss, their general trend being N.N.W. or N.W. These are also fairly prominent, though not as much as the quartz reefs. In contrast with the quartz reefs which show the effects of some crushing, the trap dykes are free from disturbance or metamorphism.

RAJPUTANA.

Much attention has been bestowed on Rajputana by the Geological Survey of India during the last two decades. The geological mapping of this large tract has recently been brought to a conclusion by the combined work of C. S. Middlemiss, A. M. Heron, B. C. Gupta, A.L. Coulson, P. K. Ghosh and others. Geological descriptions of parts of the country have appeared in several monographs while an excellent summary of its pre-Vindhyan geology has recently been published by Heron (*Trans. Nat. Inst. Sci. I*, No. 2, 1935).

The characteristic feature of the country is the Aravalli mountain system which, though originally formed in the Pre-Cambrian and rejuvenated in post-Vindhyan times, still survives as prominent ranges striking northeast from Gujarat to near Delhi. The Central part of the Aravalli ranges is occupied by a synclinorium formed by the Delhi system of rocks. The main formations of Pre-Vindhyan age found in Rajputana are as below :

5. Malani suite of igneous rocks.
4. Delhi system.
3. Raialo series.

TABLE 12—PRE-VINDHYAN FORMATIONS OF RAJPUTANA (After A.M. Heron)

Jodhpur	Mewar ; Ajmer-Merwara (Main syncline)	Chitor , Nimbahera , Sadri (unmetamorphosed).	Jaipur.	Alwar.
Vindhyans Malani Volcanic series	Delhi system Calc-gneisses. Calc-schists Phyllites & biotite-schists. Quartzites. Basal arkose-grits	Upper Vindhyans Lower Vindhyans (Semri series) Jiran Sandstone	Ajaogarh series Alwar series	Ajabgarh series Hornstone breccia. Kushalgarh limestone Alwar Series
Raialo (Makrana) Marble ; Limestones of Ras	Raialo Garnetiferous biotite-schists. Raialo (Rajnagar) marble Basal grit—local.	Raialo (Bhagwanpura) limestone.		Raialo limestone Raialo quartzite.
Shales (Sojat) Schists of Godwar.	Aravalli system Phyllites, cherty limestones, quartzites and composite gneisses. Basal quartzites, grits and local conglomerates Thick volcanics (local).	Khardeola grits. Badesar quartzites Ranthambhor quartzites. Shales and cherty limestones. Basal quartzites and grits. —Great Boundary Fault— Binota shales.	Quartzites and schists of Baonli-Awan ridge and *Bechun, Biana and Lalsot* hills. Volcanics of Basi. Schists of Rajmahal	
Grey, homogeneous gneiss	Banded gneissic complex	Bundelkhand Gneiss.	Gneissic granite of Karela and Ganor.	

2. Aravalli system.
1. The Banded Gneissic Complex and Bundelkhand Gneiss.

The succession of rocks of Pre-Vindhyan age of Rajputana, as given by Heron, is reproduced in Table 12. Of these, the Delhi system is now regarded as probably equivalent to the Cuddapahs, so that only the older formations will be described here.

The Bundelkhand Gneiss.—In its typical form, the Bundelkhand gneiss is a pink to reddish, medium grained, non-foliated, non-porphyritic granite. The chief minerals are quartz, orthoclase, subordinate microcline, and some ferromagnesian minerals. The quartz has a violetish opalescence while the felspars are usually somewhat altered. The rather sparsely occurring ferromagnesian minerals—biotite and green hornblende—are more or less altered to epidote and calcite. Veins of pegmatite are infrequent but those of microgranite and aplite are common. Here, as in Bundelkhand, the rock is traversed by prominent quartz reefs and numerous dolerite dykes. There is little doubt that the Bundelkhand gneiss of Rajputana is identical with that of Bundelkhand, though the two are separated by over 250 miles of younger rocks.

Towards the west, near the junction of Berach and Bagan rivers, the Bundelkhand gneiss gradually becomes well foliated and grey coloured, with knots of quartz and felspar and small quantities of sericite and chlorite. The gradation is probably due to metamorphism.

Over a very large part of its exposure this formation is more a granite than a gneiss and resembles the younger granites (Bellary gneiss, Closepet granite, Dome gneiss, etc.) rather than the gneisses of the other Archæan areas of Peninsular India. Dr. Heron states, however, that there is a small but distinct 'erosion unconformity' between them and the Aravalli schists which are the equivalents of the Dharwars, and hence regards them as older than the Aravallis.

The Banded Gneissic Complex.—The rocks belonging to this group consist of alternating bands of biotite-gneiss and granite. Biotite- and chlorite-schists, which may represent early sediments, are found as constituents of these in Southern Mewar. In places they grade into a granite-gneiss or even into an unfoliated granite. They contain also some hornblende-schists and epidiorites, representing altered basic igneous rocks. The gneissic complex is traversed by pegmatite and aplite veins apparently derived from granitic rocks of different ages.

Banded gneisses also occur in Central and North Mewar and in Ajmer, comprising dark-coloured schists and garnetiferous granulites intruded by biotite-granite. Another type of gneiss which may belong to the same group occurs west of the synclinorium and consists of a fine-grained and somewhat foliated porphyritic granite.

There is, according to Heron, a distinct 'erosion unconformity' between the Gneissic Complex and the overlying Aravallis. The Gneissic Complex is nowhere exposed in juxtaposition to the Bundelkhand gneiss, so that the relationship between these two is not known.

The Aravalli system.—The Aravalli system is dominantly argillaceous in composition and of great thickness. The rocks show increasing metamorphism as they are followed from east to west.

The basal beds, which rest on Bundelkhand gneiss or the Gneissic Complex, are arkose and gritty quartzites. Above these come shales and phyllites with which are associated some altered basic volcanics in places. Impure argillaceous and ferruginous limestones occur in two facies, one being a lenticular ferruginous limestone as in Bundi and Mewar and the other a black massive limestone as near Udaipur city. In some places there are quartzites instead of limestones. The whole series of rocks is well foliated and injected lit-par-lit by granitic rock, resulting in composite gneisses.

An unmetamorphosed facies of the Aravallis occurs in Eastern Mewar. This has been named the *Binota shales* east of the Great Boundary Fault of Rajputana and consists of low-dipping, brown and olive shales with ferruginous and clay concretions. To the east, the Binota shales are succeeded by the Jiran sandstones, Vindhyans or the Deccan trap. To the west of the Boundary Fault, the Aravallis are represented by steep-dipping slates and impure limestones intruded by dolerite. Followed westwards, these shales become first distinctly slaty or phyllitic and later schistose, with the development of staurolite, garnet and kyanite.

The youngest members of the Aravallis are the reddish sandstones and quartzites seen near Ranthambhor and Sawai Madhopur in Jaipur State. The unmetamorphosed Aravallis of Chitor can be followed north-eastwards along the strike through Bundi State into South-eastern Jaipur, where they are associated with the Ranthambhor quartzites. These rocks have resemblance to the shales of the Gwalior Series but there seems to be no doubt that they are of Aravalli age.

The Gwalior series of Gwalior city and neighbourhood are separated from the Aravallis by a belt of Vindhyans having a width of about 80 miles and resemble the unmetamorphosed Aravallis. Though they lie distinctly to the east of the continuation of the strike of the Aravallis, it is not improbable that they really belong to the Aravalli system.

Near the Mewar-Partabgarh border, there are several exposures of an amygdaloid, associated with ferruginous sandstones and cherts and overlaid by the *Khardeola grits.* These last consist of conglomerates, grits, greywackes and slates intercalated with slates of Aravalli aspect. There may be a slight unconformity between the Aravallis and these rocks.

The Aravallis have now been continuously mapped from Rajputana into Gujarat where they were first described as the *Champaner series*. The identity of the Champaners with the Aravallis has now been definitely established. In Gujarat they contain manganese ores.

The Aravallis have been intruded by fine-grained aplo-granite which is found as bosses and also as lit-par-lit intrusives, *e.g.*, near Udaipur, continuing thence into Dungarpur. There are also ultrabasic rocks, now seen as talc-chlorite-serpentine rocks. Other rocks, including granite, epidiorite and post-Delhi dolerite, are also met with, but these are less important than the ones mentioned above.

Intrusive into the Aravallis are the alkali-syenites of Kishengarh State. They comprise elæolite-and sodalite-syenites and pegmatites of the same type, the latter showing very coarse, light blue sodalite and felspar. The sodalite has often a fine carmine colour when freshly broken but this fades away on exposure to light. The colour fades more slowly in diffused light.

Raialo series.—The Raialo series overlies the Aravallis and is overlaid by the Delhi system, the junctions in both cases being unconformable. They consist of white limestones, about 2,000 feet thick, and thin basal sandstone and conglomerate. The limestones often rest directly on the older rocks without the intervention of the basal sandstones, and are found in widely separated localities such as Jodhpur and Eastern and Central Mewar.

The typical Raialo limestone is medium grained, saccharoidal and dolomitic in composition. Near Nathdwara, Rajnagar and Kankroli it is a white dolomite excellent for ornamental purposes and is overlain by garnetiferous biotite-schists. Other exposures are found in the hills of Eastern Mewar. Its equivalent in South-east Mewar is the Bhagwanpura limestone, a fine-grained rock which runs parallel to the Boundary Fault from Chitor southwards.

The celebrated Makrana marble of Jodhpur is a calcite-marble correlated with the Raialos, though it is on the north-western side of the Aravallis. The common variety is white, with pale greyish cloudy patches, but there are also white, pink and blue-grey varieties. It is continued to the south-west where it is a rather impure saccharoidal calcitic limestone containing diopside and other calc-silicates. The Makrana marble has been used in many famous buildings in Northern India, including the Taj Mahal at Agra and the Victoria Memorial at Calcutta.

ASSAM.

The Assam plateau lies along the continuation of the Archæans of Bihar but is separated from the latter by the Ganges-Brahmaputra valley. The plateau comprises the Garo, Khasi and Jaintia hills and to its north-east is the detached area of the Mikir hills.

The Archæans are represented here by gneisses, schists and granites, having a general N.E.-S.W. direction of strike of foliation, *i.e.*, parallel to and more or less along the continuation of the Eastern Ghats of Orissa. There is naturally much local variation, and in parts of the Garo hills the Satpura strike may be seen.

Extensive tracts of the ancient rocks are found in the Khasi and Jaintia hills. The oldest seem to be banded, composite, biotite-granite-gneisses. The granitic constituent is sometimes porphyritic and sometimes fine grained and aplitic, and consists of quartz, microperthite, some microcline, oligoclase and biotite, with garnet, apatite, zircon and rare sphene as accessories. The gneisses are associated with garnet-quartzites with or without sillimanite. In the area west of Shillong, there are hornblende-biotite-gneisses and biotite-cordierite gneisses with N.E.-S.W. strike of foliation.

The gneissic complex is apparently overlain by the *Shillong series* which is regarded as younger. The Shillong series is mainly of sedimentary origin and is the equivalent of the Dharwars. It is composed of quartzites, conglomerates, phyllites, sericite-, chlorite-, mica- and hornblende-schists, with occasional carbonaceous slates and banded ferruginous rocks. Some of the schists are garnetiferous. The assemblage bears some resemblance to the Iron-ore series of Chota Nagpur and to the Dharwarian rocks in general. Similar rocks are exposed in the Simsang valley in the Garo hills and also in parts of the Mikir hills.

The Shillong series was first intruded by the *Khasi greenstones*—epidiorites, amphibolites and amphibole-schists —which have been folded up with them and are therefore presumably of Archæan age. It shows some gradation towards gneisses near the junction with granitic rocks. Distinctly of a later age is the *Mylliem granite* which forms bosses and also thin interfoliar veins in the schists. It is a pink, homogeneous, fairly coarse biotite-granite containing porphyritic pink microcline, orthoclase, some acid plagioclase, biotite and hornblende, with apatite, zircon, magnetite and sphene as accessories. Over most of its area the granite is fairly massive and non-foliated but is occasionally streaky and may show xenoliths of quartzite and basic segregations. A grey granite also occurs in these areas which is thought to be a variety of the Mylliem granite.

In the granite and gneisses are found certain lenses and patches of intermediate to basic pyroxene-granulites which greatly resemble the charnockites. This should cause no surprise since similar occurrences, thought to be metamorphosed mixed rocks, have been found in recent years in Mysore, Bastar, and other areas.

The granite, and to some extent the gneisses, are traversed by dykes of dolerite ; in the more southern areas there are flows of the same rock which are frequently vesicular and amygdaloidal, with intercalated ash-beds. These are the *Sylhet traps*, which are pre-Upper Cretaceous in age and resemble the Rajmahal and Deccan traps. The rock is a dolerite or basalt, sometimes with olivine which is generally more or less serpentinised.

CORRELATION OF THE PENINSULAR ARCHAEANS.

The study of the Archæan rocks is beset with many difficulties which do not crop up in the case of the later sedimentary systems. There is, in the Archæans, a complete absence of fossils which are of invaluable help in determining the geological age. They include a great variety of formations, both igneous and sedimentary, but the original characters have been obliterated by repeated changes. Metamorphism has produced not only mineralogical and structural changes but has also removed or introduced materials resulting in marked changes in composition. In addition to the effects of temperature and pressure, there are also those of igneous contact, magmatic stoping, assimilation and hybridism. The cumulative effect of these factors is the production of a bewildering variety of petrological types with complex characters which must necessarily be confusing and difficult to unravel. It is common experience that similar rock types may originate from very diverse original materials and that quite dissimilar types may be evolved from one type of original rock.

Intensive work has been, and is being, done in various parts of the world to solve the difficulties confronting the study of these ancient formations. Though notable progress has been made during the present century, a great deal still remains to be done, especially in the physical and chemical problems involved.

In the correlation of sedimentary formations it is usual to rely on the lithology, stratigraphical superposition and fossil contents for purposes of age determination and correlation, since one or more of these is always available for settling questions of inter-relationship of strata. These criteria are, however, either absent or comparatively of little help in the case of Pre-Cambrian formations, and especially of metamorphic complexes, for they are devoid of fossils, their lithology is transformed by metamorphism and their stratigraphical relationships confused by intricate folding, disturbance and dislocation.

Nevertheless, these and other criteria have to be used in connection with these ancient rocks. Sir L.L. Fermor has discussed this question in the introductory part of his memoir on the 'Ancient schistose formations of Peninsular India' (*Mem. G.S.I.* LXX, Pt. 1, p. 9-25) under the following heads :—

1. Stratigraphical sequence and continuity.
2. Structural relationship, *e.g.*, presence of unconformities and relationship to periods of folding.
3. Relationship to igneous intrusions.
4. Associated ore-deposits of epigenetic origin.
5. Lithological composition.
6. Chemical composition.
7. Grade of metamorphism.
8 Uranium-lead and thorium-lead ratios.

These criteria may now be briefly examined.

1. The stratigraphical sequence worked out in detail in one area may prove very helpful in an adjacent one where the lithological units and grade of metamorphism are similar. Local variations are, however, to be taken into account.

2. The sequence may be made complex by folding, shearing, and overthrust phenomena. Inverted and incomplete sequences are common and folding may sometimes be so complex that only repeated and close study may finally help to solve the question of inter-relationship of the strata. Unconformities which separate two groups of strata are usually marked by conglomerates, but these latter are often crushed and schisted, some of the adjacent rocks also becoming involved in the crushing. Structural features are of great importance in the study of these rocks since these might prove helpful when other criteria fail.

3. Several periods of intrusion of granitic and basic rocks are recognised in the Archæans If the sequence of igneous action is once satisfactorily established, it will be possible to observe the effects of successive intrusions on the associated formations and deduce the age of the latter. At least three granitic intrusions are inferred to

have taken place at different times during the Archæan era in India, but the igneous history is different in different areas and our knowledge of this aspect of the subject is still scanty and far from satisfactory.

4. Ore formation is often related to igneous activity and a knowledge of the history of ore-deposits can be of much help in stratigraphical problems.

5 & 6. Lithological and chemical composition of the component parts of a succession are valuable criteria in determining parallelism in stratigraphical sequences. But it should be realised that, even if the beds are continuous over large areas, they are liable to lateral variation. Metamorphism and changes effected by igneous emanations may alter the character of the beds within short distances. Yet, certain types of peculiar composition, found in widely separated areas, may serve as useful indicators of particular horizons. Though such evidence may not be entirely dependable may itself, it might prove important if used in conjunction with other evidences.

7. The effects of metamorphism of different grades, under varying conditions of load, compression and temperature, are now well recognised. The effects can be of very varied types even in a single, more or less continuous, area. For purposes of correlation, the intensity or grade of metamorphism and the local metamorphic history will have to be carefully studied, in conjunction with other factors.

8. The present century has seen the development of radioactivity which has had a very profound influence on fundamental physical concepts. Since radioactive disintegration of certain elements proceeds at definite rates and results in definite end-products, these measurable quantities can be used for determining the time that has elapsed since these materials were formed in the crust. As lead and helium are the final products of the radioactive disintegration of uranium and thorium, the careful quantitative determination of lead and helium and their ratio to the parent elements can yield data as to their age. There are, however, several uncertain factors involved —the degree of weathering and alteration, accession or loss of material by replacement, the presence of isotopes, etc. In using the helium method, the uncertainties are even greater as we do not know what influence the physical properties, structure, texture, environment, etc., of the sample, and the mode of collection and preparation thereof, have on the preservation of the helium evolved. In spite of the difficulties, however, useful results have been got, though the data are yet very scanty.

CORRELATION.

The above-mentioned criteria can be applied with success in limited areas wherein the rock series are more or less continuous. Uncertainties come in when correlation is sought to be made between detached or distant areas.

The schistose or Dharwarian rocks are now recognised as the oldest Archæans in most of the areas. The oldest Dharwars are probably of igneous origin, the sedimentary material gradually increasing in the younger strata. In Rajputana, however, the Banded Gneissic Complex and the Bundelkhand gneiss are regarded as older than the Aravallis.

In several areas a part of the Dharwars is characterised by the association of crystalline limestones and manganese-bearing rocks, and another part by banded ferruginous rocks and iron ores. These associations can be used as criteria for purposes of correlation, on the assumption that at a certain period of the earth's history these special types of sediments were deposited. The manganese-bearing and marble rocks belong to an older series than the iron-ore-bearing rocks.

The manganese-marble association is seen in the Sausar series, Gangpur series, the Champaners of Gujarat, part of the Aravallis, the lower portion of the Jubbulpore rocks, the Eastern Ghats rocks with kodurites and marbles, and a few small exposures in Mysore like the Sakarsanite and Bandite series. These may be regarded as forming the lower division of the Dharwarian.

Banded ferruginous rocks and iron-ores characterise the Iron-ore series of Chota Nagpur and Bastar, the Sakoli series, the Chilpi Ghat series, the Dharwars of the type area, the Shillong series, the Middle Dharwars of Mysore, the rocks of Salem, the upper portion of the sequence in Jubbulpore, etc. In some areas they are associated with manganiferous sediments, the manganese-ore segregated from which is usually ferruginous and constitutes lateritoid deposits. These different groups may

TABLE 13—ROUGH CORRELATION OF THE PENINSULAR ARCHAEANS.

Mysore.	Madras	Ceylon.	Eastern Ghats and Bastar.	Chota Nagpur	Central Provinces	Rajputana	Assam
Closepet granite	Bellary, Hosur, Arcot and other granites	Wanni gneiss	Granite	Singhbhum granite Dome gneiss ?	Amla granite.	(Bundelkhand Gneiss ?) Alkali syenite?	Mylliem granite
Charnockite	Charnockite	Charnockite	Charnockite	—	—	—	—
Peninsular gneiss	Peninsular gneiss	Bintenne gneiss	Granite-gneiss	Chota Nagpur or Bengal gneiss.	Granite-gneiss	?	Granite-gneiss.
Upper Dharwar (Clays, silts, grits, etc.).	?	?	Kopayi Stage ?	Kolhan Series ?	?	Raialo Series ?	?
Middle Dharwar (Banded ferruginous rocks quartzites, etc)	Magnetite— and Hæmatite quartz schist, etc.	?	Bailadila Iron-ore series.	Iron-ore series	Sakoli and Chilpi series.	Aravalli system & Champaner series	Shillong series
Lower Dharwar (Chloritic, hornblendic and micaceous schists, etc)	Chloritic schists, etc.	Khondalites, Calc-gneisses, etc	Bengpal series, Khondalites, Kodurites, etc.	Gangpur series (gondites, marbles, etc)	Sausar series Sonawani series (Gondites, marbles, etc.)		Granulites, calc-gneiss, etc.
Oldest Archæans	?	?	?	Older metamorphics.	Older schists ?	Bundelkhand gneiss ? Banded gneiss ?	?

therefore be put together in an upper division of the Dharwarian system.

The Raialos form an upper division above the Aravallis, and may be considered the equivalents of the 'Upper Dharwars' of Mysore. The newly separated Kolhan series of Singhbhum may be their equivalent or may be even of Cuddapah age.

The Dharwarian system invariably includes basic rocks which have been folded with them and metamorphosed. Two or more periods of granitic intrusion are recognised, the latest granite being generally non-foliated and hence later than the main diastrophism. The earlier gneissic granites include the Peninsular gneiss, the Bengal gneiss, the Banded gneissic complex of Rajputana, etc. The later granite is represented by the Closepet granite, the Bellary, Hosur and Arcot gneisses, the Dome gneiss, the Singhbhum granite, the Amla granite and Mylliem granite.

The complexity of the Archæans prevents us from attempting anything more than the above broad indication of correlation. Much detailed and intensive work will have to be accomplished before an acceptable scheme of detailed correlation becomes possible. Table 13 gives the general equivalents as suggested in the above discussion.

CHAPTER V.

THE ARCHAEAN GROUP—EXTRA-PENINSULA.

Pre-Cambrian formations occur throughout the length of the Himalaya but only a few regions have so far been studied— Kashmir-Hazara, Simla-Garhwal, Sikkim-Bhutan and parts of Burma. Information on other parts is either very meagre or wanting.

There is also a special difficulty in dealing with this region, *viz.*, that there is not always sufficiently detailed information for separating the Archæan and Algonkian formations. We have therefore to deal with all the Pre-Cambrian rocks of the Himalayas here though it may not be logical to consider the Algonkians before dealing with the Cuddapah and Vindhyan systems of the Peninsula.

A considerable amount of work has been accomplished in the Himalayas in recent years by D.N. Wadia, W.D. West and J.B. Auden and by the participants in the several Himalayan expeditions.

NORTH-WEST HIMALAYA.

Pre-Cambrian rocks are developed in this region in Chilas, Gilgit, Baltistan, Northern Kashmir, Ladakh and Zanskar and continue through Kumaon into Nepal and Sikkim. In Kashmir and Hazara they are called the Salkhala series and comprise slates, phyllites, quartzites, mica-schists, carbonaceous and graphitic schists, crystalline limestones, dolomites and biotite-gneisses. They are highly folded and compressed and have been involved in the movements which brought the Himalaya mountains into being. The Salkhalas are well seen in the Nanga Parbat and in the mountains north of the Kishenganga, where they are highly metamorphosed and subjected to regional granitisation. As is to be expected, the grade of metamorphism varies from place to place, some of the slates in the less affected areas being scarcely distinguishable from the Dogra slates of a later (Purana) age.

The Salkhalas are associated with a gneissic complex, parts of the constituents of which might possibly be older. The gneisses include granulites and biotite-gneisses containing quartz, orthoclase, acid plagioclase and biotite, sometimes with porphyritic structure and prominent gneissic banding. There are also some hornblendic gneisses in the complex. The bands of the gneisses comprise schists of various descriptions—biotitic, muscovitic, hornblendic, talcose and chloritic. The gneissic rocks are well displayed in the region of the Zanskar range and to its north. Exposures are also seen in the Dhauladhar range, Pir Panjal, and other areas.

The Salkhalas are, according to D.N. Wadia, comparable to, and probably homotaxial with, the Jutogh series of the Simla area. Much of the intervening area remains yet to be mapped.

The Salkhalas and the gneisses are traversed by later igneous intrusives including gabbro, pyroxenite, dolerite, hornblende-granite, tourmaline-granite and pegmatite. The 'Central Gneiss' of the Himalaya is apparently a mixture of rocks of various ages, mainly of granitic composition, some being early Tertiary and some pre-Tertiary. The hornblende-granite is presumably of Tertiary age as it is seen to be intrusive into Cretaceous rocks at the head of the Burzil valley.

The Salkhalas and the gneisses are succeeded by the Dogra slates which are mainly argillaceous with minor layers of quartzites, quartzitic slates and flags They are unfossiliferous and are overlain by the fossiliferous Cambrians of Kashmir. Since they form a thick series, their range in age is not known, but they would appear to extend downward from Lower Cambrian to Pre-Cambrian and may be the equivalents of the Vindhyans and possibly also part of the Cuddapahs.

The Dogra slates are also found in the Pir Panjal and parts of the Kishenganga valley (Muzaffarabad district). Similar rocks are present in Hazara and in the Attock district of the Punjab where they are called the Attock Slates.

SPITI.

In Hundes and the valley of the Spiti river, north of the main Himalaya of Kangra, there are highly folded mica-schists, slates and phyllites, only the synclinals being preserved from denudation. This group of rocks has been called the *Vaikrita system* and considered as equivalent to the Dharwar system. Griesbach applied the term to the schistose members which are said to overlie a group of gneissic rocks.

The Vaikritas are succeeded by the *Haimanta system* consisting of quartzites, conglomerates, shales and slates and occupying the region between the Vaikritas on the one hand and the Silurian rocks on the other. Later work by H.H. Hayden has shown that the Haimantas are mainly Cambrian in age. Though the lower portion is unfossiliferous, Hayden preferred to include the whole of the Haimantas in the Cambrian.

SIMLA-GARHWAL.

The Sub-Himalayas of the Simla-Garhwal area contain rocks similar to those of Kashmir, designated the *Jutogh* and *Chail series.* The Jutogh series resembles the Salkhalas and contains slates, carbonaceous slates, schists and marbles, while the Chails are mainly quartzites, limestones and schistose slates. They are separated from each other by a thrust zone and both lie on younger rocks, the *Simla Slates*, which are little-metamorphosed slates bearing a great resemblance to the Dogra and Attock slates. The structures are so complex in the Simla region that it is not unlikely that the Jutoghs and Chails may be merely parts of the same series. These formations are intruded by the

Chor granite, typically exposed in the Chor mountain. The granite has produced some metamorphism on the adjacent rocks.

In the Northern part of the Chakrata area, the Jutoghs are not represented, but the Chails are well developed, containing slates, schistose grits, quartzites and limestones. The Chails rest, with the intervention of a thrust, on the Deoban limestone or the Mandhali series which are probably of Lower Palæozoic age.

The Archæan rocks of Garhwal--schists, granulites, slates, etc.—have been traced up to Vishnuprayag, Badrinath and Mana. In some areas in Garhwal, these ancient rocks have the same strike as the Aravallis of Rajputana and lie more or less on the continuation of their strike.

NEPAL-SIKKIM.

The Archæans are here represented by the *Daling* and *Darjeeling series* The Daling series is a schistose group ; it grades through a transition zone into the dominantly gneissic Darjeeling series.

The Dalings are typically slates and phyllites in the lower part and sericitic and chloritic phyllites in the upper part. The Dalings of Sikkim contain lodes of copper-ore in some places. In the transition zone the phyllites carry porphyroblasts of chlorite and biotite with occasional zones containing tiny garnets. These pass into garnet-biotite-schists, granulites and schists containing staurolite, kyanite and sillimanite. These schistose rocks are interbanded with granite-gneiss. In Northern Sikkim and adjacent parts of Nepal, there are also such rock types as marbles, calciphyres, quartzites and pyroxene-granulites amidst the gneisses.

Since the Dalings practically always underlie the Darjeelings and show a different grade of metamorphism, the two were formerly considered to be distinct series separated by a hypothetical thrust zone. J.B. Auden regards the presence of a thrust zone improbable (*Rec. G.S.I.* LXIX, p. 123-167, 1935). The Darjeelings seem to be merely the granite-injected and highly metamorphosed upper part of the Dalings. Auden has also suggested that the granitic rocks of Dutatoli and Lansdowne in Garhwal may be the same as the granitic constituent of the Darjeelings, and that a similar granite has given rise, by disintegration, to the felspathic sandstones of the Middle Siwaliks of the Darjeeling-Nepal foot-hills.

BHUTAN AND EASTERN HIMALAYA.

In the Buxa Duars of Bhutan, lying to the east of the Darjeeling area, a group of rocks containing dolomitic limestones and quartzites was called the *Buxa series*, and correlated with the Simla slates. Recent work indicates that they contain slates, phyllites, quartzites, mica-schists, talc-schists, limestones, dolomites, banded ferruginous rocks and chlorite-quartz-magnetite-schists. They are said to resemble the Dharwarian rocks of Chota Nagpur but may contain representatives of the Cuddapahs also. The whole series is thrust over Lower Gondwana rocks, parts of which undoubtedly are the equivalents of the Barakars with coal seams.

Argillaceous schists and gneisses are known in the Aka hills, these having been correlated with the Darjeelings by La Touche Godwin-Austen found similar rocks in the Daphla hills. The Abor hills near the Sadiya frontier tract contain quartzites, phyllites, slates, mica-schists, limestones and dolomites, according to J.C. Brown. The Mishmi hills show a large variety of schistose and gneissic rocks including quartzites, mica-schists, chlorite-schists, amphibolites, granulites and kyanite and garnet bearing rocks. A.M.N. Ghosh has recorded that these are associated with composite gneisses, intrusive granites and pegmatites. The rocks therefore correspond to the Dalings and Darjeelings. The Miju hills and the Daphabhum similarly show quartzites, limestones, schists, garnetiferous gneisses, etc.

The Himalayan Archæans have not been studied in as much detail as some of the Peninsular Archæans, but a rough indication of the correlation may be given here. The Salkhalas of Kashmir-Hazara, the Jutoghs and Chails of the Simla region, the Dalings and Darjeelings of Nepal-Sikkim, the Buxa series of Bhutan and the gneisses and schists of the Assam Himalaya seem to be generally the equivalents of the Dharwarian rocks of the Peninsula. In addition to the folding, metamorphism and igneous intrusions suffered by the Himalayan rocks in Archæan times, they have been subjected to the mountain-building movements of Tertiary times, being thereby sheared, overthrust and often inverted. They present therefore extremely complicated structures which can be unravelled only by prolonged and careful study.

BURMA.

The western part of Burma consists of comparatively young strata ranging in age from Cretaceous to Tertiary. The older rocks—Archæans, Palæozoic and Mesozoic—occur in the belt which includes the Shan Plateau on the north and Tenasserim in the south, to which we shall now direct our attention

MYITKYINA.

The northern end of this is the Myitkyina region where the occurrence of ortho-gneisses and schists of Archæan age is known. They extend northwards into the adjoining parts of China.

MOGOK STONE TRACT.

The Mogok tract, which lies between the Irrawaddy and the Shan Plateau some distance north of Mandalay, is an exceedingly interesting area since it contains a variety of rock types and yields several gemstones. The crystalline complex here, called the *Mogok series*, consists of a group of gneisses and schists of mixed origin—biotite-gneisses, cordierite-gneisses, garnet-biotite-granulites, garnet-sillimanite-schists, crystalline limestones, calciphyres, calc-granulites, quartzites, pryoxene-scapolite-gneisses, etc. The garnet-sillimanite-schists resemble the khondalites of the Eastern Ghats. There is a gradation from the crystalline limestones to calciphyres and calc-granulites, and these are interbanded and occur also as inclusions in the later intrusives. They are folded with the gneisses and have a general strike of E. 30° N. and very steep dips. The minerals in the calciphyres and calc-granulites are calcite, dolomite, spinel, diopside, phlogopite, forsterite, scapolite, sphene and graphite. At their contact with acid intrusives are found rocks containing diopside, felspar, nepheline and calcite. The excess alumina in the intrusive and in the calcareous rocks has crystalised out as ruby, sapphire or ordinary corundum The quartzites of this region apparently represent arenaceous bands associated with the calcareous sediments.

The sedimentary and metamorphic series are intruded by syenites and granites and by a series of minor intrusions including basic and ultrabasic rocks. The syenites are found mainly as sheets and lenses and have been involved in the folding of the region. They consist of dominant orthoclase and microperthite with moonstone schiller, some quartz, aegirine, hypersthene or titanaugite. Iron-ore, zircon and apatite are the chief accessories. There are also alkali rocks in close association with the limestones ; indeed, the alkali rocks seem to be absent away from the calcareous rocks. This lends support to the view that the alkali rocks and syenites are products of desilication of a granite by the limestone, in accordance with Daly's hypothesis of origin of alkali rocks. But, as the syenites are disturbed and folded, they may represent an earlier phase of granitic intrusion than the Kabaing granite. The Kabaing granite and associated pegmatites are unaffected by the folding, the former often containing inclusions of limestones and other rocks in its peripheral portions. The Kabaing granite consists of abundant felspar, quartz, biotite and minor accessories, the felspars being frequently partly kaolinised.

Closely associated with the calcareous rocks there are also hornblende-augite rocks, amphibole-pyroxene-felspar rocks, hornblende-nepheline and ægirine-nepheline rocks and different types of nepheline syenites, which occur as dykes and sills. There are also ultrabasic types including peridotites, picrites, norites and garnet-pyroxene rocks resembling eclogites. Amongst these minor groups of intrusives are rocks closely resembling intermediate and basic charnockites of India.

A large variety of gemstones is found in this region, of which the ruby is the best known. Ruby mining has been carried on here for many years and still continues. The other gemstones are sapphire, colourless corundum, spinel, scapolite, apatite, nepheline, garnet, peridot, lapis lazuli, zircon, topaz, tourmaline, beryl (aquamarine), rock crystal, amethyst and moonstone.

The rock types of this area bear the impress of high grade metamorphism and have a typical Archæan aspect. All recent workers agree that the crystalline limestones and associated schists are metamorphosed sedimentaries. Amongst the gneissic complex of this region there are, of course, igneous constituents of different ages. Some of the basic and ultrabasic intrusives and the Kabaing granite represent later intrusives.

Dr. L. A. N. Iyer who mapped a large part of the area, and Sir L. L. Fermor appear to regard all the Mogok rocks as of Archæan age. But Dr. E. L. G. Clegg has suggested (*Mem. G. S. I.*, 74, Pt. 1, p. 9, 1941), that some of the rocks, and especially the limestones, may be of a later age. The Mogok limestones are said to be continuous with those further north and the limestones in the second defile of the Irrawaddy have been proved to be as young as the Cretaceous.

SHAN STATES.

Between Mogok and the fossiliferous formations of the Northern Shan States there is an extensive area of the Archæan rocks, well developed in the Tawng-Peng State and called the *Taung Peng System* by La Touche. This includes the biotite-schists of Mong Long, the Chaung Magyi series and the Bawdwin volcanic series. Of these only the Mong Long schists are probably definitely referable to the Archæan. The biotite-schists are intruded by granites containing tourmaline and garnet and traversed by veins of quartz.

THE CHAUNG MAGYI SERIES overlies the Mong Long schists with a transitional zone. It consists of slaty shales, phyllites, quartzites, graywackes and also carbonaceous slates. The series in dominantly argillaceous and non-calcareous and is developed in the hilly parts of the Shan Plateau, extending into the Southern Shan States and the Yamethin district on the one hand and into Northern Shan States and Yunnan on the other. The Chaung Magyis are intruded by granite bosses and basic dykes, the former having produced contact alterations in the argillaceous rocks.

TENASSERIM.

THE MERGUI SERIES.—In the Mergui, Tavoy and Amherst districts of Lower Burma there is developed a group of rocks called the *Mergui series*. It includes quartzites, conglomerates, limestones, argillites, greywackes and agglomerates, the argillites being sometimes carbonaceous, and also the most important by volume. The greywackes and agglomerates are next in importance and apparently represent pyroclastics. Dark and white, fine-grained to saccharoidal limestones occur sparingly. The series is intruded by granite which has produced contact metamorphism, with the development of hornstones and schists containing biotite, andalusite, sillimanite, garnet, etc. The rocks have a N.N.W.-S.S.E. strike parallel to the general trend of the mountains. They are much disturbed and folded and are overlain by the Moulmein limestone which is regarded as of Permo-Carboniferous age.

The age of the Mergui series is in doubt, some taking it to be Pre-Cambrian and others Upper Palæozoic. In support of the latter view is the fact that the Moulmein limestone lies conformably over them in some places. The Mergui rocks are, however, entirely unfossiliferous.

Another series of rocks, called the *Taungnyo series*, occurs in the same region and contains similar rock types. This series is said to overlie the Mergui series, but it is not always possible to distinguish the two and map them separately. They may both be of the same age.

CORRELATION OF THE BURMESE ROCKS

The Chaung Magyis are Pre-Cambrian in age, as they are overlain by the Bawdwin volcanics which intervene between them and the graptolite-bearing Ordovician strata. In the present state of our knowledge it is not possible to say whether they are Dharwarian or Purana or both. They are unfossiliferous and have suffered regional and contact metamorphism

There is even greater uncertainty about the Merguis. They are also unfossiliferous and much disturbed and may be of any age older than the Permo-Carboniferous. If they are Palæozoic in age, we can find their parallel amidst the rocks of the Sub-Himalayan region.

The gneisses and crystalline limestones of the Mogok tract have a typical Archæan aspect. A suggestion has however been made that the limestones may belong to the Plateau Limestone age or later but this can be proved only by connecting up this area with the neighbouring tracts by continuous mapping.

CHAPTER VI.

MINERAL RICHES OF THE ARCHAEANS.

The Dharwarian rocks and the associated gneisses constitute the most important mineral-bearing formations of India. They contain a large variety of useful metallic ores, industrial minerals and rocks such as the iron-ores of Bihar, Orissa, Central Provinces and South India ; the gold of Mysore, Hyderabad, Chota Nagpur ; the copper-ores of Nellore, Bihar and Sikkim ; the chromite of Bihar and Mysore ; the many non-metallic minerals used as abrasives, refractories, pigments, ceramic materials, gems, building and ornamental stones, etc. The occurrences of the chief minerals will be briefly described in the following paragraphs.

GOLD.

Amongst the several bands of Dharwarian rocks of South India the more easterly bands of Mysore and Hyderabad contain gold deposits of importance, though old workings have been found in all the important bands. The gold occurs in quartz veins, the best values being associated with the bluish quartz The veins occur in shear zones in the schists and at and near the junction of the schists and gneisses. The veins seem to be of different ages as some are crushed and sheared and others unaffected. The ore is of hypothermal (high temperature hydrothermal) origin the gold being associated with arsenopyrite, pyrrhotite and pyrite. The wall rocks are often sericitised and chloritised by the ore-forming liquids. In Mysore it is believed that the gold quartz veins are related to the granitic constituent of the Champion gneiss.

The Kolar schist belt, which is 30 miles long and 3 to 4 miles broad, is composed of hornblendic rocks, ferruginous quartzites, gneisses and granites with a zone of autoclastic conglomerate along the eastern border. The structure of the belt is synclinal. The Champion lode is gold-bearing throughout its length of 5 miles and varies in width from a few inches to 15 feet or more, with an average width of around 4 feet. In places it is composed of thin parallel veins or veined schists. It strikes nearly N.-S. parallel to the schistosity of the hornblende-schists and dips, near the surface, at 45^0 - 55^0 towards the west, gradually steepening at lower levels and becoming nearly vertical at depths of 7,000 feet or more. The lode contains numerous ore-shoots and barren patches and intercalations of mica- and amphibole-schists.

There are now four mines in the Kolar Gold Field—The Mysore, Champion Reef, Ooregum and Nundydroog ; a fifth, the Balaghat mine, went into liquidation in 1932. All the mines are now actively working at depths of over 8,000 feet vertically down from the surface, the temperature at these depths being around 125^0 to 130^0 F. The ore-shoots continue undiminished in richness and will presumably continue to as great a depth as may be possible to mine. The average tenor of the ore is 10 penny-weights per ton and it is easily treated by blanketing, amalgamation and cyanidation. The present production averages a third of a million ounces per year and the total value of gold produced in this field since the commencement of operations in 1892 to 1940 is about £90,000,000 of which £25,000,000 have been distributed as dividends.

Mining has been done also in the Maski band in Raichur district (Hyderabad) in the Gadag band in Dharwar district and Sangli State and in other bands in the Anantapur district (Madras). Gold-quartz veins occur in Wynad in Malabar, where there was considerable activity a little before the close of the last century. In many places in Chota Nagpur, Bihar, etc., there are auriferous veins, and though gold washing is done even at the present day in the streams draining these areas, no veins have yet been located which are rich enough to support a modern mining enterprise.

COPPER.

Copper ores are found only in a few localities—*e.g.*, the Singhbhum district in Bihar, Nellore in Madras and in Sikkim.

Ores composed mainly of chalcopyrite, pyrrhotite and pentlandite occur in Singhbhum in the main overthrust zone in the Iron-ore series, extending from Duarapuram, through Kharsawan and Seraikela States, to Bhairagora, a distance of 80 miles. They are thought to be related genetically to the sheared soda-granite in which they occur. The adjacent country rocks like epidiorite and quartzite also contain a few lodes. The ores have been worked at Mosaboni, Matigara and Rakha Mines, but exploitation is now confined to Mosaboni where they contain about 4 per cent. copper and a little nickel. They are smelted at Maubhandar near Ghatsila where refined copper and brass are regularly produced. At Bhotang, Dikchu and other places in Sikkim, copper ores are found in the Daling series intruded by the Sikkim granitic gneiss. The ore consists of pyrrhotite, chalcopyrite, galena and blende with small quantities of the sulphides of bismuth and antimony. The ore-bearing areas are in difficult mountainous country, though the lodes are known to contain 3 to 7 per cent. copper and are workable.

Copper ores occur near Sleemanabad in Jubbulpore district in Dharwarian schists as veins containing chalcopyrite, tetrahedrite, galena, barytes and calcite. Oxidised ores are found near Garimanipenta in the Nellore district, Madras, but these have not been prospected in detail. Old workings for copper exist in Jaipur State in Rajputana, in the Hazaribagh district of Bihar and in some places in Nepal.

CHROMITE.

Chromite is found in association with ultrabasic rocks traversing the Dharwars in Mysore, Salem, and Singhbhum. The occurrences in Salem are small and sporadic but those of Mysore and Singhbhum are worked and yield a steady output. In Singhbhum they occur at and around Jojohatu near Chaibasa as lenses and veins in peridotites, saxonites and dunites. The best occurrences in Mysore are in the Nuggihalli schist belt in the Hassan district and between Mysore and Nanjangud, in altered ultrabasic rocks. In recent years, some veins and pockets found in ultrabasic rocks in the Kondapalle hills in the Kistna district, Madras, have yielded a small output.

IRON-ORE.

High grade hæmatite ores derived from the replacement of banded hæmatite-quartzites occur in several areas of Dharwarian rocks. Rich and extensive deposits containing over 60 per cent. iron occur in a series of ridges in South Singhbhum, Mayurbhanj, Keonjhar, Bonai, Bastar, Chanda, Drug, Mysore, and in [redacted] Goa. The metamorphism of similar formations has produced quartz-magnetite schists in Mysore, Salem and Trichinopoly, the magnetite being to some extent associated with hæmatite. The deposits of Bihar, Orissa and Central Provinces contain not less than 8,000 million tons of high grade hæmatite and at least as much ore of lesser grade. Indeed, one authority has estimated that they contain as much as 20,000 million tons of ore of different grades. The ore reserves in South India are also large and must run into a few thousand million tons. The magnetite-quartzites are rather of low grade but should be amenable to magnetic concentration.

Most of these ore-bodies are of original sedimentary origin, though a few unimportant ones in North Singhbhum are regarded as replacements of schists and phyllites by iron.

MANGANESE-ORE.

Manganese-ores occur in India in three types of deposits, *viz*., in association with gondites and kodurites and as lateritoid ores.

Gondite is a rock composed essentially of quartz and spessartite with varying amounts of manganese-pyroxenes, amphiboles, etc. It is believed to have been produced by the metamorphism of manganiferous sediments, the impure portions forming silicates and the pure ones such primary ores as psilomelane, braunite, hollandite, sitaparite and vredenburgite (a mixture of hausmanite and jacobsite). The gonditic type of deposits is found in Bombay and Central India (Narukot, Jhabua) Central Provinces (Chhindwara, Nagpur, Bhandara, Balaghat) and further east (Gangpur State). This group contains the best quality ores and has large reserves.

The second type is associated with kodurite, a hybrid rock consisting of felspar, spessartite-andradite (contracted to spandite), rhodonite, quartz and apatite. It is developed in the Ganjam and Vizagapatam districts on the eastern coast of India and is usually highly phosphoric. The composition of the rock varies very widely and ranges from acid to ultrabasic, the latter including garnet-rock and pyroxenite. This group of rocks was originally described by Fermor[1] as an igneous suite characterised by spandite but his view was later revised.[2] The original view was also criticised by the American petrologist Whitman Cross.[3] In the altered condition, these rocks consist of litho-marge, ochres and wad. The ore-bodies in them are irregular but occasionally attain large dimensions as at Garbham and Kodur. The ores consist mainly of psilomelane with some pyrolusite, braunite, and

---

[1] *Rec. G.S.I.* XXXV, p 22, 1907, *Mem G S I*, XXXVII, Chap. XII, XIII, 1909

[2] *Rec G S I*, XLVI, p 102, 1915

[3] *Journ. Geol.*, XXII, p. 791-805. 1914

mangan-magnetite, and are high in iron and phosphorus and low in silica.

The lateritoid deposits have resulted from the surface alteration of manganiferous Dharwarian rocks such as phyllites, schists and ferruginous quartzites. The ores contain appreciable quantities of iron and vary from manganese to iron ores through every gradation, the minerals present being pyrolusite, psilomelane, wad and also limonite and earthy hæmatite. Such deposits occur in Sandur State (Bellary), Mysore, North Kanara, Jubbulpore, Keonjhar, etc.

LEAD-ORE.

Deposits of lead-ore occur in Mewar and Jaipur States in Rajputana and in several places in Bihar as veins of galena associated with some sulphides. None of these has, however, proved important enough to be worked on a commercial scale. The lead-zinc ores of Zawar in Mewar have been investigated recently by the Geological Survey of India but the results have not yet been published.

TIN AND TUNGSTEN ORES.

A small deposit of tinstone and wolfram occurs at Chakkarbandah in the Hazaribagh district and two other small wolfram deposits have been worked in Bihar and the Central Provinces. Numerous important occurrences are found in the rocks of Burma, particularly in the Mergui and Tavoy districts. They are associated with arsenopyrite, molybdenite and bismuthinite. The granites which have given rise to them are probably of Mesozoic age so that these ores should properly be assigned to that age though the host rocks may in many cases be Archæan.

NICKEL AND COBALT.

The presence of nickel in the copper ores of Bihar has already been mentioned. Cobalt ores (cobaltite and danaite) are disseminated in the Aravalli schists and slates at Khetri in Rajputana. These are used in a small way for the manufacture of the sulphate and for making a blue enamel employed in jewellery. Cobalt and nickel ores are known to occur in Nepal but no published details are available regarding them.

TITANIUM.

Titaniferous magnetite is fairly common in several of the magnetite occurrences in various parts of India. Ilmenite is found as veins or lenses in the mica-pegmatites of Bihar, and with wolfram at Degana near Kishengarh in Rajputana. The most important source of ilmenite is, however, the coastal sands of Travancore and Cape Comorin, these having been derived from the gneissic rocks and concentrated by the action of sea waves. Similar, but smaller, deposits occur along parts of the coasts of Malabar, Tinnevelly, Tanjore and Vizagapatam in the province of Madras. A large tonnage of ilmenite is nowadays annually exported from Travancore to England and the United States.

OTHER METALLIC ORES.

Molybdenite.—There is occasionally a small production of molybdenite from Tavoy. The mineral is known to occur in the Palni hills, in the Godavari district, Chota Nagpur and Kishengarh State but no useful deposit has so far come to light.

Stibnite.—The antimony sulphide, sibnite, occurs in gneisses near the Shigri glacier in Lahaul. The deposit is said to be extensive enough for regular production but the locality is very inaccessible. The stibnite contains some gold and is associated with galena and blende.

Several small deposits of stibnite have been recorded in Southern Shan States and Amherst district, Burma, in the Jhelum district, Punjab, in the Jubbulpore district and Mysore State. The Burmese deposits are found, however, in post-Archæan rocks.

Arsenic sulphides.—Minerals of arsenic occur sporadically in the mica belt of Hazaribagh and near Darjeeling. (The orpiment mines of Chitral occur in calcareous shales and marbles in close association with a basic intrusive. The deposits are of (?) Mesozoic age).

Columbite-Tantalite.—These minerals are found in Archæan pematites in the Singar Zemindari of Gaya, at Pananoa hill in Monghyr, and in Trichinopoly district.

Vanadium.—Vanadiferous magnetite occurs associated with ultrabasic intrusives of Dhalbhum and Mayurbhanj. The deposits in Mayurbhanj are said to be of large size but have not yet been properly investigated.

Uranium.—Pitchblende and uranium-ochre have been recorded as occurring in the pegmatites of Gaya though no workable deposits have been discovered.

NON-METALLIC MINERALS.

Mica.—The chief muscovite occurrences are those of the mica belt of Bihar in Gaya, Hazaribagh and Monghyr districts, of Nellore, Salem, and Nilgiris in Madras and of Ajmer in Rajputana. The Bihar mica belt is 60 miles long and 12 miles wide, the chief mining centres being Kodarma and Giridih. The 'ruby mica' produced here is of the best quality and is much in demand for use in the electrical industry.

The Nellore mica belt occurs between latitudes 14° and 15° N. in a strip of country 8 to 10 miles wide. The muscovite is generally of a pale greenish colour though light ruby mica also occurs sparingly in a part of the area. Several other granitic areas in the Peninsula show pegmatites but in most of them the mica is not sufficiently well developed nor flawless to be workable.

Phlogopite occurs in a few places in Travancore, particularly near Punalur and Neyyur, in ultrabasic rocks. Small quantities have been won from these deposits and exported.

Asbestos.—Tremolite asbestos occurs in the Dharwars in various parts of India—Hassan and Bangalore in Mysore, Salem district in Madras, Seraikela State in Singhbhum, Bhandara in C.P., Idar State and Ajmer-Merwara.

Apatite.—Apatite-magnetite rock occurs at several places along the main shear zone of Singhbhum, where it has been worked during the last two decades. The pegmatites of Hazaribagh and Nellore and the kodurite rocks of Ganjam and Vizagapatam contain apatite which might be amenable to concentration.

Corundum.—This mineral occurs in several places and has been worked and used as an abrasive. It is found in the syenitic rocks of Coimbatore, S. Kanara and Salem, and in anorthosites in Salem ; with sillimanite in Rewa, Bhandara and Khasi hills, and in alkali-syenites in Kashmir.

Garnet.—Garnet which can be crushed and used as an abrasive is of wide distribution in many of the garnetiferous schists of Dharwarian age, and almost every Archæan tract in India is capable of yielding some quantity of this mineral.

Graphite.—Workable, though not large, deposits of graphite occur in the khondalites or gneisses of Kalahandi and Patna States of Orissa, in the Godavari, Vizagapatam and Tinnevelly districts of Madras, in Travancore State and in the Warangal district of Hyderabad State.

Magnesite.—The ultrabasic rocks of Salem and Mysore have in some places been altered to magnesite. The best known occurrences are those of the Chalk Hills near Salem and of the Mysore district in Mysore, these being under active exploitation.

Sillimanite and Kyanite.—Sillimanite is a constituent of certain Archæan gneisses and schists. Workable deposits, apparently the only ones so far known in the world, occur associated with the Shillong series of the Assam plateau, especially in the Sona Pahar and in Nongstoin State.

Sillimanite-corundum rocks are found at Pipra in Rewa State and in the Bhandara district of the Central Provinces. Sillimanite is an important constituent of the khondalites of the Eastern Ghats and of certain gneisses in the Coimbatore district of Madras.

Kyanite is rather more widespread than sillimanite, being found in gneisses and in kyanite-quartz-rocks. The best known deposits occur along the main shear zone in the Iron-ore series of Dhalbhum and Mayurbhanj, the one at Lapsa Buru in Kharsawan having provided thousands of tons for export.

Steatite and Talc-schist.—These are widely distributed in the Archæan terrane and good deposits of steatite are occasionally found, as in Jubbulpore, in Jaipur State and in several places in South India.

Gem stones.—A large number and variety of precious and semiprecious stones are found in the Archæans. Amongst them are: Ruby, sapphire, spinel, garnet, scapolite, lapis lazuli, olivine, tourmaline, zircon, topaz, moonstone from the Mogok tract ; sapphire from Kashmir ; aquamarine from Rajputana, Madras and Kashmir; chrysoberyl from Coimbatore in Madras and Kishengarh in Rajputana; garnet from Jaipur, Mewar and other states in Rajputana ; tourmaline from the Shan States, Nepal and Kashmir.

Building and ornamental stones.--The Archæan gneisses and granites form an inexhaustible source of excellent building stones. The porphyritic and gneissic granites such as the Bellary gneiss, Arcot gneiss, Chota Nagpur gneiss, etc., yield durable and good building stones. The banded gneisses and charnockites are also excellent, many of these having been used in the building of temples and public edifices in Southern India. The temples of Seven Pagodas near Madras are hewn out of charnockites, while those of Madura, Trichinopoly and other places are built of the gneissic granites.

Many of the crystalline limestomes in the Dharwarians are rocks of high decorative value. The Makrana marble has been used in the construction of the Taj Mahal and other buildings in Northern India. Several of the white, grey and coloured marbles in Rajputana, Baroda, Central Provinces and Madras have occasionally been used for building purposes. There are also numerous occurrences of slates, quartzites and schistose flagstones which serve the local needs for construction. A beautiful green, fine-grained ornamental stone is the fuchsite-quartzite worked in Mysore, its fine green colour being due to the presence of the chrome-mica fuchsite.

SELECTED BIBLIOGRAPHY

Adams, F.D. The Geology of Ceylon *Canadian Jour. Res.* **1**, 467-486, 1929.

Ball, V. Geology of the Mahanadi basin. *Rec.* **10**, 167-185, 1877.

Brown, J.C and Heron, A.M Geology and ore deposits of Tavoy. *Mem.* **44** (2), 1923.

Chatterjee, S.C. Anorthosites of Bengal Calcutta Univ. Press, 1937.

Coates, J.S. Geology of Ceylon. *Ceylon Jour Sci B.* **19** (2), 101-187, 1935.

Coulson, A.L. Geology of Sirohi State, Rajputana, *Mem* **63** (1), 1933.

Crookshank, H. Western margin of the Eastern Ghats in Southern Jeypore, *Rec.* **73**, 398-434, 1938

Dunn, J.A Geology of Northern Singhbhum *Mem.* **54**, 1929.

Dunn, J.A Stratigraphy of South Singhbhum *Mem.* **63** (3), 1940.

Dunn, J.A. and Dey, A.K. The geology and petrology of Eastern Singhbhum and surrounding areas. *Mem.* **69** (2), 1942.

Fermor, L.L. The manganese ore deposits of India. *Mem* **37**, 1909.

Fermor, L.L. The age of the Aravalli Range *Rec* **62**, 391-409, 1930.

Fermor, L.L An attempt at correlation of the ancient schistose rocks of Peninsular India. *Mem* **70**, 1936—.

Foote, R.B. Dharwar system, the chief auriferous series in South India. *Rec.* **21**, 40-56, 1888 ; *Rec.* **22**, 17-39, 1889.

Foote, R.B. Geology of the Southern Mahratta country. *Mem.* **12**, 1876

Foote, R.B. Geology of the Bellary district. *Mem.* **25**, 1895.

Foote, R.B. Geology of Madura and Tinnevelly districts. *Mem.* **20** (1), 1883

Ghosh, P.K Charnockite series of Bastai State. *Rec.* **75**, paper 15, 1941

Griesbach, C L. Geology of the Central Himalayas. *Mem.* **23**, 1891.

Gupta, B.C. Geology of Central Mewar *Mem.* **65** (2), 1934.

Gupta, B.C and Mukerjee, P.N. Geology of Gujarat and S. Rajputana. *Rec.* **73**, 164-205, 1938

Hayden, H.H. Geology of Spiti. *Mem.* **36** (1), 1904.

Heron, A.M. Geology of N.E Rajputana. *Mem.* **45** (1), 1917.

Heron, A.M Soda rocks of Kishengarh *Rec.* **56**, 179-197, 1924.

Heron, A.M. Synopsis of the pre-Vindhyan geology of Rajputana. *Trans. Nat. Inst. Sci.*, **1** (2), 1935.

Heron, A M. Geology of South-eastern Mewar, Rajputana. *Mem.* **68** (1), 1936.

Holland, T.H The charnockite series *Mem* **28** (2), 1900.

Holland, T H The Sivamalai series of elæolite syenites and corundum syenites. *Mem* **30** (3), 1901.

Iyengar, P Sampat The acid rocks of Mysore. *M.G.D. Bull.* **9**, 1920

Iyer, L A.N Granitic intrusions and associated rocks in Ranchi and Singhbhum *Rec* **65**, 490-533, 1932.

Jones, H.C Iron ores of Bihar and Orissa. *Mem.* **63** (2), 1934.

King, W. and Foote, R B. Geology of Trichinopoly, Salem, etc. *Mem.* **4** (2), 1864

King, W. The gneiss and transition rocks of Nellore. *Mem.* **16** (2), 1880.

King, W. Sketch of the progress of geological work in the Chattisgarh division of the C.P. *Rec.* **18**, 169-200, 1885.

King, W Geology of Travancore State. *Rec.* **15**, 87-92, 1882.

Krishnan, M.S. Dharwars of Chota Nagpur, etc *Proc* 22nd *Ind. Sci. Cong* 1935 (Address to the Geology section).

Krishnan, M.S. Geology of Gangpur State *Mem.* **71**, 1937

Mallet, F.R. Geology of Darjeeling and Western Duars. *Mem.* **11**, (1), 1874.

Pilgrim, G E. and West, W D The structure and correlation of the Simla rocks. *Mem* **53**, 1928

Pilgrim, G.E. Geology of a portion of Bhutan. *Rec* **34**, 22-30 1906.

Rao, B. Rama. Recent investigations on the Archæan complex of Mysore *Proc. Ind Sci Cong.* 1936, p. 215-244.

Rao, B Rama, The Charnockite rocks of Mysore. *M.G.D. Bull.* **18**, 1945.
Rao, B Rama The Archæan complex of Mysore. *M.G.D. Bull.* **17**. 1940
Rao, M.B. Ramachandra. Petrography of hornblende schists, Kolar. *M.G.D. Bull* **16**, 1937.
Rao, M.B Ramachandra and Rao, K. Sripada. Origin and correlation of the metamorphic rocks of Sakarsanhalli area. *M.G.D. Bull.* **14**, 1934
Rau, S. Sethurama. The geology of Mergui. *Mem.* **55** (1), 1930.
Smeeth, W F Outlines of the geology of Mysore *M.G.D. Bull*, **6**, 1916.
Stillwell, F. L. The metamorphic rocks of Adelie Land. *Australian Antarctic Expedition*, 1911-14. *Sci. Rep. A*, III (1), 1918.
Vrendenburg, E.W. Considerations regarding a possible relationship between the charnockites and the Dharwars. *J.A.S.B., N.S.* **15**, 433-448, 1918.
Washington, H.S. The charnockite series *A.J.S.* **41**, 323-337, 1916.

MINERAL RESOURCES.

(*This is a general list of papers on mineral deposits irrespective of their geological age.*)

————Quinquennial Review of Mineral Production : *Rec.* **39**, 1910 ; 46, 1915 ; 52, 1921 ; 57, 1925 ; 64, 1930 ; 70, 1936.
————Several bulletins in the series "Bulletins of Indian Industries and Labour." Government Press, Delhi.
————Several bulletins appearing in the Records of the Geological Survey of India, Vol. **76**, since 1941
Barber, C T. The natural gas resources of Burma. *Mem.* **66**, Pt. 1, 1935.
Bose, P N. Manganese-iron and manganese ores of Jubbulpore. *Rec.* **21**, 71-89, 1888 ; *Rec.* **22**, 216-226, 1889.
Bose, P.N. Mineral resources of Mayurbhanj State. *Rec* **31**, Pt. 3, 1904.
Brown, J.C. Geology and ore deposits of the Bawdwin mines. *Rec.* **48**, 122-155, 1917
Brown, J C Cassiterite deposits of Tavoy. *Rec.* **49**, 23-33, 1918.
Brown, J.C A geographical classification of the mineral deposits of Burma *Rec* **56**, 65-108, 1924.
Brown, J.C. "India's Mineral Wealth." Oxford Univ. Press, 1936.
Brown, J.C. and Heron, A.M Tungsten and tin in Burma. *Rec.* **50**, 101-121, 1919.

Chhibber, H L. "Mineral Resources of Burma." Macmillan, London, 1934.
Christie, W A.K. Note on the salt deposits of Cis-Indus Salt Range. *Rec.* **44**, 241-264, 1914.
Clegg, E.L.G A note on the Bawdwin mines. *Rec.* **75**, paper 13, 1941
Clegg, E.L G Mineral Resoures of Burma. Government Press, Rangoon, 1939
Cotter, G. de P. Sanni sulphur mine *Rec.* **50**, 130-138, 1919.
Cotter, G. de P Oil shales of Eastern Amherst. *Rec* **55**, 273-313, 1924
Coulson, A.L. Barytes in the Ceded districts of Madras *Mem.* **64**, Pt. 1, 1933.
Coulson, A.L Asbestos in the Ceded districts of Madras. *Mem.* **64**, Pt. 2, 1934
Coulson, A.L. Mineral resources of the N.W. Frontier Province. *Rec.* **75**, Paper 2, 1940.
Dunn, J.A. Aluminous refractory minerals—Kyanite, Silliminite and Corundum *Mem.* **52**, Pt 2, 1929.
Dunn, J.A. Mineral deposits of Eastern Singhbhum. *Mem* **69** 1937
Dunn, J A Mineral resources of the Bihar Province. *Mem.* **78**, 1941.
Dunn, J.A., and others. The Economic Geology of Orissa. Government Press, Cuttack, 1943.
Fermor, L.L Manganese ore deposits of India. *Mem.* **37**, 1909.
Fermor, L.L. Mineral resources of Bihar and Orissa *Rec* **53**, 239-319, 1921
Fox, C.S Bauxite and aluminous laterite occurrences of India. *Mem.* **49**, Pt. 1, 1923.
Fox, C.S The Jharia Coalfield *Mem.* **56**, 1930.
Fox, C.S Natural history of Indian Coal. *Mem* **57**, 1931
Fox, C S Lower Gondwana Coalfields of India *Mem.* **59**, 1934.
Gee, E R Geology and coal resurces of Raniganj coalfield *Mem.* **61**, 1932.
Gee, E.R Economic geology of Northern Punjab. *T.M G I I.*, **33**, Pt. 3, 1937
Hatch, F.H. The Kolar gold field. *Mem* **33**, Pt. 1, 1900.
Hayden, H H. and Hatch, F H Gold fields of Wainad. *Mem.* **33**, Pt 2, 1901
Heron, A.M Antimony deposits of Thabyu, Amherst Dt. *Rec.* **51**, 34-43, 1931.

Heron, A.M. Mineral resources of Rajputana *T.M.G.I.I.* **29**, 1935.
Holland, T.H. Iron ores and iron industries of Salem. *Rec.* **25**, 135-158, 1892.
Holland, T.H Corundum Government of India Press, Calcutta, 1898.
Holland, T.H. Mica deposits of India. *Mem* **34**, Pt 2, 1902.
Jones, H.C. Antimony deposits of S. Shan States. *Rec.* **53**, 44-50, 1921.
Jones, H.C. Iron ores of Bihar and Orissa. *Mem.* **63**, Pt. 2, 1934.
Krishnan, M S. Mineral resources of Central Provinces and Berar. *Rec.* **74**, 386-429, 1939.
La Touche, T.D. Bibliography of Indian Geology, Part I-B (mineral index). Government of India Press, Calcutta. 1918.
Middlemiss, C S. Ultra-basic rocks and derived minerals of the Chalk Hills and other localities, Salem. *Rec.* **29**, 31-38, 1896.
Middlemiss, C.S. Corundum localities in Salem and Coimbatore *Rec* **29**, 39-50, 1896 ; *Rec.* **30**, 118, 1897.
Mirza, K. Mineral resources of Hyderabad State. *Hyd Geol. Survey*, 1937.
Pascoe, E.H. Oilfields of Burma. *Mem* **40**, Pt 1, 1909.
Pascoe, E.H. Petroleum occurrences of Assam and Bengal. *Mem.* **40**, Pt. 2, 1914.
Pascoe, E H. Petroleum in the Punjab and N.W. Frontier Province. *Mem.* **40**, Pt. 3, 1920.
Smeeth, W F. and Sampat Iyengar, P. Mineral Resources of Mysore. *M.G D. Bull*, **7**, 1916.
Stuart, M. Potash salts of the Punjab Salt Range and Kohat. *Rec.* **50**, 28-56, 1919.
Swaminathan, V.S. Mineral resources of Madras. *T M.G.I.I.*, **25**, 81-175, 1930.
Tipper, G.H. Monazite sands of Travancore. *Rec.* **44**, 186-195, 1914.
Sen, A.M. Review of the mineral production of Mysore from 1915 to 1929 (with map). *M.G.D. Bull*, **11**, 1931.

CHAPTER VII.

THE CUDDAPAH (KADAPA) SYSTEM.

General.

As already remarked, the close of the Dharwarian era was marked by an intense play of orogenic forces which folded up the previously formed rocks, and by intrusions of granitic rocks on a large scale. Then followed a period of denudation which produced a profound discordance which is known as the Eparchæan unconformity. Later orogenic activity has affected the rocks of the Cuddapah and Vindhyan systems which correspond roughly with the Algonkian and Cambrian, but its effects were comparatively feebler than those of the earlier activities. Of these two systems, however, the Cuddapahs have been more affected than the Vindhyans.

In the Cuddapah and Vindhyan times, the Peninsula had already attained a great deal of stability and the seas in which the sediments were laid down were apparently restricted in extent. The major outcrops are semicircular or crescentic, along the convex side of which the rocks dip gently, while on the concave side they are characterised by high dips and close folds and sometimes by even overthrusts. The compressive forces must therefore have been directed from the concave sides. There is also some evidence to show that the sediments were derived to a large extent from lofty mountains which lay in proximity to the concave sides.

Constitution.

The Cuddapah rocks are found lying on the denuded and upturned edges of earlier formations—Dharwars and Gneisses. They comprise shales, limestones, quartzites, sandstones, conglomerates, banded jaspers, etc. The shales are finely laminated while the limestones are bedded but not crystalline as those of the Dharwars. The rocks are metamorphosed only to a very low degree, producing slaty and phyllitic types and not schists.

ABSENCE OF FOSSILS.

Though some of the shales of the Cuddapahs are of ideal constitution for the preservation of fossils, it is remarkable that so far they have yielded no fossils. The limestones may probably have been chemical precipitates. The absence of fossils may be attributed to the fact that the animals living in that period had no hard skeletons. In view of the fact that algæ and similar primitive forms have been discovered in some Pre-Cambrian rocks in North America, it is not unlikely that similar evidences of life may be available in the rocks of the Cuddapah System.*

DIVISIONS OF THE SYSTEM.

The Cuddapahs are divisible into two main divisions, the lower one being associated with volcanic rocks and their hypabyssal equivalents. The two divisions are separated by a well-marked unconformity. The Upper Cuddapahs are less altered and disturbed than the Lower and resemble the overlying Vindhyans in some measure. The maximum thickness of the whole system exceeds 20,000 ft., indicating geosynclinal conditions of deposition.

DISTRIBUTION.

The Cuddapah system derives its name from the district in the Madras Presidency where it is well developed. The Cuddapah and Kurnool rocks here form a broad crescent-shaped outcrop whose concave border is on the east where the folded strata form the Velikonda range which forms part of the Eastern Ghats. Between here

* Mr. M. R. Srinivasa Rao has reported the discovery of the presence of algal structures in limestones of Cuddapah age from near Ravalacheruvu, Anantapur district. *Current Sci.* 12, 207-208, 1943

and the large basin in Chhattisgarh there are small outcrops in Jeypore and Bastar. The Chhattisgarh area and the smaller outcrops in Eastern India appear to have constituted one large basin which has been separated into several parts by folding, faulting and denudation. Here also the concave and highly disturbed eastern margin is clearly seen. Another large basin, consisting mainly of Vindhyans, occurs in Eastern Rajputana, continuing underneath the Deccan trap of Central India into the Son-Narbada valley. In Rajputana this has been thrust from the north-west whereas in Central India the direction of compression is from the south-west to north-east.

MADRAS AREA.

The Cuddapah system was first studied by W. King in the Cuddapah and adjoining districts of the Madras Presidency (*Mem. Geol. Surv. Ind.* VIII, 1872). According to him the stratigraphical succession of this system is as follows :—

KURNOOL SYSTEM.

Kistna Series (2,000 Ft.)	Srisailam quartzites. Kolamnala slates. Irlakonda quartzites.
Nallamalai Series (3,400 Ft.)	Cumbum slates. Bairenkonda quartzites.
Cheyair (Cheyyeru) Series (10,500 Ft.)	Pullampet (Tadpatri) slates. Nagari (Pulivendla) quartzites.
Papaghni Series (4,500 Ft.)	Vempalle slates and limestones. Gulcheru quartzites

ARCHAEANS.

The lowest series is named after the Papaghni river, a tributary of the Penner. It consists of two divisions,

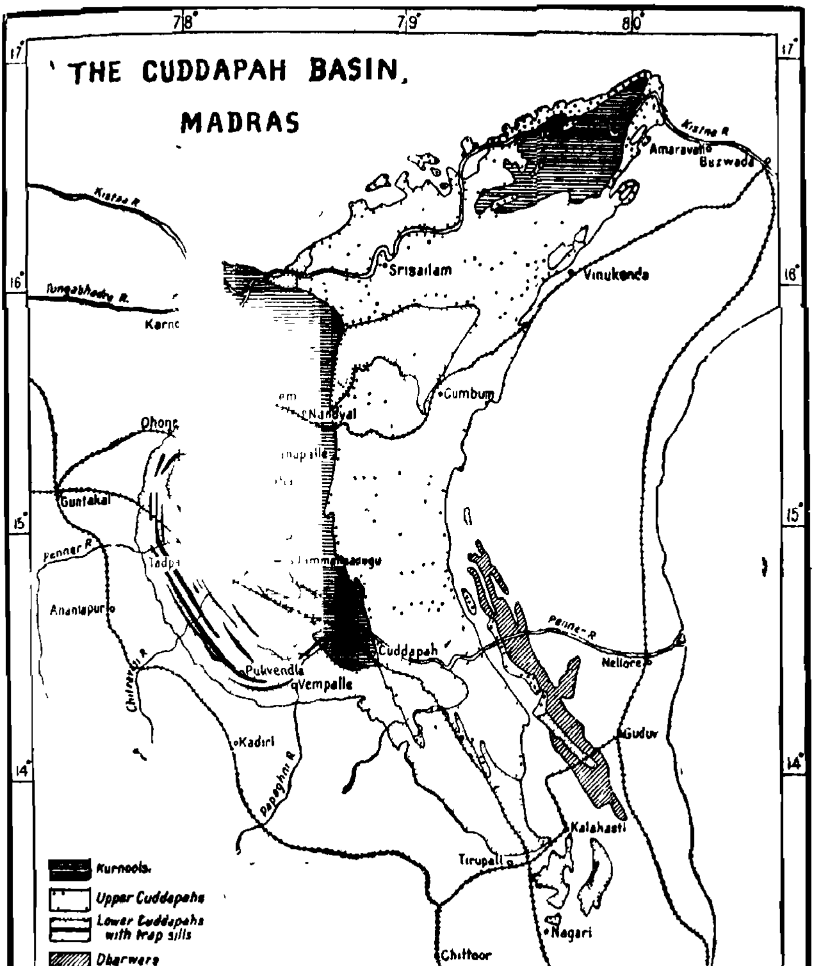
Vempalle is the correct spelling used on modern maps for the place which King spelt as Vaimpalli the lower Gulcheru (Guvvalacheruvu) stage consisting of conglomerates, sandstones, grits and occasional shales which rest unconformably on an Archæan basement. The Vempalle stage conformably overlies the Gulcherus and includes shales, slates and limestones which are partly dolomitic. The limestones contain variously coloured bands of chalcedony. Intruded into the Vempalles, particularly in the upper beds, are persistent sills of dolerite and basalt. This stage is of considerable economic importance, since deposits of barytes and asbestos are found more or less at the junction of these traps with the dolomitic limestones. These basic intrusives also invade the Cheyair series and are thought to be roughly contemporaneous with the Nallamalai series and distinctly older than the Kistna series.

The Cheyair (Cheyyeru) series takes its name from the Cheyyeru river. It is well developed in the two areas traversed respectively by the Cheyyeru and Penner rivers and separated by a strip of the Kurnool system. In the northern (Penner) area the lower beds are called the Pulivendla stage after the town of the same name. It comprises sandstones, quartzites, conglomerates, grits and flags. The pebbles of the conglomerates are to some extent derived from the chert bands of the Vempalles. The corresponding beds of the southern area (Cheyyeru valley) are called Nagari quartzites, prominently exposed in the Nagari hills north-west of Madras.

The upper beds in the Penner area are called Tadpatri slates which conformably overlie the Pulivendlas. They are dominantly slaty shales, while limestones with chert, bands and trap sills are also to be found. In the southern area the same beds are known as Pullampet slates and limestones.

The Nallamalai series, which occupies the largest area of any of the divisions of the Cuddapahs, takes its name from the Nallamalai hills and is particularly well developed in the eastern part of the Cuddapah basin. The lower beds are the Bairenkonda quartzites which rest with a slight unconformity on the cheyairs. In the Nallamalai hills they are highly folded and contorted

MAP V



and form prominent ridges. The softer Cumbum slates lie in the synclinal folds between these ridges. These comprise slates and shales of varying shades of colour and degrees of hardness and interbedded bands of quartzite and limestone. The slates are often highly folded and metamorphosed to phyllitic types. The limestones are grey in colour, finely crystalline and often micaceous or talcose. It is of interest to note that lead ores are found in these limestones near Nandialampet north of Cuddapah.

The uppermost group, called the Kistna series, is found in the plateau region traversed by the Kistna river and is unconformable with the underlying Nallamalai series. The lower beds, the Irlakonda quartzites, form the plateau on the western side. The Kolamnala shales forming the middle stage are found in the area traversed by the stream of that name. Overlying these are the Srisailam quartzites forming the plateau on the north and east and named after the well known Srisailam temple on the Kistna river.

KALADGI SERIES.

Between Kaladgi and Belgaum in the Southern Mahratta country, the Upper Cuddapahs are represented by the Kaladgi series divisible into two groups. The lower group consists of basal conglomerates, sandstones and quartzites followed by siliceous limestones, hornstones, shales and again by thick beds of limestones and shales. The latter beds are exposed near Kaladgi where the limestones are varicoloured and capable of yielding beautiful marbles. The lower Kaladgis have an aggregate thickness of 8,000 to 11,000 ft.

The Upper Kaladgis, consisting of quartzites, conglomerates, shales, limestones and hematite-schists, are about 3,500 ft. thick, the hematite-schists being sometimes rich enough to be used as iron-ore. The Upper Kaladgis are of restricted distribution, being found in synclinal folds in the north-eastern part of the area, the axis of folding having a trend of W.N.W.-E.S.E. They are overlain by the Deccan trap amidst which they sometimes appear as inliers.

The Kaladgis are now known to be intruded by granitic and basic rocks in a few places. Dr. L. A. N.

Iyer has discovered that the granites have altered the Kaladgis to typical biotite-and garnet-bearing granulites and mica-schists in the contact zone in the Ratnagiri district. They may therefore be really of upper Dharwarian age. This region also contains dolerite, gabbro, picrite and serpentine-chromite rock as intrusions, mainly in the rocks of Archæan age.

PAKHAL SERIES.

Along the Godavari valley and north of the Kistna river, there occur certain rocks which Dr. King described under the name of Pakhal Series (*Mem. XVIII*, p. 209, 1880). They show slates with interbedded sandstones and limestones forming the lower part (Pakhal division), and an arenaceous succession forming the upper part (Albaka division), the total thickness being estimated at 7,500 ft. These were regarded by King as the equivalents of the Upper Cuddapahs. Recent work by the Hyderabad Geological Survey shows that the Pakhals include phyllites, crystalline limestones and banded ferruginous rocks recalling, according to Dr. C. Mahadevan, parts of the Archæan succession in Singhbhum and Gangpur, but not typical Cuddapah rocks. The Pakhals will therefore have to be relegated to the Dharwarian.

PENGANGA BEDS.

Rocks similar to the Cuddapahs, comprising a lower limestone group and an upper shaly group, have been described as occurring in the Upper Pranhita valley to the west of the Wardha valley coalfield. The limestones contain bands of ribbon jasper.

Patches of Cuddapah rocks are found in the Jeypore-Bastar region where they overlie gneissic rocks and comprise quartzites, limestones, shales and phyllites. The eastern and south-eastern boundaries are highly disturbed and folded, whereas the western boundaries are comparatively little affected but irregular, showing that the latter represent more or less original deposition.

In the Chhattisgarh area of the Central Provinces a large area is occupied by Cuddapah rocks, comprising a lower arenaceous division (quartzitic sandstones with conglomerates at the base) and an upper limestone and shale division. They include the Raipur limestone and the Chandarpur sandstone, but there is some doubt whether these might not belong to the Vindhyans.

BIJAWAR SERIES.

This series, first recognised in the Bijawar State in Bundelkhand (Central India) occurs in a series of outcrops extending from Bundelkhand to the south of the Narbada and has a thickness of less than 800 ft. in the type area (H.B. Medlicott : *Mem.* II, p. 35, 1860). Quartzites and sandstones, sometimes conglomeratic, form the basal beds resting on gneisses. Siliceous limestones and hornstone-breccia are found with the quartzites. These are irregularly distributed and are of less than 200 ft. thickness. These are overlaid by ferruginous sandstone containing pockets of hematite. The rocks are either horizontal or have a low south-easterly dip, though in a few places in the south they have been subjected to crushing.

The Bijawars are associated with lavas, tuffs, sills and dykes of basic composition with micro-pegmatitic patches, but there are also olivine-bearing rocks. The dykes of the Bijawar igneous suite are supposed to be the parent rocks of the diamonds found in the conglomerates of the Vindhyan and Kurnool systems They may thus correspond to the 'diamond pipes' of South Africa, though, so far as known, none of the basic rocks has the composition of kimberlite. An investigation into the question of the original source of the diamonds is highly desirable.

A similar succession of rocks is found in the Dhar Forest, Jubbulpore and Rewa on the one hand and in the Son valley of Bihar on the other.

The succession in Jubbulpore consists of phyllites, mica-schists, calcitic and dolomitic marbles, banded ferruginous quartzites with which are associated iron and manganese ores, and basic sills (and flows ?), the whole assemblage bearing a remarkable similarity to the Iron-ore Series and part of the Gangpur Series of Chota Nagpur. There is little doubt that these 'Bijawars' are to be assigned the same age as the Singhbhum-Gangpur rocks, *i.e.*, Dharwarian. (*Mem.* XXXVII, pp. 803-806, 1909).

The same remarks apply to the 'Bijawars' of the Narbada and Son valleys, whose easternmost extension is found in the Rajgir, Kharakpur and Sheikhpura hills in the Gaya and Monghyr districts. They comprise sandstones and conglomerates, slates, limestones, jasper and porcellanoid beds, chlorite-schists and basic lavas. In the Mirzapur district, Mallet regarded these (*Mem.* VII, Art. I, pp. 22-23, 1871) as comprising two series separated by an unconformity. At the contact with intrusive granitic rocks, the mica-schists and phyllites have been converted into composite gneisses, while the basic rocks have been epidioritised. Subsequent examination has shown that these 'Bijawars' are also to be classed with the Dharwars. (*Mem.* LXII, Pt. II, p. 145, (footnote), 1933).

THE DELHI SYSTEM.

This system extends over a large part of Eastern Rajputana, from near Delhi to Idar, but is best developed in the main Rajputana synclinorium of Ajmer-Merwara and western Mewar. This synclinorium can be connected with the occurrences in Alwar and Jaipur States through a series of small ridges of quartzite and arkose-conglomerate. In Ajmer-Merwara there are two synclines separated by a tongue of pre-Aravalli gneisses, the junction zone on both sides of this tongue being marked by shearing. The western syncline is much intruded by the Erinpura granite and epidiorite. The two synclines coalesce to the south, in Jodhpur and Mewar. Here, for a distance of some 40 miles, the synclinorium is only six miles wide. Further south it widens and is also evidently burried deeper, enabling higher zones to appear in the Central core.

The Delhi system unconformably overlies the Raialo series and is in turn overlain unconformably by the Lower Vindhyans. It is probably to be correlated with the Cuddapah system, but it differs from the latter in having been subjected to great orogenic disturbances. Rajputana seems to have been a region which experienced intense diastrophism in post-Delhi times when other regions in India, containing the supposed equivalents of the Delhis, were quiescent.

The succession in the main synclinorium is shown below :

Ajabgarh Series (5,000 Ft.)	5. Biotitic limestones (Calc-gneiss and Calciphyres. 4. Calcareous shales and impure limestones (Calc-schist). 3. Phyllites and biotite-schists.
Alwar Series (10,000 Ft.)	2. Quartzites. 1. Arkose, grits and conglomerates.

The above succession is well seen in the main synclinorium. In Alwar State the *Alwar Series* contains also the *Kushalgarh limestone* (1,500 ft. thick), and the *Hornstone breccia* (small but variable thickness) which are absent in the main synclinorium and in Jaipur. The Alwar series is well developed in the northern and southern parts of the synclinorium, almost disappearing in the middle. Its basal beds always show close affinities with, and evidence of derivation from, the rocks on which they lie, the older gneisses giving rise to arkos and grit, and phyllites giving rise to fine-grained quartzites.

In the *Ajabgarh series*, the biotite-schists are much intruded by veins and lit-par-lit-sheets of aplitic material. The calc-schists are thin-bedded impure limestones, slabby in character, which have been profusely intruded by pegmatite and aplite in contrast with the calc-gneisses which are coarser and roughly banded and generally more resistant to weathering and which show less intrusive material.

The Delhi system is comparatively little metamorphosed and of small thickness in Eastern Mewar, and is believed to be represented by the *Sawa grits* and shales and by the *Jiran sandstones.* The former are found to the west of the Main Boundary Fault and the latter to its east. The Sawa grits are coarse white sandstones and conglomerates showing ripple marks and current bedding. The upper portion is a white or pale grey shale containing bands of white chert. When followed southwards, the Sawa grits seem to pass into the Jiran sandstones though the two types in their own type areas have not much resemblance to each other. The Jiran sandstone is a quartzite resembling the Kaimur sandstone and has been called 'Delhi quartzite' by Hacket. It is typically a hard, compact, grey quartzite frequently stained with purple. It is covered on the north by the Lower Vindhyans and on the east by the Deccan trap.

The Delhi system is intruded by the *Erinpura granite* which shows a great deal of variety in its form and texture and is seen over a large area west of the Aravalli range. It is often coarse and porphyritic and associated with aplite and pegmatite veins. The *Idar granite,* including its granitic, microgranitic and granophyric phases, is the equivalent of the Erinpura granite in southern Rajputana. Effusive phases of these are rare, in contrast with the *Jalor* (with hornblende and biotite) and *Siwana* (with hornblende) *granites* which have their volcanic phase in the Malani rhyolites, tuffs and porphyries. These latter may be grouped together as the *Malani suite of igneous rocks* which occupy a tract of country 150 miles long (E.-W.) and 120 miles broad (N.-S.) in Jodhpur State and the neighbourhood. The Malani rhyolites, as they are called, include felsites, devitrified lavas and glassy rhyolites intercalated with acid tuffs and pyroclastic breccias. They are found for a long distance north-west of Jodhpur extending into the Punjab as far as the Sangla hills. They include also some porphyritic representatives. The Malani suite, including the plutonic phases—the Jalor and Siwana granites—is intrusive into the Delhis, and is later than the Erinpura granite. The rocks are found lying undisturbed over the Aravallis but show a very marked unconformity with the overlying Upper Vindhyans. Hence their age is post-Delhi and may be Lower Vindhyan.

The granitic rocks were preceded by basic rocks, now seen as epidiorites and amphibolites, particularly on the north-western flank of the synclinorium. Ultrabasic rocks are also found intruded into the Delhis, but altered to talc and chlorite schists such as those of Beawar, and talc-serpentine rocks with magnesite veins found to the south of Ajmer.

The elæolite and sodalite syenites and syenite-pegmatite are thought to be pre-Delhi in age. In the Sirohi State there is a small occurrence of a group of igneous rocks, with interesting differentiates, comprising alkali-syenites, gabbro, dolerite, pyroxenite and picrite, which are clearly later than the Erinpura granite but earlier than the rocks of the Malani suite of Western Rajputana.

The general succession of the Delhi system in Rajputana is given in the following table (after A.M. Heron).

TABLE 14.—THE DELHI SYSTEM.

Jodhpur.	Main Synclinorium Mewar & Ajmer-Merwara.	Chitor and Nimbahera.		Jaipur.	Alwar.
Vindhyans of W. Rajputana.					
Malani igneous suite		Lower Vindhyans.			
(Delhi system not present).	'Calc gneisses' 'Calc-schists' Phyllites and biotite-schists	Boundary	Fault	Ajabgarh series.	Ajabgarh series. Hornstone breccia. Kushalgarh limestone.
	Quartzites Arkose-grits	Sawa shales and grits.	Jiran sandstones	Alwar series.	Alwar series
Raialo series (Makrana marbles).	Raialo Series	Raialo series.	-	—	Raialo series.

GWALIOR SYSTEM.

Around Gwalior city there is a group of rocks separated from the Aravallis by a strip of country 80 miles wide and occupied by Vindhyan rocks. They have a great deal of resemblance to the unmetamorphosed portion of the Aravallis as found near Hindaun and with the shales and jaspers of Ranthambhor in Jaipur State.

The Gwaliors have been divided into a lower *Par series* and an upper *Morar series* by C. A. Hacket (*Rec.* III, p. 34, 1870). The Par series, comprising quartzitic sandstones and shales, rest upon the Bundelkhand gneiss and are practically horizontal and undisturbed. The Morar series comprise shales, limestones, hornstones, ribbon-jasper and contemporaneous basic lavas of andesitic or basaltic composition.

The correlation of the Gwaliors is a matter of great difficulty. They lie on the Bundelkhand gneiss and are practically unaltered sedimentaries. Though they resemble the unmetamorphosed Aravallis in lithology, they are probably of Cuddapah age, since they have a horizontal disposition and are unaltered. Their immunity to metamorphism and disturbance may, however, be due to their isolation from the main area of orogenic activity in Rajputana.

ECONOMIC MINERALS.

The Cuddapah system is not as important as the Dharwarian in the variety and richness of its mineral wealth. But it contains a few products which are of some importance.

Slate is quarried at Kund from a few bands in the Delhi System. Good sandstones are also available from the same system and are quarried in the Alwar State.

There are important deposits of limestone and slate amongst the Cuddapah rocks. The slates of Markapur on the Nellore-Kurnool border, belonging to the Nallamalai series, are quarried and used as school slates and paving slates. The limestones and dolomites found in this system are not much used, except locally as building stones. The banded jaspers (Bijawar) and cherts are excellent decorative stones which have been used in inlaid work in some famous buildings, such as the Taj Mahal.

Steatite has been worked at Muddavaram in the Kurnool district and near Tadpatri in the Anantapur district. Talc schists derived from ultrabasic rocks intrusive into the Delhi System are found near Beawar and Ajmer in Rajputana.

Barite (barytes) occurs as fissure veins and replacement veins in the limestones of the Vempalle stage near their contact with basic sills, or in the sills themselves. The basic sills are of post-Cheyair age. The most important deposits occur near Pulivendla and Kotapalle in the Cuddapah district, Nerijamupalle and Mutssukota in the Anantapur district and at Balapalapalle and other places in the Kurnool district. The Alwar quartzites of the Delhi System contain fissure veins of barite at Sainpuri and Bhakhera near Alwar.

The Vempalle limestones also contain deposits of chrysotile asbestos at the junction of the dolomitic limestone with a basic sill ; such deposits are seen near Rajupalem, Brahmanapalle and Lingala in the Pulivendla taluk of the Cuddapah district.

The Cuddapahs do not contain metalliferous deposits of importance. Iron ore deposits of comparatively small dimensions occur in several places and they have been drawn upon formerly for local smelting in primitive furnaces. At Jangamrajupilli and a few other places in Cuddapah and Kurnool, there are argentiferous lead ore deposits but they seem to be of little economic importance. The Delhi System in Rajputana contains some small deposits of copper, nickel and cobalt ores which were formerly worked in a small way.

An interesting stone, but not of any economic importance, is the flexible sandstone of Kaliana in Jind State, Rajputana. It is a sandstone out of which the original felspathic matter has been removed, leaving an interlocking mass of sand grains which allow of a slight hinged movement. Slabs of this material, even if only a few inches in length, exhibit this property.

SELECTED BIBLIOGRAPHY.

(CUDDAPAH AND VINDHYAN SYSTEMS)

Auden, J.B. Vindhyan sedimentation in the Son valley, Mirzapur District. *Mem.* **62** (2), 1933

Chapman, F. Primitive fossils, probably atrematous and neotrematous brachiopoda. *Rec.* **69**, 109-120, 1936

Foote, R.B. Geology of Southern Mahratta country. *Mem.* **12**, 1876.

Heron, A.M. Geology of N E. Rajputana. *Mem.* **45** (1), 1917.

Heron, A.M. Vindhyans of Western Rajputana. *Rec* **65**, 457-489, 1932.

Heron, A.M. Gwalior and Vindhyan systems in S.E. Rajputana. *Mem.* **45** (2), 1922.

King, W. Kadapah and Kurnool formations in the Madras Presidency. *Mem.* **8**, 1872.

Lake, P. Basic eruptive rocks of the Cuddapah area. *Rec.* **23**, 259-261, 1890.

Mallet, F.R. Vindhyan series as exhibited in the North-western and Central Provinces of India. *Mem.* **7** (1), 1869.

Medlicott, H.B. Vindhyan rocks and their associates in Bundelkhand. *Mem.* **2** (1), 1859.

·Oldham, R.D. Flexible sandstone or itacolumite. *Rec.* **22**, 51-55, 1889.

Oldham, R.D. Geology of the Son valley in Rewah State and parts of Jubbulpore and Mirzapur. *Mem.* **31** (1), 1901.

Sahni, M.R. *Fermoria minima* : a revised classification of the organic remains from the Vindhyans. *Rec.* **69**, 458-468, 1936.

Vredenburg, E. *Geology of the State of Panna with reference to the* diamond bearing deposits. *Rec.* **33**, 261-314, 1906.

Vredenburg, E. Suggestions for the classification of the Vindhyan system. *Rec.* **33**, 255-260, 1906.

Bajpai, M.P. The Gwalior traps. Jour. Geol., XLIII, 61-75, 1935.

CHAPTER VIII.

THE VINDHYAN SYSTEM.

The Cuddapahs were succeeded by the rocks of the Vindhyan system after a time interval marked by earth movements and erosion. The Cuddapahs were then folded and metamorphosed to some extent though the intensity of the forces at play was much feebler than that which acted at the close of the Dharwarian era.

The system derives its name from the great Vindhya Mountains, a part of which is found to form the prominent range of sandstones to the north of the Narbada valley, particularly in Bundelkhand and Malwa. It occupies a large basin extending from Dehri-on-Son to Gwalior and Hoshangabad and from Chitorgarh to Agra, except for a part of Bundelkhand. Oldham estimates the area of the exposures as about 40,000 square miles with a further 25,000 square miles lying underneath the Deccan trap.

Over the greater part of the area, only the upper portion of the Vindhyans is developed, usually resting on the Cuddapahs or older rocks with a very pronounced unconformity. In the Son valley, where the Lower Vindhyans are well developed, an unconformity is seen between them and the upper divisions. The Vindhyans are distinctly less disturbed than the Cuddapahs but the lines of disturbance tend to be common in both. Within the Vindhyan system itself there are distinct unconformities, often marked by conglomerates, separating the different series.

The Vindhyans are, like the Cuddapahs, unfossiliferous. In recent years however, the Suket Shales have yielded small discoid impressions considered to be organic remains and assigned to the genus *Fermoria* related to the primitive brachiopod *Acrothele*. There is, however, a difference of opinion as to whether they are inorganic or organic, and if the latter, whether they are plant or animal remains.[1]

The Vindhyans consist of four main series, named as follows :—

			Feet.
Upper ..	Bhander Series —	mainly arenaceous and calcareous	1,500
	Rewa Series	mainly arenaceous	500-1,000
	Kaimur Series	mainly arenaceous	500-1,300
Lower .	Semri Series	mainly calcareous	1,000-3,000

SEMRI SERIES.

From Sasaram westwards to the watershed between the Son and the Narbada, the Lower Vindhyans are exposed underneath the prominent scarp of Kaimur quartzites for a length of some 240 miles. Here the maximum width of this series is about 16 miles, but further east it narrows down to a width of less than 2 miles. This is the type area of the Semri series.

The lowermost beds of this series in the Son valley, called the *Basal Stage*, are 2,000 ft. thick and consist of basal conglomerates and the Kajrahat limestone beds. They are followed by shales and sandstones which have been silicified and converted to porcellanites (the *Porcellanite Stage*) attaining a thickness of about 300 ft. The *Kheinjua stage* overlying this is about 600 ft. thick and consists of olive shales, fawn limestone and glauconitic sandstones which show ripple marks and other characters pointing to shallow water and sub-aerial deposition. Above this comes the *Rohtas stage*, 400 to 700 ft. thick, consisting of alternating beds of limestones and shales which support a flourishing lime and cement industry. The limestone varies in quality from bed to bed, much of it being of high grade and containing over 80 per cent. calcium carbonate, less than 3 per cent. magnesium carbonate and about 10 per cent. silica. In the upper

[1] Chapman, F *Rec G.S.I*, LXIX p 109-120, 1935.
Sahni, M.R, *Ibid*, p 458

part there are large stone nodules in shales, while still further up siliceous limestones occur.

The Semri series is intruded by dykes of dolerite and basalt in a few places in the Son valley. The basic rock contains both augite and rhombic pyroxene, zoned plagioclase, ilmenite and pyrite, with patches of micrographic quartz and felspar and occasional glass.

The Semri series is found also in the Karauli State of Rajputana where the Aravalli phyllites are overlain by sandstones and conglomerates and these in turn by the *Tirohan limestone.* Above the Tirohan limestone is a zone of breccia (*Tirohan breccia*) which is due to the removal of lime by solution from the beds and the consequent collapse. An unconformity intervenes between these and the overlying Kaimurs. The Tirohan limestone is apparently the equivalent of the Rohtas limestone and both are underlain by beds containing glauconite.

On the southern side of the Vindhyan tract, in the Chitor-Jhalrapatan area, shales of probable Aravalli age are overlain successively by grits and conglomerates, Nimbahera shales, Nimbahera limestones and Suket shales, the thickness of this group of Vindhyan beds being about 1,000 ft.

TABLE 15.—THE SEMRI SERIES AND ITS EQUIVALENTS.

Son Valley.		Karauli.	Chitor.
Rohtas Stage.	Alternating limestones and shales	Tirohan breccia Tirohan limestone.	Suket shales Nimbahera limestone.
Kheinjua Stage.	Glauconite beds. Fawn limestone. Olive shales.	Glauconite-bearing beds.	Nimbahera shales.
Porcellanite Stage.	Porcellanites and silicified rocks.	Sandstones and conglomerates.	Grits and Conglomerates.
Basal Stage.	Kajrahat limestone Basal conglomerate		

KAIMUR SERIES.

In the Son valley the Kaimur series contains two bands of quartzite in the lower division which may be gritty and even conglomeratic and shows current bedding. The lower quartzite passes upwards into flagstones and shales showing ripple-marks and sun-cracks, and these into thin bedded micaceous and carbonaceous shales with sideritic bands. Interbedded with these are banded and jointed porcellanites, fragments of which are found in the next succeeding gritty bed called the *Susnai breccia.* This breccia is undoubtedly of epi-clastic origin and marks a break in sedimentation, though the base of the Kaimurs is to be put at the base of the lower quartzite.

The Susnai breccia is overlain by the upper silicified quartzite (Lower Kaimur) with marked current and lenticular bedding and ripple-marks, which forms a very conspicuous scarp, 40 ft. high, in the Son valley. Above this are other quartzites and also sandstones and mudstones which show extensive replaçement by iron and have characteristics of shallow water deposits. These pass upwards into the *Bijaigarh shales* which are carbonaceous, pyritiferous and micaceous and generally bleached or yellow in colour. Lenticles of bright coal (vitrain) are found in these and some beds are fairly rich in carbonaceous matter.

The Upper Kaimurs, overlying the Bijaigarh shales, consist of greenish flagstones and sandy siltstones (generally showing current-bedding and ripple-marks) which crop out along the Kaimur scarp and are exemplified in the Mangesar hill. The green material apparently includes chamosite, chlorite and green mica. Above these are the *Dhandraul quartzites* which are white to purplish in colour. The Upper Kaimurs have a thickness varying from 500 to 1,000 ft.

In Bundelkhand the Kaimurs show a basal conglomerate containing pebbles of jasper, the main formation being a fine-grained quartzite of greyish or brownish colour with conspicuous current-bedding.

Kaimur Series	Upper	Dhandraul quartzite.
		Scarp sandstone and conglomerate.
	Lower	Bijaigarh shales.
		Upper quartzites.
		Susnai breccia
		Lower quartzites and shales

REWA SERIES.

The Kaimurs are succeeded by the Rewa series composed of somewhat coarser sandstones than those of the Kaimurs, and current-bedded flagstones. The two series are separated by a zone of diamond-bearing conglomerate. The divisions recognised in Central India in the Rewa and the overlying Bhander series are as below :—

Bhander Series	Upper Bhander sandstone.
	Sirbu shales
	Lower Bhander sandstone.
	Bhander limestone (Nagode).
	Ganurgarh shale.
—Diamond-bearing conglomerate—	
Rewa Series	Upper Rewa sandstone.
	Jhiri shales.
	Lower Rewa sandstone
	Panna shales.
—Diamond-bearing conglomerate—	
Kaimur Series	

The existence, in Bundelkhand, of the Lower Rewa sandstones and Panna shales is questioned by Vredenburg who states that the diamond-bearing conglomerate occurs at the base of the Jhiri shales. In Gwalior, however, there are two shale bands separated by a sandstone, between the Kaimurs and the main Rewa sandstone.

BHANDER SERIES.

The uppermost division of the Vindhyans is the Bhander series, which is separated from the Rewa series by a horizon of diamond-bearing conglomerate. The

Bhander sandstones are fine-grained and soft, usually of a red colour with white specks. When light-coloured they often show red streaks. They are fairly thick-bedded and yield large blocks which are used in building. The Upper Bhanders frequently show ripple-marks. The Bhander limestone is of variable thickness and quality, passing from a good limestone to a calcareous shale.

In some parts of Rajputana the Bhanders show veins and thin beds of gypsum intercalated with the sandstones and shales. This and the prevalence of red tints constitute the evidence of deposition under arid conditions.

In the great Vindhyan basin the sandstones and quartzites form a series of well-marked scarps while the intervening strata being soft, give rise to sloping talus. The chief members persist over large areas with fairly uniform characters. Taken as a whole, the structure of the Vindhyan area is that of a basin, the sandstones forming plateaux. Over the greater part of the area the beds are nearly horizontal, but they show evidence of disturbance near the north-west and south-east margins. In the Dhar Forest and near Jhalrapatan, the Vindhyans are folded and show steep dips.

The Vindhyans are thickest in the southern and south-western areas. The Upper Vindhyans are 11,000 ft. thick in the south-west, 4,500 ft. in the north-west and about 4,000 ft. in Bundi State. The Lower Vindhyans are either thin or absent in the north-west, the Kaimurs overlapping them and coming to rest directly on the gneisses or the Bijawars.

The margins of the Vindhyan basin show a good development of sandstones, while the shales are best developed in the centre and east, passing gradually laterally into sandstone. The prevalence of current-bedding and ripple-marks in the strata is indicative of shallow water origin; while the red sandstones, of the Kaimurs and Bhanders for example, probably indicate semi-arid and continental conditions.

The Vindhyans have been deposited on peneplaned older rocks and there are evidences of semi-contemporaneous earth movements. Int he Son-Narbada valley the compression seems to have come from the south or south-west, while in the area between Chitor and Hoshangabad the compressive forces have acted from the south-west and west. In Rajputana they have been affected by over-thrusts from the west, with the development of the Main Boundary Fault which has a throw of some 5,000 ft. and which brings the undisturbed Bhanders against the highly folded Aravallis. This fault can be traced for a distance of about 500 miles, part of it coinciding with the course of the Chambal river. There are, however, some strips and outliers of Vindhyans to the west of this fault, *e.g.*, the Kaimurs from Bundi to Indargarh.

The Vindhyans of Rajputana are invaded by the Malani group of acid igneous rocks, which include the Jalor and Siwana granites, granophyres, porphyries and the Malani rhyolites. These acid rocks are cut by later basic dykes which are probably of the same age as those found intruding into the Semris of the Son valley.

KURNOOL (KARNUL) SYSTEM.

The Cuddapah basin in the Madras province contains two areas of younger rocks resting unconformably on the Cuddapahs—one in the Kundair valley stretching up to the Kistna, and the other in the Palnad tract. This younger group of rocks, constituting the Kurnool system, has a thickness of about 1,200 ft. and has been affected on the eastern margin by the same disturbances which acted on the Cuddapahs. This system is regarded as the equivalent of the lower Vindhyans.

The Kurnools have been sub-divided into four groups, composed mainly of limestones with subordinate shales and sandstones.

Series	Stages
Kundair	Nandval shales Koilkuntla limestones
Paniam	Pinnacled quartzites Plateau quartzites.
Jammalmadugu	Auk shales. Narji limestone.
Banganapalli	Banganapalli sandstones.

The Banganapallis are rather coarse sandstones of grey and brown colours, sometime shaly, felspathic or ferruginous. They contain abundant small pebbles of quartz, jasper, chert and slate, derived mostly from the Cheyair series. They are the main source of diamonds in the Kurnool formations. Some of the exposures have been extensively worked for diamonds, which industry was active in this region till about a century ago.

The lower beds of the Jammalamadugu series consist of limestones—the Narji limestones—of various colours, especially blue-grey, buff and fawn. They are about 400 ft. thick at Narji where the rock is much quarried for building purposes. They are succeeded by the Auk shales, of buff and purplish colours. The Paniam series, developed around Paniam (Panem) and Undutla, comprises sandstones and quartzites. The topmost series, named after the Kundair since it occupies the valley of that river, has a thickness of 500 to 600 ft. The lower third of this is a compact fine-grained limestone (Koilkuntla) while the upper part consists of impure limestones and calcareous shales named after the small town of Nandyal.

The above divisions, though well developed in the Kundair valley, are not all easily recognised in the Palnad area. Limestones are prominent in the latter, and below the limestones is a diamond-bearing conglomerate.

BHIMA SERIES.

Named after the Bhima river, a tributary of the Kistna, this series is developed in the Gulbarga District of Hyderabad State and in the Bijapur District of Bombay. It occupies an area of roughly 2,000 sq. miles, lying over the Archæan formations.

The rocks are divided into a lower and an upper series by W. King and R. B. Foote, but recent work by the Hyderabad Geological Survey (based on information kindly supplied by Dr. C. Mahadevan) shows that a threefold division is preferable :

Upper (300 ft.) ..	Black, blue, buff and purple shales with local sandstones at the bottom and flaggy limestones at the top.
Middle (500 ft.) .	Creamy, grey, bluish and buff limestones and flaggy limestones.
Lower (350 ft.) ..	Sandstones and green and purple shales. The bottom beds are conglomeratic while the topmost beds are often calcareous.

The lower Bhimas are sandstones and shales, laid down in a gradually deepening sea. The middle division, consisting mainly of limestones, was deposited in deeper waters, probably as chemical sediments. At this period the basin of deposition attained its greatest extent and width, for some of the beds overlap the earlier Bhimas and lie directly on the gneiss. The upper division points to the contraction and shallowing of the basin, the deposits being mainly shales.

The eastern and southern parts contain only the lower and middle divisions while the upper division is found in the north and west. The deposits are nearly horizontal or low-dipping over large areas but show high dips and evidence of disturbance in the neighbourhood of some faults and at the junction with the Deccan traps.

The Bhimas are devoid of fossils, though the constituent beds are well suited to the preservation of organic remains. The Kaladgis (which are referable to the Cuddapahs) lie to their west but nowhere in contact with them. The lithology, horizontal disposition and unmetamorphosed nature of the Bhimas point to their being the equivalents or the Kurnool formations.

SULLAVAI SERIES.

There is a group of rocks called the Sullavai series in the Godavari valley consisting of slates, quartzites, sandstones and conglomerates. They are well exposed near Sullavai and in the Dewalmari hills, where the quartzites recall the appearance of the Pinnacled quartzites of the Kurnools. They have a thickness of 1,200 to 1,600 ft., and overlie the Pakhals unconformably.

CORRELATION OF THE VINDHYANS.

The Vindhyans are developed in two areas: one comprises the Vindhyans of Rajputana and Central India which are continued in the south of Bundelkhand and Bihar. The lower part of the system contains some marine deposits, including limestones, while the upper part consists of deposits of a semi-arid climate represented mainly by red sandstones and shales with which gypsum is occasionally associated. The other is the Cuddapah basin in the Madras Presidency where the Kurnool system is developed; this comprises marine sediments which are regarded as the equivalents of the Lower Vindhyans. The Vindhyans of both the regions are devoid of identifiable fossil remains, though some of the strata are eminently fitted for the preservation of fossils.

The Cambrian formations of the Salt Range, especially the 'Purple Sandstones,' bear a striking resemblance to the Upper Vindhyans of Central India as pointed out by Dr. C. S. Fox (*Rec. G. S. I.* LXI, p. 173, 1929) and to some strata in the Cambrian Hormuz series of Iran. It is not possible to consider the formations in these different areas as anything more than rough equivalents in geological age, though they are strikingly similar in lithological characters.

Deposits of about the same age are to be found in the unfossiliferous ancient sediments of the Extra-Peninsula which are generally assigned to the late Pre-Cambrian. These are the Attock slates, Hazara slates, Simla slates, Jaunsar series, part of the Haimanta System of Spiti and part of the Buxa series of Bhutan. Probably even the Chaung Magyis and the Mergui series may, in part, belong to the same age.

ECONOMIC MINERAL DEPOSITS.

Diamond.—For many centuries past, diamonds have been won from the Vindhyan and Kurnool formations. They are found as pebbles in the Banganapalli group of the Kurnools and in the conglomerates separating the different series of the Upper Vindhyans in the Panna State of the Central India, as also just outside the Cuddapah basin in Sambalpur in Orissa. The original source of the diamonds which came to be deposited in the conglomerates is not known, though it is thought that they may have been derived from certain volcanic necks. The volcanic neck at Wajra Karur, which bears a superficial resemblance to the kimberlite ' pipes ' of South Africa, shows no real similarity on close examination.

Limestone.—The limestones of the Vindhyans are amongst the most important sources of raw materials for the lime and cement industry—*e.g.*, in the Son valley in Bihar and U. P., in Rewa, in Jubbulpore and in the Bhima valley.

The Narji limestones of the Guntur and Kurnool districts are capable of yielding excellent building stones and ornamental stones. The flagstones quarried near Yerraguntla (Cuddapah district), near Betamcherla (Kurnool district) and other places, popularly known in the Madras Presidency as ' Cuddappah slabs ' are widely used as paving stones, fence stones, steps and table-tops. According to King's map, these ' slabs ' are derived from the Jammalmadugu and Kundair formations of the

Kurnools. They are easily split into slabs half an inch or more in thickness and up to 6 ft. by 4 ft. in size. They are calcareous slates capable of taking a fairly good polish. The Auk shales contain some good fire-clays and ochres, as near Betamcherla.

Building and decorative stones.—Some of the limestones of the Lower Vindhyan and Lower Bhander stages show spherulitic structures, the concentric shells of which display different colours. Beautiful stones of this kind, found at Sabalgarh near Gwalior, have been used in the inlaid decorations in the buildings of Agra. Some of the buildings of Chitorgarh have been built of Nimbahera limestones. The limestones of the Palnad region (Guntur district), particularly the Narji limestones, are excellent building and ornamental stones, some varieties with deep red and green colours being quite attractive. These limestones have been used in the Buddhist sculpture of Amaravati on the Kistna river.

The Vindhyan sandstones have been extensively used from ancient times for architectural purposes because of their fine and uniform grain, pleasing colours and the ease with which they can be worked, dressed and carved. The Buddhist stupas of Sarnath, Barhut and Sanchi; Emperor Akbar's city of Fatehpur Sikri near Agra and the great Moghal buildings at Agra, Delhi, and Lahore, including the famous masjids at Delhi and Agra; the palaces and forts at Chunar, Agra, Jodhpur and other places; the modern administrative offices of the Government of India at New Delhi—have all used Vindhyan sandstone in their construction. The stones are used in a variety of ways—flagstones for flooring and roofing, window sills, pillars, fence posts, telegraph poles, milestones and so on.

CHAPTER IX.

THE PALAEOZOIC GROUP : CAMBRIAN TO CARBONIFEROUS.

THE CAMBRIAN SYSTEM.

Fossiliferous marine Palæozoic rocks are practically absent from the Peninsula (except for the small patch of Lower Permian age near Umaria, and possibly the Suket Shales of Upper Vindhyan age) but they are well represented in parts of the Extra-Peninsula and Burma. The Cambrian System, which is the earliest of the Palæozoic systems, is met with in three areas, *viz.*, the Salt Range, Kashmir and Spiti, where it is represented by richly fossiliferous beds.

THE SALT RANGE.

The most easily accessible area in which the Cambrians are exposed is the Punjab Salt Range where a good succession of the strata is met with. Before proceeding with the description of the strata themselves, a short description of this important region is given.

General description.—The Salt Range is essentially a plateau-like topographical feature lying between the meridians 71° E. and 74° E. It trends roughly E-W. except between Mt. Sakesar and the Indus where it is N.-W.-S.E. Both the northern and southern slopes form parts of flexures. The northern slope shows strata with moderate northerly dips and merges into the Potwar plateau which lies between the Salt Range and the Kala Chitta hills. The southern slope is an overfold, thrust towards the south ; it forms therefore a series of escarpments which rise abruptly from the plains and in which the strata are clerly exposed. Several ravines cut across

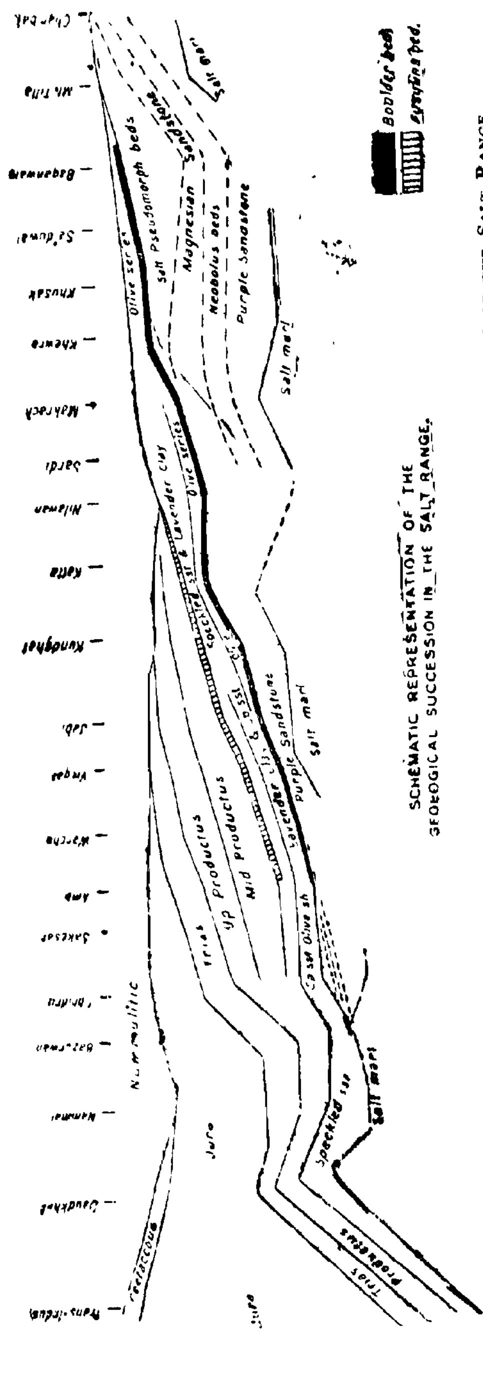


FIG. 1.—SCHEMATIC REPRESENTATION OF THE GEOLOGICAL SUCCESSION IN DIFFERENT PARTS OF THE SALT RANGE

the range at different places, revealing excellent transverse sections for study.

The oldest beds exposed are of Cambrian age which appear to include thick salt and gypsum beds. Upon them rest marine strata ranging in age from Upper Carboniferous to Eocene, the succession becoming more complete as one proceeds from east to west. The upper part of the scarp is composed of either the Permian or Eocene limestone. The Eocene strata, when followed across the range northwards are overlain successively by the Murrees and the Siwaliks.

At the eastern extremity near the Jhelum river, the Eocene beds rest directly on the Cambrian. The Olive Series of Upper Carboniferous age appears as a thin bed a few miles to the west and becomes gradually thicker further westward. The glacial Boulder-beds and Speckled sandstones are first seen near Khewra while further west, in the Nilawan ravine, about 45 miles from the eastern end, Productus beds make their appearance. The latter two gradually thicken in a westerly direction. The places which have given their names to the stages of the Productus Limestone occur at different distances west of Nilawan. The Productus Limestone attains its full development near Kundghat (25 miles west of Nilawan ravine) where also the Triassic beds make their appearance between the Permian and Eocene. A little further west, near Amb, Jurassic strata are to be seen.

This gradual thickening of marine strata and the fuller succession in the west provide an indication that the sea gradually retreated westward during deposition and that it was deep in the west.

The range takes a sudden bend to the south-west, beyond the Indus. The strata are generally well developed and thick in the Trans-Indus extension of the Salt Range.

The Cambrian comprises the following series of strata :

Salt Pseudomorph Shales (450 ft.) ..	Red to purple and greenish shales with casts or pseudomorphs of cubic salt crystals.
Magnesian Sandstones.. (250 ft.)	Well bedded cream-coloured dolomitic sandstone or arenaceous dolomite
Neobolus beds (100 ft.)..	Fossiliferous grey shales, slightly micaceous, characterised by the presence of the brachiopod *Neobolus.*
Purple sandstone (450 ft.)	Fine grained purple sandstones with shales at the base.
Salt marl (1500 ft.) ..	Bright red calcareous clay or marl with much salt and gypsum.

SALT MARL.

Nature and distribution.—Apparently the oldest beds of the Cambrian succession in the Salt Range are the Salt Marls (also known as the Saline Series). They form a practically unstratified mass of fine-grained marl, conspicuously red to dull purple or maroon in colour, and contain disseminated grains of sodium chloride, gypsum and carbonates of calcium and magnesium. Though no bedded structure is noticeable at the surface, sections in the mines sometimes show bedding and contortions of the layers. It is soft and homogeneous and does not contain coarse materials like sand and pebbles. Occasionally, there are green and grey blotches in the marl, these being generally streaky and kneaded out. There are also strings and lenticles of gypsum and dolomite in the marl, and the two may show a transition from one to the other. The outer portion of the dolomite has then a honey-combed structure which grades outwards into pumiceous structure and into canals and later into reticular patches in which the spaces of the reticules are filled by gypsum. At Khewra and in the Nilawan ravine the marl shows a band of bitiminous shale and also patches of a highly altered purplish trap. This trap may, in places, have a thickness of over 10 feet.

In the Eastern Salt Range the marl shows roughly three divisions or stages. The lower division, having a thickness of several hundred feet, is composed of marls, gypsum, bituminous shale and some dolomite ; the middle one, with a thickness of at least 600 ft., shows thick beds of rock salt ; the upper division, about 200 ft. thick, shows massive gypsum, bituminous shales and some flaggy dolomite. The middle and upper divisions are particularly well seen in the Trans-Indus region of Kohat.

The Salt Marl is best developed at Khewra where it attains a thickness of some 500 ft., the lower half of which constitutes beds of pure rock salt which is colourless to pale pink. The occasional impure earthy bands in the salt are locally called *kallar*. The upper half contains numerous intercalations of *kallar*, gypsum, and sulphates and chlorides of alkalis and alkaline earths. The gypsum forms lenses and beds in and above the marl, and in some places (*e. g.*, Mari, Kalabagh, Sardi, Khusak, Katta and Saiduwali) contains excellent small bi-pyramidal crystals of quartz. These crystals have been shown to contain inclusions of anhydrite from which it may be inferred either that much of the gypsum was originally anhydrite or that the included gypsum was converted to anhydrite during the crystallisation of the quartz.

Gypsum.—The gypsum is generally nearly pure, though it might show a gradation to limestone and dolomite. It is compact and massive to saccharoidal, white to grey, dark bluish grey or sometimes pink. Plates of selenite are occasionally found while the cores of the nodular masses may contain anhydrite.

Salt.—The beds of rock salt are often massive and may sometimes attain a thickness of 100 ft. The salt is pink to white in colour with rare grey blotches, the laminæ showing different degrees of opacity. In places some layers may be translucent or even transparent. Where there are alternating bands of different shades of colour, a stratiform appearance is produced, though the bands may really be lenticular in shape. Contortions of beds are sometimes seen in the salt and *kallar* but these are not so complicated nor so minutely folded as the layers in gypsum. Potash and magnesia salts—sylvite (KCl), kieserite ($Mg\ SO_4$-H_2O) and langbeinite ($K_2 Mg_2 (SO_4)_3$) are also sometimes associated with the *kallar*.

The rock salt is worked at a number of places along the southern face of the Salt Range—Khewra, Warcha, Kalabagh, etc.—the best known mines being those at Khewra (Mayo mines). In these mines there are 4 or 5 beds of salt with an aggregate thickness of over 200 ft. In the Kohat region also there are salt beds which show evidence of disturbance and faulting. Here the salt is more grey than red, due perhaps to very small amounts of bituminous matter, and massive salt beds stand out as hills in this practically rainless region.

Origin of the Saline Series.—The salt marl shows great complexity of structure, folding and disturbance. These peculiarities were explained by Oldham as having resulted from the metamorphism of some pre-existing rock by the action of acid vapours. Dolomite, limestone and shale are believed to have been attacked by vapours and solutions of sulphuric acid and hydrochloric acid, giving rise to a marl containing remnants of the calcareous rocks together with the gypsum and common salt produced in the process. C. S. Middlemiss, following up an idea originally suggested by Dr. Fleming, and realising the great tectonic disturbance to which the saline series has been subjected, suggested that it was probably of the nature of a hypogene intrusive. E. H. Pascoe thought that the series was of sedimentary origin and of Tertiary age, and that its anomalous position below the Cambrian beds of the Eastern Salt Range was due to thrust phenomena. The overthrust hypothesis was first propounded by Koken and Noetling and supported by Zuber, Holland and others. W. A. K. Christie was of the opinion that the saline series was similar in all respects to the sedimentary salt beds in other parts of the world and that the marl belonged to the last phase of desiccation of an inland sea basin, preceded by deposition of some potash salts. The well known plasticity of salt under pressure was held to be responsible for the obliteration of the bedded character. D. N. Wadia and L. M. Davies have shown, from stratigraphical and palæontological evidence, that the massive gypsum of the Kohat region is, at least in part, derived from the gypsification of the Laki (Eocene) limestone. It may therefore be conceded that the Saline series is of sedimentary origin and that its structure is the result of intense tectonic disturbance to which it was subjected during the Tertiary era.

Age of the Saline Series.—The Salt Marl is generally found just under the Purple Sandstones in the eastern part of the Salt Range but this is not always the case. The junction of these two formations shows always a brecciated appearance, the top of the marl being often full of fragments of the overlying sandstone. The marl occupies the cores of folds and flexures or shear zones near Amb, Dandot and other places. In the Amb glen, the marl underlies the boulder bed (of Talchir age) and below it are Permian strata in an inverted condition. It has apparently been squeezed into this position here. In some other places the marl appears over the Speckled Sandstone, while between Dandot and the Makrach valley it transgresses on to the Nummulitic strata. At Kallar Kahar and Vasnal in the plateau part of the Range, inliers of the marl can be seen amidst Tertiary strata. The disturbance is rather less pronounced in the Trans-Indus region. At Kalabagh on the Indus the Salt Marl is folded and occupies a position between the Nummulitics and the 'Orange Series' of presumably Siwalik age. The overfolded and faulted anticlines in the Kohat area often show, on the southern side, thrust faults marked by the presence of saliferous rocks. Here the series appears to be part of the

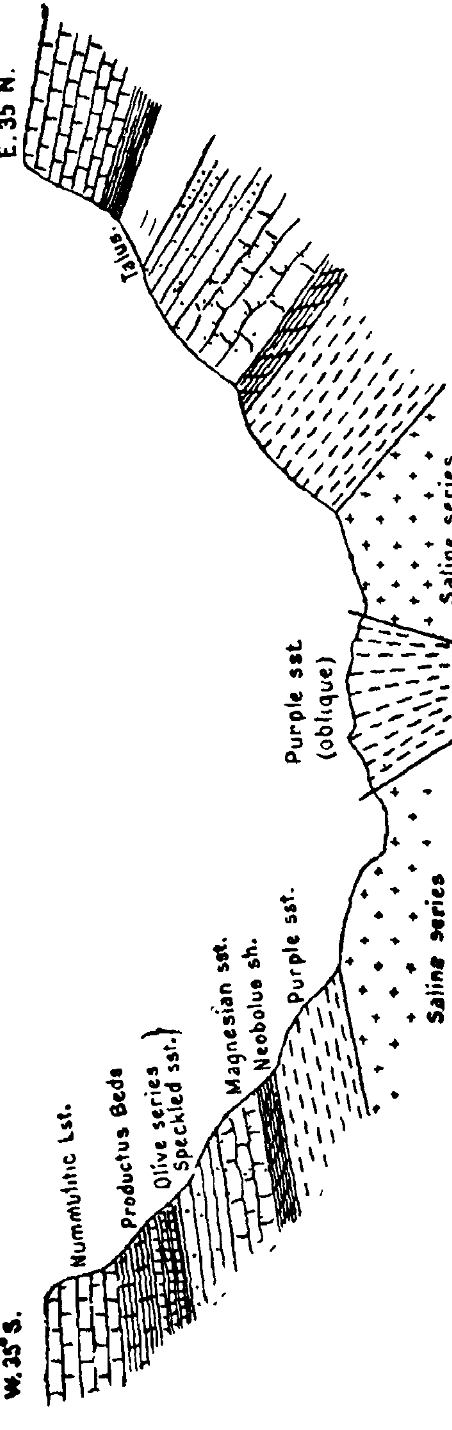


FIG. 2 – SECTION ACROSS THE NILAWAN RAVINE, SALT RANGE (AFTER A. B. WYNNE *Mem.* 14.)

Eocene succession, since the upper Ranikot limestone is transformed into gypsum underlain by Salt Marl and overlain by the Laki beds. At Daud Khel, the Eocene Sakesar limestone is seen to pass laterally into gypsum which directly overlies the Salt Marl. This gypsum looks very similar to that associated with the Salt Marl in other places in the Salt Range, and according to E. R. Gee, the limestone—gypsum transition occurs within the space of a few hundred yards. Some carbonised plant fragments including leaves of dicotyledons, have been observed in the marl near Katha, while some dolomitic bands within the massive gypsum of the Kohat region have yielded fish remains referable to a Tertiary age. The occurrence of the Saline Series below the Cambrian in the Eastern Salt Range, and in the Eocene of the Kohat area in the Trans-Indus region, both apparently in conformable positions, has led to the view, expressed by Wynne and other early observers, that it may be different ages in the two areas. As the great complexity of the structures in the Cis-Indus region was realised, it was suggested that the infra-Cambrian position was not normal but due to thrusting and squeezing. On this latter view, Pascoe, Wadia, and Davies have advocated that the Salt Marl is all of Eocene age in both the regions.

In a contribution to this controversy, C. S. Fox showed, a few years ago, that there were certain clear sections in the Cis-Indus Salt Range where the Saline Series lies below the Cambrian succession without much visible sign of disturbance. E. R. Gee, who remapped the whole of the Salt Range within the last decade, came to the conclusion that it is of the nature of a *nappe* which came into existence in late Eocene and Oligocene times by the overriding of the Saline Series southward by pre-Eocene rocks, this involving a bodily movement of the strata for a distance of some 20 miles. He found also evidence for late Tertiary and sub-Recent movements which have further complicated the structure. Since the commencement of his work in 1927, Mr. Gee consistently advocated an Eocene age for the Saline Series of both the regions, but recently he has revised his opinion and now supports a Cambrian (of Pre-Cambrian) age for that of the Punjab Salt Range.

It would appear, therefore, that this controversial question is far from settled, even after the revised and detailed mapping of the last decade. Interpretations differ as to whether the Eastern Salt Range occurrences are in their normal position or not. The fact that Gee is now supporting the older view (Cambrian or Pre-Cambrian age) may be taken as indicating that the case for the normal interpretation of the structures is quite strong. It is known that there are salt deposits of various ages in different parts of the world —*e.g.*, Tertiary in the Gulf coast region of the U.S.A., Triassic in England, Permian in Germany and Cambrian in Iran. The suggestion of a Cambrian age has, therefore, no improbability attached to it. Nevertheless it is intriguing that salt deposits of two very different ages should have been deposited in these two areas (Salt Range and Trans-Indus region) which now lie so close to each other.*

PURPLE SANDSTONE.

It has already been mentioned that the Salt Marl is generally overlain, in many places in the Eastern Salt Range, by the Purple Sandstones. These are fine-grained sandstones, dull red to purple in colour, showing current-bedding, ripple-marks and other evidences of deposition in shallow water and in a rather arid climate. The lower beds are shaly and are sometimes called Maroon Shales. The Purple Sandstones are entirely unfossiliferous and can be seen as far west as Chidru. Lithologically they

* On this question see the two symposia on the Age of the Saline Series held under the auspices of the Indian Academy of Sciences and National Academy of Sciences and published in 1945 and 1946 in the Proceedings of the National Academy of Sciences.

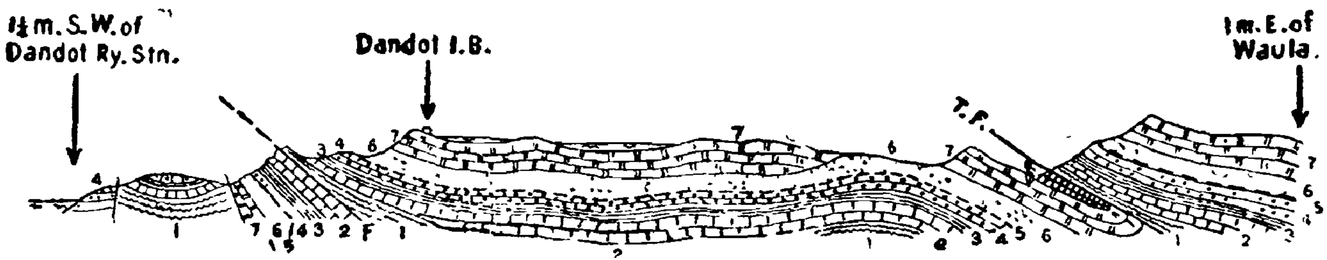


FIG. 3 — SECTION ACROSS THE DANDOT SCARP (AFTER E. R. GEE).
1. Salt Marl. 2. Purple Sandstone. 3. Neobolus Shale. 4. Magnesian Sandstone. 5. Salt Pseudomorph beds. 6. Speckled Sandstone (with boulder-bed at the base). 7. Nummulitic Limestone (with coal seam near base). 8. Lower Siwalik (Kamlials). F—Fault, T. F.—Thrust fault.

have a great resemblance to the Bhander or Rewa Sandstone of the Vindhyan System with which they can probably be correlated. Their junction with the Salt Marl is generally disturbed and fragments of sandstone are often found embedded in the marl.

NEOBOLUS BEDS.

The Purple Sandstones are overlain by dark grey shales containing intercalations of dolomite, this stage being called the Neobolus Beds from the fact of their containing the primitive brachiopod *Neobolus* (*N. warthi, N. wynnei, etc.*). They are 20 to 200 ft. thick and are particularly well exposed in the Khusak hill not far from Khewra. Other fossils in these shales are :—

Trilobites : *Ptychoparia richteri, P. sakesarensis, Redlichia noetlingi, Chittidillia plana* ; *Conocephalus warthi* ; Brachiopods : *Lingula warthi, Lingulella wanniecki, Mobergia granulata, Discinolepis granulata, Orthis warthi*, Pteropod : *Hyolithes wynnei*

The fossil assemblage indicates a Middle Cambrian age, mainly the lower part thereof.

MAGNESIAN SANDSTONES.

The succeeding Magnesian Sandstones are prominently displayed in the scarps of the Eastern Salt Range. They are mainly cream coloured dolomitic sandstones or arenaceous dolomites and flags, sometimes showing fine lamination and thin shale bands of green to dark colour. They show fucoid and annelid markings and contain the Cambrian gastropod named *Stenotheca*.

SALT PSEUDOMORPH SHALES.

Succeeding the Magnesian Sandstones conformably there are bright red to variegated shales with laminated sandstone layers. The shales contain cubic pseudomorphs or casts which represent replacement of salt crystals by clay on the shores of an enclosed basin. The crystalline form of the salt crystals is shared by both the upper and lower surfaces of each bedding plane. Excellent sections of this zone may be seen near Pidh, Dandot, Nilawan ravine, etc.

Parts of the Cambrian succession are seen also in the Mari-Indus and Kalabagh area where the Salt Marl occurs with gypsum. The southern part of the Khasor range, especially a little to the northwest of Saiduwali in Dera Ismail Khan district, shows a thick-sequence (400 ft.) consisting of Purple Sandstone, flaggy dolomite, bitumin-nous shale, greenish grey shale and massive white to pink gypsum. It is not known how much of this is Cambrian and how much post-Cambrian, but at least the lower part is presumably Cambrian.

The Salt Range Cambrians are succeeded directly by the glacial boulder bed of Talchir age just as in the case of the Vindhyans of the Peninsula. The rough parallelism which exists between the Vindhyans and the Salt Range Cambrians would suggest that the latter bordered on the Peninsula in the Cambrian (and late Pre-Cambrian) times.

KASHMIR.

In the Baramula district, north of the Kashmir valley, a good Palæozoic sequence is found, including Cambrian strata. In the Hundwara basin the Dogra Slates (Pre-Cambrian to early Cambrian) are conformably succeeded by clay slates, greywackes and quartzites which contain Annelid tracks and some badly preserved organic remains, which may be of Lower Cambrian age. They pass upwards into thick-bedded blue-grey clays, arenaceous shales and thin-bedded limestones containing identifiable fossils in places. The fauna is peculiarly rich in tri-lobites :

Trilobites . *Agnostus* sp., *Conocoryphe frangtengensis*, *Tonkinella kashmirica*, *Microdiscus* sp., *Anomocare hundwarensis*, *Solenopleura lydekkeri*.

Brachiopods *Acrothele* aff. *subsidua*, *Obolus kashmiricus*, *Lingulella* sp., *Botsfordia* cf. *coelata*.

Also pteropods (*Hyolithes*) and cystids (*Eocystites*).

The affinities of the species indicate a Middle to Upper Cambrian age, the resemblance being more to similar beds in Iran, Indo-China and North America than to those in the Salt Range and Central Himalayas.

SPITI.

In the Spiti valley, beyond the crystalline axis of the Kangra Himalaya, there is exposed a great geosynclinal basin with its axis N.W.-S.E. in which a complete succession of fossiliferous strata from the Cambrian to Eocene is to be found. The Cambrian strata, comprising the Himanta System, are found on the south-western flanks of the basin, lying over the Vaikrita System of Pre-Cambrian age. The Haimanta System consists of three main divisions :

		Feet.
Haimanta System	Upper — Grey and green micaceous quartzites, thin slates, shales and light grey dolomite. .	1200
	Middle — Bright red and black slates with some quartzites .	1000
	Lower — Dark slates and quartzites (highly folded) which probably include Pre-Cambrian strata	2000-3000

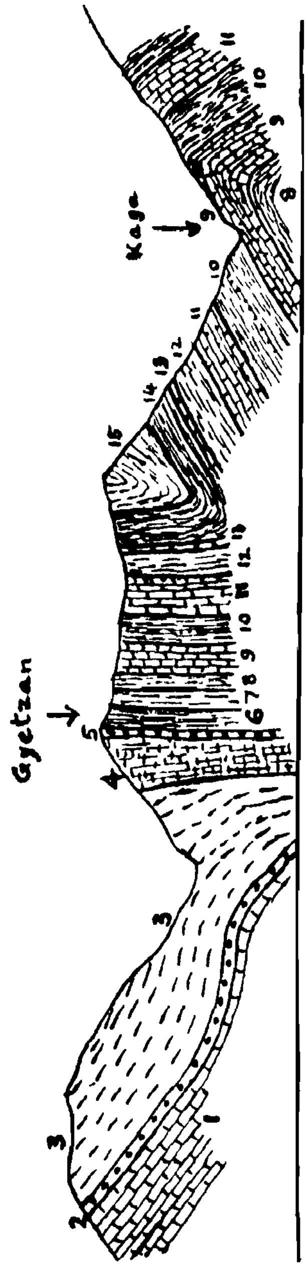


FIG 4.—SECTION ON THE PARAHIO RIVER, SPITI.
(AFTER H. H. HAYDEN *Mem.* 36, Pt. 1)

1. Cambrian dolomite 2 L Silurian conglomerate 3. Red (L Silurian, quartzite. 4 Silurian limestone. 5. Muth quartzite. 6. Productus shales. 7 L. Trias and Muschelkalk 8. Daonella shales 9. Daonella limestone. 10 Grey shales 11. Dolomite with Tropites beds 12 Juvavites beds 13. Coral limestone. 14. Monotis shales. 15. Quartzite series.

The beds are particularly well exposed in the valley of the Parahio river which is a tributary of the Spiti river. The lower and middle divisions are unfossiliferous, but the upper (see details below) contains Middle to Upper Cambrian fossils in several horizons. In Hayden's opinion all the three divisions should be included under the Cambrian.

Parahio River section of Upper Haimantas.

	Lithology.	Thickness. in feet.
19.	Conglomerate	
18.	Quartzites and siliceous shales ..	50
17.	Grey dolomite weathering brownish red .	20
16.	Flaggy sandstone, quartzite and siliceous slate ..	40
15.	Grey dolomite weathering brownish red .	30
14.	Siliceous slates with grey quartzite bands and thin beds of pink dolomite ..	250
*13.	Dark siliceous slates with fragmentary fossils .	10
12.	Siliceous slates and flaggy quartzites ..	30
*11.	Siliceous and argillaceous slates with trilobites ..	6
10.	Grey slaty quartzite capped by thin dolomite .	50
*9.	Slates, siliceous above and argillaceous below, with trilobites ..	30
8	Dark grey quartzite ..	60
*7	Pink shaly dolomitic limestone, with trilobites	12
*6	Calcareous quartzite with *Lingulella* and trilobites, underlain by a narrow band of limestone and slates with trilobites .	10
5.	Grey micaceous quartzite with thin bands of mica-schists.	150
*4.	Slates alternating with narrow bands of limestone, with *Lingulella* and trilobites ..	10
3.	Slate, chiefly siliceous, and quartzite ..	150
*2.	Dark slate with trilobites .	30
*1.	Red and green slaty quartzite with fossils in the uppermost beds ..	250
		1188

Fossils are found only in the zones marked with an asterisk. The fauna is rich in trilobites of which *Oryctocephalus* and *Ptychoparia* are particularly well represented. Most of the trilobite species are not known elsewhere, but there is a good resemblance to the fauna of western

N. America though not to that of Europe. The fossiliferous beds range in age from Middle to Upper Cambrian and the fossils include :

Trilobites	*Agnostus spitiensis, Microdiscus griesbachi, Redlichia noetlingi, Oryctocephalus salteri, Ptychoparia spitiensis, P. stracheyi, P. consocialis, Conocephalites memor, Anomocare conjunctiva, Olenus haimantensis.*
Brachiopods	. *Nisusia depsaensis, Lingulella haimantensis, L. spitiensis Acrotreta parahioensis, Obolella* cf. *crassa, Acrothele praestans*
Echinoderms	*Eocystites* sp Pteropod *Hyolithes*

The Haimantas are well developed also in the Kumaon and Garhwal Himalayas, in the mountains north of Kulu and in Lahaul.

BURMA.

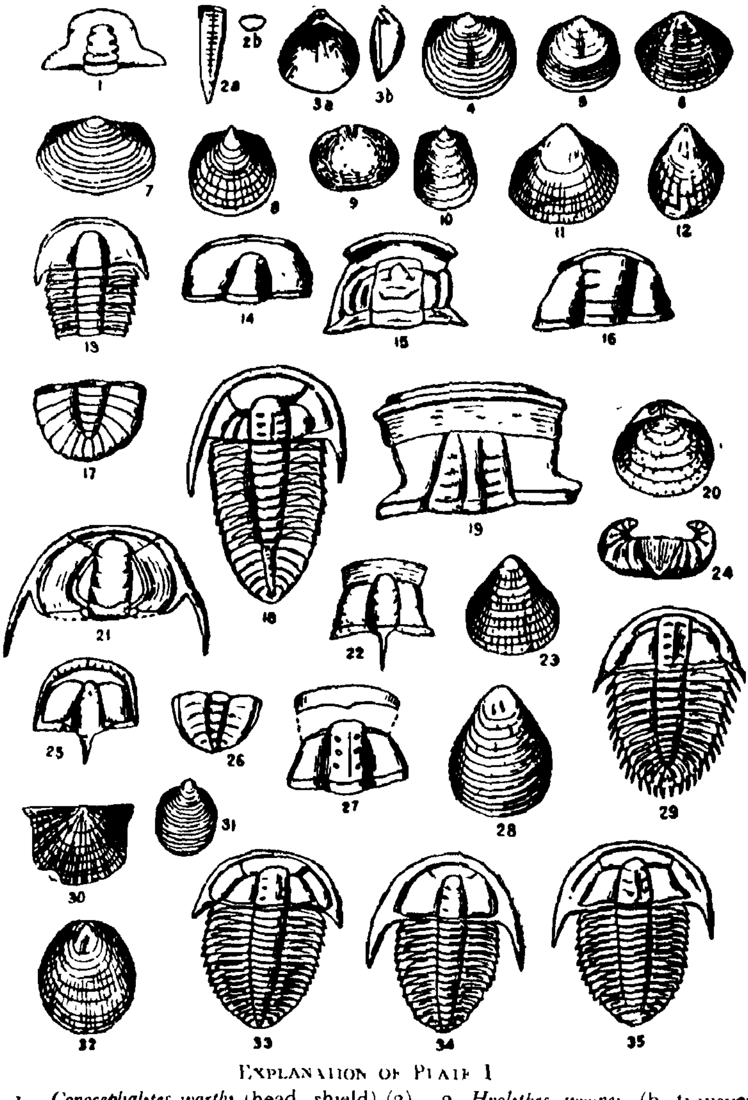
No fossiliferous Cambrian rocks have so far been discovered in Burma, but part of the Chaung Magyis of the Shan States, the Mergui series of Mergui and also some volcanic rocks may probably belong to this age.

THE BAWDWIN VOLCANICS.

In the neighbourhood of Bawdwin (23° 6′ : 97° 18′) in the Tawngpeng State near the China border, the Chaung Magyis are overlain by the Pangyun beds, consisting of quartzites, grits, sandstones and shales and some rhyolitic grits. These grade perfectly into the Bawdwin volcanic series and have a general N.W.-S.E. strike. They are composed dominantly of tuffs and subordinate rhyolites containing clear grains of quartz and having a brown or chocolate colour. They are seen to have suffered much crushing and at the surface are soft and light grey owing to decomposition. The rhyolites and tuffs are probably the effusive phase of the Tawngpeng granite which is exposed at a distance of five miles west of the volcanics.

The Bawdwin lead-zinc-silver ore-body occupies a prominent fault and shear zone (the Bawdwin fault) which is over 8000 ft. long and 500 ft. wide in which the tuffs and rhyolites have been replaced by Pb-Zn-Ag ore. All gradations can be found from solid ore through partly replaced tuffs to unrepalced volcanic rocks. The

PLATE I
CAMBRIAN FOSSILS



EXPLANATION OF PLATE I

1. *Conocephalites warthi* (head shield) (2) 2 *Hyolithes wynnei* (b, transverse section) (3/2). 3. *Orthis warthi* (3/2). 4. *Lakhmina linguloides* (2). 5, 6. *Neobolus warthi* (2). 7. *Neobolus wynnei* (2) 8 *Shizopholis rugosa* (4). 9. *Discinolepis granulata* (3) 10. *Lingula warthi* (2). 11. *Obolus kashmiricus* (1/2). 12. *Botsfordia* cf *coelata* (3/2). 13. *Conocoryphe sejuncta* (1/2). 14. *Conocoryphe frangtengensis* (1/2). 15. *Hundwarella personata* (2/3). 16. *Tonkinella*

ore is mainly a fine grained mixture of argentiferous galena and sphalerite with some chalcopyrite, often showing signs of considerable crushing. The ore-body is lens-shaped and about 3000 ft. long and of varying width. It is cut up by two faults, the Yunnan fault in the north and the Hsenwi fault in the south, into three sections; the northern section, called the *Shan lode* has an average width of 20 ft.; the central section, the *Chinaman lode* has an average width of 50 ft. but is in places 140 ft.; the southern section, called the *Meingtha lode* is 20 ft. wide. The ore-body as a whole strikes N.N W. and dips towards the west, with a northerly pitch. The hanging wall is well defined while the foot-wall is often indefinite and grades into the country rock. The core of the ore-body is a solid mass of ore, while the margins contain increasing proportions of country rock. There are also some subsidiary lodes in the neighbourhood which are called the Chin, Burma and Kachin lodes.

The shan lode contains rather high silver, low zinc and some copper in the higher levels. The zinc and lead increase in the lower levels. The original ore reserves were estimated at over 20 million tons.

The Chinaman lode contains about 20 per cent. zinc at the higher levels, this decreasing to 9 per cent. at the bottom. Lead is more or less steady at about 25 per cent., but the silver content decreases from 31 oz. (to the ton) in the upper levels to 14 oz. in the lower levels.

The Meingtha lode is similar to the Chinaman lode in the upper levels, but with lower Pb-Zn and higher

kashmirica (cranidium) (2/3) 17. Do (pygidium) (2/3). 18. *Anomocare hundwarense* (1/3) 19 *Ptychoparia dadapurensis* (2/3). 20 *Mobergia granulata* (2/3) 21 *Hoeferia* (*Redlichia*) *noetlingi* (2/3). 22. *Ptychoparia richteri* (2/3) 23. *Lingulella wanniecki* (6) 24 *Pseudotheca waageni* (3/2) 25. *Microdiscus griesbachi* (head shield) (6). 26. Do (pygidium) (6). 27. *Anomocare conjunctiva* (2) 28 *Lingula haimantensis* (3) 29. *Oryctocephalus salteri* (4). 30. *Nisusia depsaensis* (3). 31. *Acrotreta parahioensis* (4). 32. *Acrothele praestans* (3). 33. *Olenus haimantensis* (2). 34. *Ptychoparia maopensis* (2) 35. *P. stracheyi* (2).

copper. In the lower levels it is high in copper with little Pb-Zn, but containing some nickel and cobalt. The original reserves in the Chinaman lode were about 7 million tons and in the Meingtha lode about 1.6 million tons. The average ores of the different lodes have the following assay values :

	Silver oz/ton	Lead per cent.	Zinc per cent	Copper per cent
Shan lode	17 8	21.5	10 7	2.09
Chinaman lode	21.1	25 0	16.1	0 40
Meingtha lode	13 0	15 2	9 0	1.97
General average	19.1	22.7	13 8	1 05

The ore reserves in the mines at the beginning of 1940 were about 3.5 million tons, the annual production being around 400,000 to 500,000 tons.

The minerals identified in the ores by Dr J. A. Dunn are : pyrite, arsenopyrite, lollingite, gersdorffite, sphalerite, chalcopyrite, cubanite, tetrahedrite, galena, bournonite, boulangerite, pyrargyrite, ankerite, calcite, quartz, and sericite. The ore assemblage points to mesothermal conditions of deposition. In the oxidation zone were found anglesite, cerussite, pryromorphite, calamine, malachite, azurite, massicot, goslarite and brochantite. The mineralisation is probably connected with the Tawngpeng granite and is accompanied by widespread silicification and sericitisation of the country rock.

The Tawngpeng granite is the plutonic equivalent of the Bawdwin volcanics. It is found in the State of the same name and also in the Mong Tung State in South Hsenwi. It is a biotite-granite containing no tourmaline. Of about the same age are the siliceous tuffs containing

J C Brown · Geology and ore deposits of Bawdwin mines. *Rec 48* 121-178, 1917

A B. Colquhoun . *Trans Amer Inst Min Eng*, *69*, 211, 1923

M H Lowman : *Op cit 56*, 181, 1917.

A B. Colquhoun · *Mining Mag. 44*, 329-333 , *45*, 23-26, June and July, 1931

J. A. Dunn : A microscopic study of the Bawdwin ores *Rec 72*, 333-359, 1937.

E L G. Clegg A note on the Bawdwin mines, Burma. *Rec. 75*. paper 13, 1941 angular quartz fragments in a fine-grained chloritic groundmass, which occur near the Lagwe Pass on the Burma-China frontier.

Many of the islands of the Mergui Archipelago show granite, porphyry, rhyolite and agglomerate. The products of this volcanism have been deposited with the sediments of the Mergui series. There are also some felsites and amphibolised basic rocks which are intrusive into the Merguis and may be semi-contemporaneous with them.

THE ORDOVICIAN AND SILURIAN SYSTEMS.

SPITI.

As already remarked, the Spiti area shows a full succession of Palæozoic rocks. The Cambrian formations described already are overlaid by a thick series of shallow water deposits consisting of conglomerates, quartzites and grits and these in turn by shales and limestones, this whole succession being referable to the Ordovician and Silurian. The lower, arenaceous part is about 1500 ft. thick while the upper calcareous and argillaceous strata have a thickness of 500 to 600 ft.

TABLE 16.—LOWER PALAEOZOIC SUCCESSION IN SPITI.

Upper Silurian	Muth quartzite.	
Silurian	8. Grey siliceous limestone weathering red	80 ft
	7. Grey limestones, weathering brown, with brown and red marls	70 ft.
	6. Grey coral limestone	50 ft.
	5. Shaly limestone with brachiopods, gastropods and corals	30 ft
?	4. Hard grey dolomitic limestone	40 ft.
Ordovician	3. Dark grey limestone with cystids	40 ft.
	2. Dark foetid limestone with trilobites and brachiopods	200 ft.
	1. Shaly and flaggy sandstone with plants and *Orthis*	150 ft.
	0. Flaggy quartzites and siliceous shales passing down into red quartzites with conglomerates at base (unfossiliferous)	1500 ft
Upper (and partly Middle) Cambrian	Shales, slates, quartzites, etc	1200 ft
Lower Cambrian	Red and Black slates and quartzites	1000 ft
	Dark slates and quartzites	2000—3000 ft.

Practically all the beds in the above succession contain fossils. Bed No. 2 is particularly rich in trilobites and brachiopods and is referable to Caradocian age. The beds above it contain cystids and brachiopods which indicate a transition from Ordovician to Silurian. The siliceous limestone (Bed No. 8) below the unfossiliferous Muth Quartzite shows *Favosites*, *Pentamerus*, and other fossils on weathered surfaces and is of early Wenlock age, the Upper Silurian being part of the Muth quartzite. The fossils in the two systems are mentioned below :—

ORDOVICIAN FOSSILS	
Trilobites	*Asaphus emodi* var. *milamensis*, *Illaenus brachioniscus*, *I. punctulosus*, *Calymene nivalis*, *Cheirurus mitis*.
Brachiopods	*Orthis* (*Dinorthis*) *thakil*, *Dalmanella testudinaria*, *Leptaena rhomboidalis*, *L trachealis*, *Strophomena chamerops*, *Refinesquina umbrella*, *R aranea*, *R. muthensis*, *Plectambonites himalensis*, *Christiania nux*.
Lamellibranchs & Gastropods	*Pterinea thanamensis* ; *Lophospira himalensis*, *L. pagoda*, *Bellerophon ganesa*, *Conradella* aff *obliqua*
Cephalopods	*Orthoceras kemas*, *Cyrtoceras centrifugum*, *Gonioceras* cf *anceps*.
Bryozoa	*Ptilopora*, *Phylloporina*, *Ptilodactya*
Actinozoa ..	*Streptelasma* aff *corniculum*, *Heliolites depauperata*.
Pteropods .	*Tentaculites*.
SILURIAN FOSSILS	
Trilobites ..	*Encrinurus* aff *punctatus*, *Calymene* sp
Brachiopods	*Orthis* (*Plectorthis*) *spitiensis*, *Dalmanella basalis*, *Orthis calligramma*, *Leptaena rhomboidalis*, *Orthothetes* aff. *pecten*, *Pentamerus oblongus*.
Lamellibranchs ..	*Palaeoneilo* cf *victoriae*
Gastropods .	*Euomphalus* cf *triquetrus*
Cephalopods .	*Orthoceras* cf. *annulatum*.
Actinozoa .	*Lindstroemia* sp., *Zaphrentis* sp., *Propora himalaica*, *Favosites spitiensis*, *Halysites wallichi*, *H. catenularia* var. *kanaurensis*

In the Ordovician, the brachiopods are abundant and trilobites comparatively much less common and mollusca rare. The Silurian fauna is rich in corals with remarkable

American affinities. Though the faunas of the two systems have local characters, they show much more affinity to those of North America than Northern Europe.

KASHMIR.

Ordovician.—The Ordovician is present in parts of Kashmir though the exposures have not yielded good fossils. In the Lidar valley it may underlie the fossiliferous Silurian exposed along the flanks of an anticline in which a complete silurian to Triassic succession is found. A similar anticline is found also in the Basmai area in the Sind valley. At Trehgam and its neighbourhood, on the northern limit of the Shamsh Abari syncline, there are greywackes, slates, and limestones which contain some fragmentary fossils.

Silurian.—The Lidar valley fold clearly exposes Silurian rocks, composed of arenaceous shales and impure limestones. The fossils include orthids, strophomenids, corals and fragmentary crinoids, which indicate a Silurian age. The Shamsh Abari syncline also contains fossiliferous Silurian slates and greywackes but the fossils are all crushed and obliterated. Elsewhere in Kashmir, the Cambrian strata are overlain by the Muth Quartzites of Upper Silurian to Devonian age, or by the Agglomeratic Slates or Panjal Trap of Middle Carboniferous or later age.

GARHWAL—KUMAON AND HAZARA.

Ordovician and Silurian rocks are known to exist in Garhwal-Kumaon south-east of Spiti. In Hazara, to the west of Kashmir, there are apparently no Lower Palæozoic rocks since the Dogra slates (which are Pre-Cambrian to Cambrian) are succeeded by a boulder bed which is regarded as the representative of Talchir boulder bed.

BURMA.

The Shan States of Burma contain well developed Ordovician and Silurian Systems. The Tawngpeng system (Pre-Cambrian to early Cambrian) is overlaid by sandstones, shales and limestones which are sub-divided as shown below :—

Nyaungbaw limestone.
Hwe-Maung purple shales.
Upper Naungkangyi stage.
Lower Naungkangyi stage
Ngwetaung sandstone.

Of these the middle three divisions are well developed, the other two being local.

The Lower Naungkangyi Stage.—This is seen in a series of exposures on the Shan Plateau and consists of marls and limestones. Good sections are to be observed in the Gokteik gorge and in the valley of the Nam Pangyum. Amongst the fossils of this stage are :—

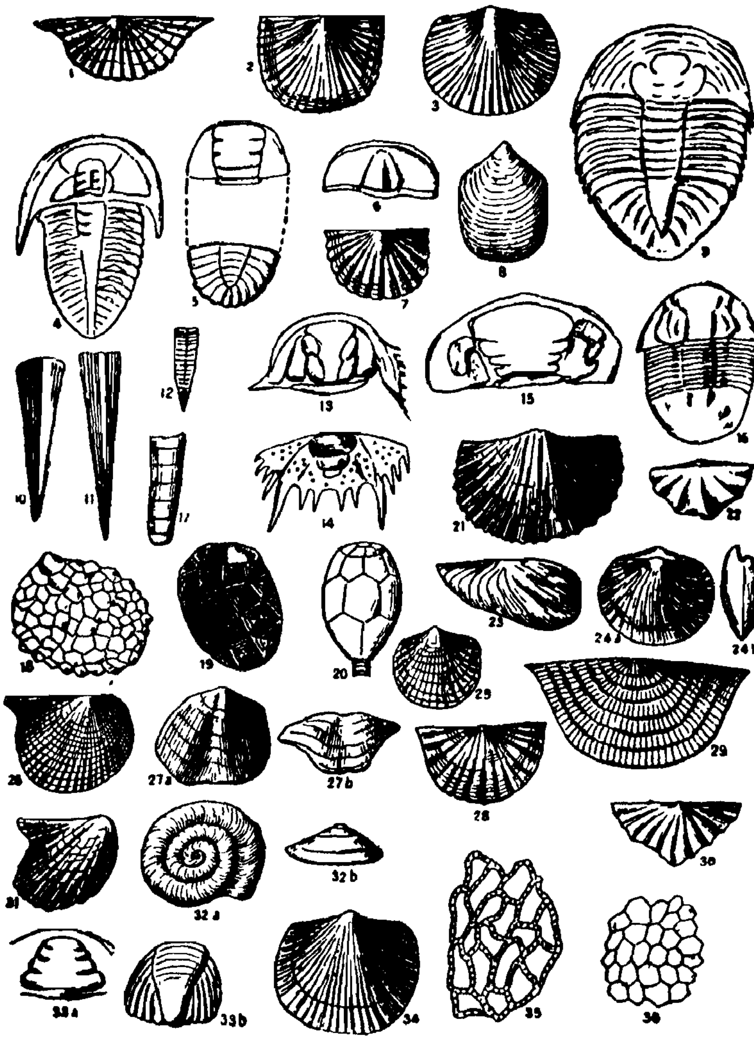
Brachiopods	*Orthis irravadica, O. subcrateroides, Leptaena ledetensis, Rafinesquina imbrex, R. subdeltoidea, Schizotreta, Plectambonites quinquecostata.*
Trilobites	*Calymene birmanica, Cheirurus dravidicus, Asaphus, Phacops.*
Cystids and Crinoids ..	*Artistocystis dagon*, and several species of *Heliocrinus* and *Caryocrinus.*
Bryozoa .	*Diplotrypa sedavensis, Phylloporina orientalis.*

The fossil assemblage shows affinities with that of the Lower Ordovician of the Baltic region of Europe, and very little with that of Spiti in which the important elements are trilobites and cystids.

The Upper Naungkangyi Stage.—This has a wide distribution in the Shan States and shows two facies—a shaly facies west of Lashio and a calcareous shaly one east of the same place. The western outcrops are about 1000 ft. thick and show evidences of crushing and compression. The chief fossil organisms in them are :—

Brachiopods .	*Lingula* cf. *attenuata, Dalmanella testudinaria* var. *shanensis, Orthis calligramma, Strophomena* sp., *Rafinesquina subdeltoidea, Porambonites sinuatus, Plectambonites sericea.*
Trilobites .	*Agnostus* cf. *glabratus, Calymene birmanica, Illaenus liluensis, Cheirurus submitis, Phacops dagon, Pilomera insangensis.*
Crinoids .	*Heliocrinus, Caryocrinus.*
Bryozoa ..	*Diplotrypa palinensis, Phylloporina, Ceramopora.*

PLATE II.
ORDOVICIAN AND SILURIAN FOSSILS.



EXPLANATION OF PLATE II

1. *Teosinella consignata* (3/2) 2 *Orthis* (Dalmanella) *emancipata* (3/2) 3. *O. hehoensis* (2). 4 *Anomocare hundwarense* (3/2) 5 *Tonkinella Kashmirica* (2) 6 *Conocoryphe franglengensis* (3/2) 7. *Orthis marhaumensis* (2) 8 *Lingula exornata* (5/2) 9 *Ogygites birmanicus* (2/3) 10 *Hyolithes clivei* (2). 11 *H loczyi* (2) 12 *Tentaculites elegans* (2) 13,14 *Acidaspis shanensis* (3). *Phacops* (*Pterygometopus*) *dagon* (2) 16 *Illaenus liluensis* (3/2) 17. *Orthoceras commutatum* (1/3). 18 *Aristocystis dagon* (1/3) 19 *Heliocrinus qualus* (1/3) 20. *Caryocrinus avellana* (1/3). 21 *Orthis calligramma* (1) 22 *Plectambonites quinquecostata* (3/2). 23 *Rafinesquina imbrex* (2/3). 24 *Orthis stracheyi* (2/3) 25 *Atypa reticularis* (2/3) 26 *Pterinea konghsaensis* (1/3) 27. *Triplecia uncata* (2/3). 28. *Rafinesquina umbrella* (2/3) 29 *Leptoena trachealis* (2) 30 *Plectambonites himalensis* (3/2). 31 *Pterinea thanamensis* (2/3). 32. *Liospira emodi* (2). 33 *Calymene nivalis* (2) 34. *Orthis* (Dalmanella) *basalis* (3/2) 35. *Halysites wallichi* (2/3) 36. *Favosites spitiensis* (2/3).

The purple calcareous shales in the eastern area are also roughly of the same age as the Upper Naungkangyis as evidenced by their fossil content.

Brachiopods *Dalmanella* sp., *Plectambonites sericea*, *Orthis testudinaria*, *O. subcrateroides*

Nyungbaw Limestone.—These limestones overlie the Naungkangyis and contain *Camarocrinus asiaticus* and other fossils which indicate that they are also Ordovician in age.

SOUTHERN SHAN STATES.

The Ordovician is developed also in the Southern Shan States where it is represented by the Mawson series, Orthoceras beds and Pindaya beds.

Mawson series.—In the eastern part of the Mawson highlands and further south, there are calcareous shales and limestones containing *Orthoceras*, *Actinoceras*, *Oxygites*, *Pliomera*, *Orthis*, *Cyrtolites*, *Helicotoma*, *etc.* These beds are of Ordovician age and contain the lead deposits of Mawson described by Dr. J. Coggin Brown (*Rec. G.S.I.*, LXV, 394-433, 1930).

Orthoceras beds and Pindaya beds.—On the western limb of the Mawson anticline, there occur purple argillaceous limestones and shales containing crinoid stems and species of *Orthoceras*, *Diplograptus and Monograptus*. The Orthoceras beds are definitely of Middle Ordovician age and their equivalents are known in Yunnan, South Manchuria and in the Baltic region.

Bands of calcareous shales, slates and thin limestones occur in the Pindaya range, bordered by Permo-Carboniferous limestones. The enclosed fauna has close relationships with that of the Naungkangyi beds, and includes cystids, trilobites, brachiopods, etc., among which may be mentioned :

Orthis cf. *irravadica*, *Ptychoglyptus shanensis*, *Yeosinella consignata*, *Christiania* cf. *tenuicincta*, *Rhinidictya* cf. *nitidula*, *Favosites*; *Caryocrinus*; *Illaenus*; *Dictyonema*

Several of the fossils are in a bad state of preservation. The Silurian of Burma has the following sub-divisions:

Zebingyi beds
Namshim sandstones and marls
Pangsha-pye Graptolite beds.

The *Graptolite beds* are found near Hsipaw and other places in the Nam-tu valley and in the Loi-lem range east of Lashio, overlying the upper Naungkangyis. Just beneath the Graptolite-bearing bands there is a bed containing trilobites. The Graptolite beds are composed of white shales of about 50 ft. thickness, containing abundant graptolites and other fossils indicating a Llandovery age:

Graptolites	..	*Diplograptus modestus*, *D vesiculous*, *Climacograptus medius*, *C. tornquisti*, *C. rectangularis*, *Monograptus concinnus*, *M. gregarius*, *M. tenuis*, *Rastrites peregrinus*, *Cyrtograptus* sp
Brachiopods	..	*Dalmanella elegantula*, *Dalmanella mansuyi*, *Stropheodonta*, *mcmahoni*, *S. feddeni*.
Trilobites	..	*Phacops* (*Dalmanites*) *hastingsi*, *Acidaspis shanensis*.
Ostracods		*Beyrichia* sp

The *Namshim* (*Namhsim*) *beds*, of the same age as the Wenlock beds of England, contain two divisions, the lower consisting of sandstones of varying degrees of coarseness and containing several trilobites and brachiopods. The former include *Calymene blumenbachi*, *Encrinurus konghsaensis*, *Cheirurus* cf. *bimucronatus*, *Phacops* (*Dalmanites*) *longicaudatus*, etc. The upper Namshim stage is marly in composition and sometimes rests directly on the Naungkangyis. These marls contain a rich fauna:

Bryozoa	.	*Fenestella* sp
Trilobites	..	*Encrinurus konghsaensis*, *Calymene blumenbachi* (*Cheirurus bimucronatus*.
Brachiopods	..	*Lingula lewisi*, *Orthis rustica*, *Orthis biloba*, *Dalmanella elegantula*, *Leptaena rhomboidalis*, *Strophomena corrugata*, *Pentamerus* cf. *oblongus*, *Atrypa reticularis*.

The *Zebingyi stage* comprises limestones and shales containing numerous fossils which show affinities to Upper Silurian and Lower Devonian of Europe, especially of the Mediterranean region. On the whole, the Devonian affinities are strong.

Graptolites .	*Monograptus dubius* and other species.
Trilobites .	*Phacops (Dalmanites) swinhoei*, *P. shanensis*.
Brachiopods .	*Atrypa marginalis*, *A. subglobularis*, *Stropheodonta comitans*, *Meristina* sp.
Cephalopods .	*Orthoceras* aff. *commutatum* and other species.

Also abundant *Tentaculites (pteropod)* and several lamellibranchs.

The Burmese Silurian has strong affinities with the Silurian of Northern Europe and England and is quite unlike the Himalayan strata of the same age. The Burmese fauna is rich in graptolites which appear to be absent from the Himalaya, while the corals which are common in the latter are scarce in the former. The connection of the Himalayan fauna with the American on the one hand, and the close affinities of the Burmese fauna with the Baltic on the other, would show that effective barriers existed between the two groups in Lower Palæozoic times.

THE DEVONIAN SYSTEM.

The Devonian system is developed in the areas in which the Lower Palæozoics occur—*i.e.*, in Spiti, Kashmir and Burma, and also in Chitral to the north-west of Kashmir.

SPITI.

A group of hard, white, unfossiliferous quartzites conformably overlies the Silurian rocks containing *Pentamerus oblongus* and other fossils of early Wenlock age and is overlaid by fossiliferous Lower Carboniferous rocks. The quartzites are 500 ft. thick and are known as the *Muth Quartzites*. They are mainly Devonian in age but the lower part is Upper Silurian.

The Muth Quartzites are found also in Kumaon—Garhwal where they have the same characters as in the type area.

In Upper Spiti and Kanaur, there are dark fissile limestones containing abundant *Orthothetes* (*O. crenistria*) and other brachiopods such as *Atrypa aspera*, *Stiophalosia*, etc. These are Middle to Upper Devonian in age.

In Byans, near the Nepal border, Devonian fossils have been found in some dark limestones near Tera Gadh camp. These include : *Atrypa reticularis*, *A. aspera*, *Pentamerus*, cf. *sublinguifer*, *Camarophoria*, cf. *phillipsi*, *Rhynchonella* (*Wilsonia*) cf. *omega*, *Orthis* aff. *bistriata* ; and also the cephalopod *Orthoceras* and the coral *Faosites*.

KASHMIR.

Devonian strata are found overlying the Silurian in the Lidar valley and in the Shamsh Abari syncline. They are hard white quartzites having a thickness of up to 2000 ft. They are lithologically similar to the Muth Quartzites of the type area and are unfossiliferous.

CHITRAL.

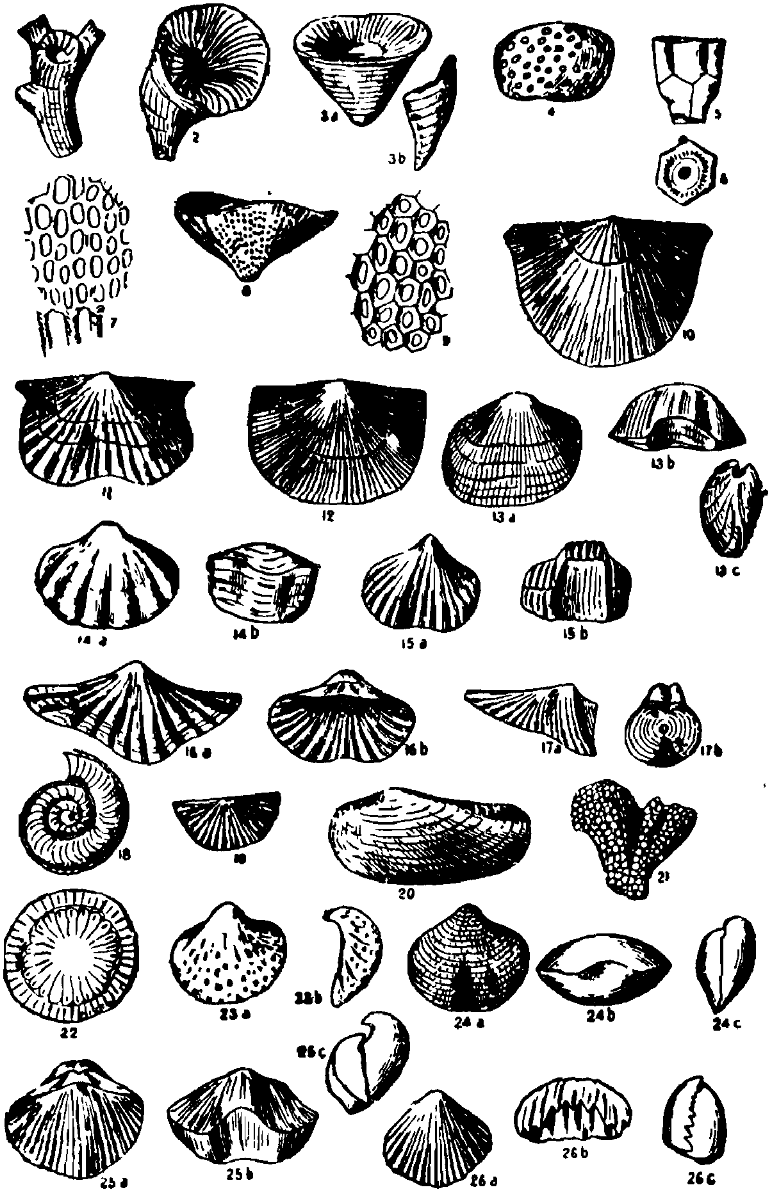
In the State of Chitral on the Afghan frontier, Devonian rocks are well developed and comprise thick limestones which are underlain by quartzites, sandstones and conglomerates. These latter are unfossiliferous and apparently represent older Palæozoic rocks. The Devonian rocks, which are generally brought into juxtaposition with conglomerates of much younger age by a great fault, comprise beds of limestone with corals and brachiopods. The fossils include :

Trilobites	*Proetus chitralensis*.
Brachiopods ..	*Spirifer* aff *primaevus*, *S.* cf. *robustus*, *Athyris*, cf. *subconcentrica*, *Pentamerus sieberi*, *Orthis* cf. *praecursor* var. *sulcata*, species of *Productella* and *Dalmanella*, *Stropheodonta phillipsi*, *Orthothetis hipponyx*, *Chonetes* aff. *embryo*, *Chonetes McMahoni*
Gastropods .	*Loxonema*, *Euomphalus*, *Pleurotomaria*.
Actinozoa	Several species of *Cyathophyllum*.

Also crinoid stems and *Fenestella*.

PLATE III.

DEVONIAN FOSSILS



EXPLANATION OF PLATE III

1. *Cyathophyllum caespitosum* (4) 2. *Zaphrentis cornicula* (2/3) 3. *Calceola sandalina* (2/3). 4. *Heliolites interstinctus* (1/2) 5 *Hexacrinus pyriformis* (3/2)

BURMA.

Plateau Limestone.—In the Federated Shan States the Silurian rocks are succeeded by the Plateau Limestones which occupy a large area. They are mainly of dolomitic composition, but argillaceous and arenaceous intercalations are known in places. The typical Plateau Limestone is a hard, light grey, fine-grained and granular rock which has been crushed and is traversed by thin veins of calcite. It contains a few traces of fossils including corals and foraminifera.

The Plateau Limestone extends in age from Devonian to Lower Permian. The brecciated nature and paucity of fossils do not permit of the separation of beds belonging to different ages. The total thickness is about 3000 ft. It was probably a limestone, later dolomitised to a large extent. The lower part of the Plateau Limestone contains two fossiliferous patches, *viz.*, Padaukpin Limestone and Wetwin Shales which have yielded Devonian fossils.

Padaukpin Limestone.—This is exposed in small area near Padaukpin situated at a distance of a mile from Wetwin railway station, and contains a rich assemblage of fossils :

Actinozoa	*Cyathophyllum birmanicum, Pachypora reticulata, Zaphrentis, cornicula, Endophyllum acanthicum, Cystiphyllum cristatum, Calceola sandalina, Favosites goldfussi, Alveolina ramosa, A. suborbicularis, Heliolites interstinctus.*
Bryozoa ..	*Fistulipora tempestiva, Selenopora coelebs, Fenestella arthritica, Hemitrypa inversa, Polypora populata, Fenestropora isolata.*

6. *H Spinosus* (stem) (1) 7 *Fenestella polyporata* (3/2) 8 *Hemitrypa oculata* (3/2) 9 *Polypora populata* (3/2) 10 *Stropheodonta interstrialis* (2/3) 11 *S subtetragona* (2) 12 *Orthothetes umbraculum* (1/2) 13 *Orthis striatula* (1/2). 14 *Pentamerus* (*Gypidula*) *brevirostris* (2/3) 15 *Rhynchonella subsignata* (2/3) 16 *Spirifer padaukpinensis* (2/3) 17. *Conocardium rhenanum* (2/3). 18 *Euomphalus radiatus* (3/2) 19 *Chonetes subcancellata* (3/2) 20 *Janeia birmanica* (2/3). 21 *Pachypora polymorpha* (2/3) 22 *Cyathophyllum* (*Thamnophyllum*) *multizonatum* (tranverse section) (1) 23 *Productus fallax* var. *chitralensis* (2/3) 24. *Athyris chitralensis* (2/3) 25 *Spirifer murchisonianus* (1/3) 26 *Camarotoechia baitalensis* (2/3).

Crinoids .. *Cupressocrinus* cf. *crassus*, *Hexacrinus* aff. *elongatus*, *Taxocrinus*.

Brachiopods .. *Leptaena rhomboidalis*, *Stropheodonta interstrialis*, *Orthothetus umbraculum*, *Chonetes minuta*, *Orthis striatula*, *Athyris concentrica*, *Pentamerus* (*Gypidula*) *brevirostris*, *Atrypa reticularis*, *Spirifer padaukpinensis*, *Rhynchonella* spp.

Trilobites .. *Phacops latifrons*, *P* (*Dalmanites*) *punctatus*.

Wetwin Shales.—The Wetwin Shales, which are yellow to buff and mottled, are exposed near Wetwin, 12 miles east of Maymyo and within a mile of the exposure of Padukpin limestone. No direct relationship could be established between these two neighbouring exposures, but the fauna of the Wetwin Shales indicates that it is slightly younger than that of Padaukpin, while there is also a difference in facies. The fossils include :

Bryozoa . *Fenestella polyporata*, var. *wetwinensis*

Brachiopods *Lingula* cf. *punctata*, *Athyris* cf *spiriferoides*, *Chonetes subcancellata*.

Lamellibranchs. *Nucula wetwinensis*, *Janeia birmanica*, *Palaeoneilo* sp.

Gastropods . *Bellerophon shanensis*, *B. admirandus*.

This fauna indicates the Eifelian stage of the Middle Devonian. It is rich in lamellibranchs and gastropods whereas the Padukpin fauna is rich in corals. The difference of the two is to be attributed to the physical environment and conditions, the Wetwin Shales being apparently lagoonal deposits. Beds of similar age are known to be present in several regions in Southern Asia such as Armenia, Iran, Yunnan and Indo-China.

THE CARBONIFEROUS SYSTEM.

SPITI.

The Muth Quartzites of Devonian age constitute a conspicuous horizon in the Himalayan area. They are overlain in Spiti by a series of limestones, shales and quartzites, called the Kanawar System, which is subdivided as follows :—

Kanawar System	Po Series (2000 ft.)	Fenestella shales Thabo stage : quartzites and shales with plants.
	Lipak Series (2000 ft.)	Limestones and shales with *Syringothyris cuspidata*, *Productus*, *etc.*

Lipak Series.—Named after the Lipak river, and well exposed near the junction of that river with the Sutlej, this series consists mainly of limestones and quartzites with subordinate shales. The limestones are generally hard, dark grey and contain thin siliceous bands. The lower portion contains some corals and brachiopods which have proved difficult to extract from the rocks. In the upper part of the series there are thin shales and limestones which have yielded good fossils among which are :

Brachiopods ..	*Productus cora*, *P. semireticulatus*, *Chonetes hardrensis*, *Syringothyris cuspidata*, *Ortholhetes* sp., *Derbyia* cf. *senilis*, *Spirifer kashmiriensis*, *Strophomena analoga*, *Reticularia lineata*, *Athyris roysii*, *A. subtilita*.
Trilobite ..	*Phillipsia* cf *cliffordi*.
Lamellibranchs.	*Conocardium*, *Aviculopecten*, *etc.*
Pteropod .	*Conularia quadrisulcata*

The fossils show that they are of Lower Carboniferous age.

Po Series.—The Po Series, which overlies the lipak Series, has two subdivisions. The lower portion, called the *Thabo stage*, contains the plant fossils *Rhacopteris ovata* and *Sphenopteridium furcillatum* which are regarded as Lower Carboniferous. The upper portion, known as *Fenestella shales*, because of the richness in some horizons of the bryozoa called *Fenestella*, *is* of Upper Carboniferous age and contains the following fossils :—

Brachiopods	*Productus scabriculus*, *P undatus*, *Dielasma* sp ,*Spirigera* cf. *gerardi*, *Spirifer triangularis*, *Reticularia lineata*.

The Po Series is succeeded by a conglomerate which contains pebbles and boulders of the underlying formations and represents a stratigraphical break which, however, is only of a short duration here, as compared with other areas.

KASHMIR.

Syringothyris Limestone.—In the Palæozoic anticline of the Lidar valley in Kashmir, the Muth Quartzites are overlain conformably by thin-bedded limestones called the Syringothyris Limestones. They are well exposed at Eishmakum and Kotsu, south-east of Srinagar, and apparently extend further out but are covered by the younger Panjal trap and alluvium. Beds of the same age are found also near Banihal in the Pir Panjal where they attain a thickness of 3000 ft. The strata derive their name from the Brachiopod *Syringothyris cuspidata* which characterises them and which show also that they are to be correlated with the Lipak Series of Spiti.

Fenestella Shales.—The Syringothyris Limestones are followed by a thickness of 2000 ft. of quartzites and shales the latter being often calcareous. They are exposed in the Lidar valley and near Banihal.

The lowest beds of these are unfossiliferous but above them come shales full of *Fenestella* and also brachiopods, corals, etc. The upper beds are mainly quartzites with shale intercalations. The more important fossils in the Fenestella shales are :

Polyzoa .	*Fenestella* and *Protoretepora ampla.*
Trilobite	*Phillipsia* sp
Brachiopods	*Productus cora*, *P. scabriculus*, *P undatus*, *P. spitiensis*, *Spirifer lydekkeri*, *S. triangularis*, *S. varuna*, *Strophalosia*, *Aulosteges*, *etc.*
Lamellibranchs	*Aviculopecten*, *Modiola*, *Pecten*, etc.

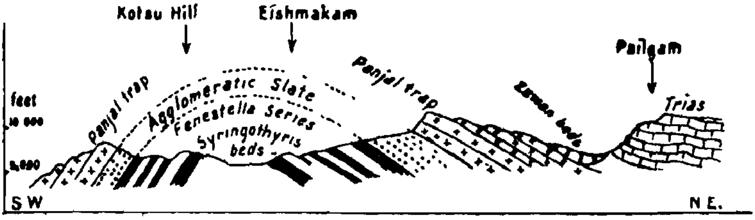


FIG 5.—SECTION ACROSS THE LIDAR VALLEY ANTICLINE, KASHMIR. (AFTER C S. MIDDLEMISS. *Rec* 40.)

The Fenestella Shales are in several places conformably associated with volcanic agglomerates which are semi-contemporaneous with them. Their exact age is somewhat uncertain because of the special characters of its fauna, but it must be somewhere in the Middle or Upper Carboniferous.

CHITRAL.

The Devonian rocks are followed conformably by Carboniferous strata in Chitral, comprising the Chitral slates and Sarikol shales. Amongst them are beds containing *Fusulina* and *Bellereophon.*

BURMA.

Northern Shan States.

The upper part of the Plateau Limestone is of Carboniferous to a Permian age, but as mentioned already, it has not been found possible to subdivide the formation in a satisfactory manner. The lower Plateau Limestone, which is dolomitic, passes up by perfect gradation into the finely crystalline, grey or blue-grey, calcitic Upper Plateau Limestone. This formation occurs in a number of hills and ridges and contains *Fusulina elongata* and some usually ill-preserved corals and brachiopods in places. Amongst the fossils which have been identified are :

Foraminifera .	*Fusulina elongata*
Anthozoa ..	*Lonsdaleia indica*, *Syringopora* sp., *Zaphrentis*, sp.
Bryozoa .	*Fenestella* cf. *perelegans*, *Hexagonella ramosa*, *Polypora*, cf. *ornata*
Trilobite .	*Phillipsia*, sp.
Brachiopods .	*Spirifer striatus*, *S. fasciger*, *Martinia dispar*, *Reticularia*, *lineata*, *Spiriferina cristata*, *Spirigera roysii*, *Spirigerella*, *derbyi*, *Schizophoria indica*, *Oldhamina* sp , *Productus cora*, *P. cylindricus*, *P. gratiosus*, *Chonetes grandicosta*, *Dielasma biplex*, *Camarophoria* sp., *Notothyris simplex*, *Marginifera* sp.
Cephalopoda .	*Xenaspis carbonaria.*
Lamellibranchs.	*Pseudomonotis*, *Pecten*, *Schizodus.*
Gastropods ..	*Pleurotomaria*, *Murchisonia*, *Holopella*, *Neritopsis.*

The fauna is Permo-Carboniferous and shows some relationship to the Lower and Middle Productus Limestone of the Salt Range. It is interesting to note that the barrier which existed between the Himalayan and Shan areas in the earlier Palæozoic had broken down during the Upper Palæozoic so that there could be intermigration of faunas.

Southern Shan States.

The Upper Plateau Limestone is found also in the Southern Shan States near Taunggyi where it has the same characters as in the north. A fossiliferous locality on the Taunggyi-Loilem road yielded abundant bryozoa but only a few brachiopods. The fauna found includes *Fusulina*, corals, *Productus* and *Lyttonia* which indicate Carboniferous to Permian age.

TENASSERIM.

The Moulmein limestone beds with associated sands and clays are about 600 ft. thick and are found overlying the Mergui series near Moulmein. They are exposed in the Thampra hill and the islands to its south, and also in the islands of the Mergui Archipelago. They have yielded fossils from north-west of Tharabwin which indicate an Upper Carboniferous age.

Foraminifera	*Schwagerina oldhami.*
Anthozoa .	*Lonsdaleia salinaria, Lithostrotion* sp
Brachiopods .	*Spirifer* sp. *Productus sumatrensis, Ahtyris* sp
Gastropods .	*Bellerophon* sp., *Murchisonia* sp.

UNFOSSILIFEROUS PALAEOZOIC STRATA.

KASHMIR-HAZARA.

Tanawal Series.—A formation of considerable thickness, composed of phyllites, quartzites, quartz-schists and conglomerates, occurs in a number of places in western Kashmir and Hazara. The rocks are more or less metamorphosed and folded up with the Dobra Slate series. The quartzites, however, appear to be silicified Infra-Trias limestones or perhaps the equivalents of the Muth Quartzites. They are entirely unfossiliferous. In the Pir Panjal, members of this series have been observed to pass laterally *into the Agglomeratic Slates. Hence, though their age* is not known with certainty, they may represent a part of the gap between the Cambrian and Upper Carboniferous. The Tanawal series is overlain by the Tanakki conglomerate which is now regarded as the equivalent of the Talchir boulder bed and the Blaini boulder bed.

SIMLA-GARHWAL.

Jaunsar series.—*In the Simla-Garhwal region the* Palæozoic is probably represented by the Jaunsar series, which is an unfossiliferous assemblage of slates, sandstones and quartzites, resting on the Simla Slate series. The Jaunsars of Garhwal are divided as below:

Jaunsar Series	NAGTHAT—Purple and green phyllites quartzites, sandstones and conglomerates.
	CHANDPUR—Phyllites, schists, banded quartzites, tuffs and lavas.
	MANDHALI—Limestones, slates, phyllites, grits and boulder bed.

The Nagthats bear much resemblance to the Tanawals of Hazara, and the Chandpurs to part of the Dalings. Further east in Garhwal, the Chandpurs rest on the Barahat series, consisting of quartzites, limestones and some lavas, which may be the equivalents of the Nagthats, since the line of separation is a thrust fault.

The Jaunsars have been affected in some places by tectonic disturbances of pre-Krol (*i.e.*, pre-Permian) age, as a result of which they have acquired the Aravalli strike direction. It is apparent that the rocks of Rajputana and of Garhwal have been affected by the same post-Vindyan tectonic movement.

TABLE 17.—ROUGH CORRELATION OF PALAEOZOIC STRATA.

	Peninsula.	Salt Range.	Hazara.	Simla-Garhwal	Tennasserim	Kashmir	Spiti.	Burma
Permian	Talchir boulder bed.	Boulder bed.	Tanakki conglomerate	Blaini Boulder bed.	Moulmein limestone	Zewan beds (Panjal trap)	Productus shales	
Upper Carboniferous						Agglomeratic Slate.	Conglomerate.	Upper Plateau Limestone.
Lower Carboniferous	Stratigraphical break	Stratigraphical break	?	?	?	Fenestella shales. Syringothyris Limestone.	Po series. Lipak series	
Devonian			Tanawal Series ?	Jaunsar Series ?	Mergui Series ?	Muth Quartzite.	Muth Quartzite	Lower Plateau Limestone with Wetwin shales and Padaukpin limestone.
Silurian						Muth Quartzite in part. Silurian	Muth Quartzite in part Silurian	Zebingyi beds. Namshim sandstones Graptolite beds

Ordovician						Ordovician?	Ordovician	Hwe-maung shales. Naungkangyi stage Mawson series, etc
Cambrian	Upper Vindhyan	Salt Pseudomorph shales Magnesian sandstone. Neobolus beds Purple sandstone. Salt marl.				Cambrian	Upper Haimanta	Bawdwin volcanics.
Pre-Cambrian	Lower Vindhyan and Kurnool Series		Dogra slates Attock shales	Simla slates	Mergui series ?	Dogra slates.	Middle and Lower Haimanta	Chaung Magyi series

It may be mentioned here that the Mergui series of Tenasserim in Burma may be of Palæozoic age and very roughly the equivalent of the Tanawal and Jaunsar series. Their position with reference to the gneisses and granites is also mainly towards the Peninsula, corresponding to the sub-Himalayan region of India.

It will be convenient at this stage to review the salient points in the Palæozoic (pre-Upper Carboniferous) stratigraphy of the Indian region. The Vindhyans of the Peninsula contain a few obscure fossils which may indicate a Cambrian age, but there are undoubted Cambrian fossils in the Salt Range in strata which bear some lithological resemblance to the Vindhyans. There are no strata between the Vindhyans and the Talchir boulder beds of Upper Carboniferous age.

The Sub-Himalayan region formed a basin in which unfossiliferous sediments were laid down: the Dogra-Attock slates and Tanawals of Hazara and Kashmir, the Simla Slates and Jaunsars of Simla-Garhwal and possibly parts of the Daling and Buxa series of Eastern Himalaya, though the last may be Dharwarian or Pre-Cambrian in age. To the same or related sedimentary basin probably belongs the Mergui series of Tenasserim which in tectonics, unfossiliferous nature and age resembles the sub-Himalayan rocks.

The third region, lying now beyond the Himalayan axis, contains fossiliferous sediments, which have been studied in Hazara, Chitral, Kashmir, Spiti, Garhwal-Kumaon and the Everest region and Sikkim. To this zone belongs the Shan States area. The seas of the Himalayan and Shan areas of deposition were however unconnected in pre-Carboniferous times since the fuanas of the two are distinct and show affinities only in Permo-Carboniferous times. The Himalayan Palæozoics have mainly American affinities while those of the Shan area have close relationship with western and north-western Europe. The stupendous compression and distortion which the Himalayan, Baluchistan and Burmese arcs have undergone prevent us from having any clear idea as to their geography in the Palæozoic times.

The Palæozoic stratigraphy of the different areas is shown in a tabular form in Table 17.

SELECTED BIBLIOGRAPHY.

Fox, C.S. Contribution to the geology of the Punjab Salt Range. *Rec. 61*, 147-179, 1928.

Gee, E.R Saline Series of N. W. India, *Curr. Sci. II*, 460-463, 1934

Griesbach, C.L. Geology of Central Himalayas. *Mem.* 23, 1891.

Hayden, H. H. Geology of Spiti. *Mem. 36* (1), 1904.

LaTouche, T. D. Geology of N. Shan States. *Mem. 39* (2), 1913.

Middlemiss, C S. Geology of Salt Range with a reconsidered theory of origin and age of the salt marl. *Rec. 24*, 19-41, 1891

Stuart, M. Potash salts of Salt Range and Kohat. *Rec. 50*, 28-56, 1919.

Stuart, M. Origin and history of the rock salt deposits of Punjab and Kohat. *Rec.* 50, 57-99, 1919.

West, W.D. Some recent advances in Indian Geology. (Salt Range). *Curr. Sci. III*, 412-416, 1934.

West, W. D. Saline Series in the Salt Range. First symposium *Proc. Nat. Acad. Sci. India, XIV* (6) 1944 ; Second symposium, *op. cit. XVI* (2-4), 1946.

Wynne, A.B. Geology of the Salt Range in the Punjab. *Mem. 14*, 1878.

Wynne, A.B. Trans-Indus extension of the Salt Range. *Mem. 17* (2), 1880.

FOSSILS.

Redlich, K. Cambrian fauna of the Salt Range. *Pal. Ind. N.S.* 1 (1) 1899.

Reed, F.R.C. Cambrian fossils of Spiti. *Pal. Ind Ser. XV, Vol. VII* (1), 1910.

Reed, F.R.C. Ordovician and Silurian fossils of the Central Himalayas. *Pal. Ind. Ser XV, Vol. VII* (2), 1912 ; *N.S. VI* (1), 1915.

Reed, F.R.C. Cambrian and Ordovician fossils from Kashmir. *Pal. Ind. N.S. XXI* (2), 1934.

Reed, F.R.C. Lower Palæozoic fossils of N. Shan States. *Pal. Ind. N. S. II* (3), 1906.
Reed, F.R.C. Ordovician and Silurian fossils of N. Shan States. *Pal. Ind. N.S. VI* (1), 1915.
Reed, F.R.C. Lower Palæozoic fauna of S. Shan States *Pal. Ind. N. S. XXI* (3), 1936.
Reed, F.R.C. Devonian faunas of N. Shan States. *Pal. Ind N.S. II* (5), 1906.
Reed, F.R.C. Devonian fossils from Chitral and the Pamirs. *Pal. Ind. N. S. VI* (2), 1922.

CHAPTER X.

THE GONDWANA SYSTEM.

INTRODUCTORY.

After the deposition of the Vindhyan rocks and their uplift into land, there was a great hiatus in the stratigraphical history of the Peninsula. At the end of the Palæozoic Era, *i.e.*, towards the Upper Carboniferous, a new series of changes took place over the surface of the globe, which brought about a redistribution of the land and sea and which was also responsible for the mountain-building movements called the *Hercynian*. At this time there existed a great Southern Continent or a series of land masses which were connected closely enough to permit of the free distribution of terrestrial fauna and flora. This southern continent included India, parts of the Malay Archipelago, Australia, South America, South Africa and Madagascar, which were probably at that time very close together. This southern continent, called Gondwana-land, shows evidence of the prevalence of the same climatic conditions and the same type of deposits. The sedimentary era initiated at this time began with a glacial climate for we find the deposits commencing with a glacial boulder-bed which has been recognised in all the above-mentioned lands. The bulk of the deposits which followed the glacial conditions was laid down as a thick series of fluviatile or lacustrine deposits with intercalated plant remains which now form coal seams. The basins of deposition must have been shallow and generally sinking, with frequent oscillations of level, for we find each cycle of deposition starting with coarse sandstones and proceeding through shales to coal seams. The plant remains embedded in these sediments have close affinities in all the lands mentioned, and comprise *Glossopteris*, *Gangamopteris*, *Neurop-*

teridium, etc. This floral assemblage, called the *Glossopteris flora*, is very characteristic of the deposits of the lower part of this system. The amphibian and reptilian fauna of this era are strikingly similar and point to unrestricted intermigration. For instance, according to Prof. Von Huene, there is an extraordinary resemblance between the Dinosurs of the Central Provinces in India and those of Madagascar, Brazil, Uruguay and Argentina. This southern Gondwana continent seems to have persisted through the greater part of the Mesozoic era and was broken up probably at the end of the Cretaceous, either by the sinking of certain connecting areas or by the drifting apart of the component parts. The close faunal and floral affinities of the Gondwana strata in India and Afiica, for instance, are reflected in their present day distribution and relationship.

NOMENCLATURE AND EXTENT.

The name *Gondwana* was introduced by H.B. Medlicott in 1872 in a manuscript report, but appeared for the first time in print in a paper by O. Feistmantel published in 1876 (*Rec. IX, Pt.* 2, *p.* 28). It is derived from the Gond kingdom of the Central Provinces where these formations were studied by Medlicott, but has also been extended to the large continent which existed in the uppermost Palæozoic and in Mesozoic times in the Southern Hemisphere.

The rocks forming this Gondwana system are of fluviatile or lacustrine nature and were deposited in a series of large river or lake basins which gradually sank along trough-faults amidst the ancient rocks. It is to this faulting that we owe the preservation of the Gondwana strata with their rich coal seams.

Distribution.—The Gondwana rocks are mainly developed along two sides of a great triangular area, the third side of which is formed by the northern part of the east coast of the Peninsula, *i..e.*, from the Godavari valley to the

Rajmahal hills. The northern side of this corresponds roughly to the Damodar, Son and Narbada valleys, trending nearly E.-W., while the south-western side runs along the Godavari valley with a N.W.-S.E. trend. In the interior of this triangle is a subsidiary belt along the Mahanadi valley. In these long and narrow tracts, the Gondwana rocks are found in a series of faulted troughs. Other groups of exposures are found along the Himalayan foot-hills of Nepal, Bhutan and Assam, and also in Kashmir and Afghanistan. Further, Gondwana rocks are seen in a series of detached outcrops along the east coast of India, between Cuttack and Cape Comorin, in the Rajmahal hills, Central Provinces, Rewa, Kathiwar, Cutch, Punjab Salt Range and Sheikh Budin hills, and also in Ceylon.

Two-fold division of the Gondwanas.—The Gondwana system is divided into two major divisions based mainly on palæontological evidence. This two-fold classification is the one adopted by the Geological Survey of India and has been strongly supported by C.S. Fox in his recent monographs on the coalfields of India. The line of division is taken as above the Panchet series, the lower portion being characterised by the Glossopteris flora and the upper by the Ptilophyllum (Rajmahal) flora.

A tripartite classification was suggested by Feismantel and followed by E. Vredenburg in his Summary of the Geology of India (1910, p. 50), where Lower, Middle and Upper Gondwanas are shown as equivalent to the Permian, Triassic and Jurassic systems of Europe. A factor, apparently in support of this, is the intervention of arid continental deposits containing Triassic reptiles and amphibians in the middle portion of the Gondwanas, the beds above and below this group indicating humid and normal conditions. Moreover, the base of the Panchet series corresponds to the base of the Trias. Though these factors make the tripartite division plausible, the evidence of the flora is entirely in favour of a two-fold division. Though the details of the stratigraphy of the different

Gondwana areas in India differ to some extent, it is clear that the Glossopteris flora practically dies out in the Panchets and is replaced completely by a more advanced one known as the Ptilophyllum or Rajmahal flora.

Sub-divisions of the Gondwanas.—The Lower as well as the Upper Gondwanas consist of three series each. In the ascending order they are the Talchir, Damuda (Damodar) and Panchet series in the lower division, and the Mahadeva, Rajmahal and Jabalpur (Jubbulpore) series in the upper division. Each series consists of stages which have received different names in the different areas where they are developed. Table 18 shows at a glance the correlation of these stages and their position in the standard stratigraphical scale.

TALCHIR SERIES.

The lowest series of this system is named after the coalfield and the State of Talcher (Talchir) in Orissa, where it was first studied. Its lowest member is a boulder-bed, which is succeeded by shales and sandstones. The boulder-bed forms a conspicuous and characteristic datum line in the geology of the Peninsula, and is in general 50 to 100 feet thick. Its equivalents are found in the Salt Range, Kashmir-Hazara (Tanakki boulder-bed), Garhwal (Mandhali beds) and in Simla (Blaini boulder-bed). The boulder-bed consists of an unsorted mixture of boulders, pebbles, fragments and clay, the boulders often showing facets and striæ of glacial origin. In most of the peninsular occurrences there is evidence, according to C.S. Fox, of this bed being to some extent a re-sorted glacial deposit, whereas in the Salt Range the ice sheets seem to have deposited the moraine materials directly in a shallow sea. The Salt Range occurrence contains boulders and pebbles of granite, Malani rhyolite, etc., which have apparently been derived from the region of the Kirana hills about 50 miles to the south and also from some parts of Rajputana. The other boulder-beds have not been studied in detail so that the sources of the constituent materials are not definitely known.

Shales and Sandstones.—The Talchir boulder-bed is overlain by shales and these in turn by sandstones, the total thickness of these being 500 to 800 feet. The shales are greenish in colour and usually break up into thin pencil-like or prismatic fragments, for which reason they are often called " neddle-shales.' The shales are arenaceous, micaceous or calcareous, and sometimes grade into sandstones which are also generally greenish or greenish brown in colour. The sandstones generally contain grains of undecomposed felspar which also furnish evidence of very cold conditions of deposition. The shales and sandstones may be intercalated with each other but the latter are more common in the upper part, indicating a general coarsening of the sediments as deposition went on. In the upper part of the Talchirs, however, the glacial conditions seem to have given place to milder climate as evidenced by the presence of fossil plants.

Distribution.—The Talchir beds are found in most of the Lower Gondwana areas of the Peninsula in the faulted troughs, and also sometimes as outliers on the gneisses of the neighbouring regions. It is thought that the deposition of a series of moraines in the early Talchir age was responsible for the formation a series of more or less connected lakes which received the sediments of the succeeding (Damuda) age.

Talchir fossils.—The plant fossils of the Talchirs occur only in the upper part and show an assemblage which is fairly distinct from that of the Damuda (Damodar) stage, but closely allied to that of the immediately succeeding Karharbari beds which are well represented in the Giridih coalfield. The important localities of Talchir fossils are Karaon (Deoghur Coalfield), Rikba (Karanpura), Latihar (Auranga), Nawadih (Hutar), Behia-Baragaon

TABLE 18 CORRELATION

[NOTE - The Lower and Upper Gondwanas

Standard scale		Gondwana divisions		Damodar valley	Rajmahal	Son-Mahanadi valleys	Satpura.
Cretaceous	Lower	Jabalpur	Umia				
Jurassic	Upper	Jabalpur	Jabalpur			Bansa beds	Jabalpur
Jurassic	Middle	Rajmahal	Kota				Chaugan
Jurassic	Lower	Rajmahal	Rajmahal	Rajmahal	Rajmahal, with traps	Athgarh sst	
Triassic	Rhætic	Mahadeva	Maleri		Dubrajpur	Tiki	Bagra Denwa
Triassic	Keuper	Mahadeva	Pachmarhi	Supra-Panchet Durgapur?			Pachmarhi (Mahadeva)
Triassic	Muschelkalk					Chicharia Parsora *	
Triassic	Bunter	Panchet	Panchet	Panchet			Almod
Permian	Upper	Damuda	Raniganj	Raniganj		Himgir Pali	Bijori
Permian	Middle	Damuda	Barren measures	Barren measures (Ironstone sh.)			Motur
Permian	Lower	Damuda	Barakar Karharbari	Barakar Karharbari	Barakar	Barakar	Barakar
Carboniferous	Upper	Talchir	Rikba				
Carboniferous	Upper	Talchir	Talchir	Talchir	Talchir	Talchir	Talchir
Carboniferous	Upper	Talchir	Boulder-bed	Boulder-bed		Boulder-bed	Boulder-bed

* According to Prof. B. Sahni, Dr. Cotter's list of fossils contained a mixture

OF THE GONDWANA STRATA.

are separated by a wavy line.]

Godavari valley	East Coast: Godavari	East Coast: Guntur	East Coast: Madras	Cutch and Salt Range.	
				Umia	Neocomian Portlandian
Chikiala	Tirupati	Pavalur	Satyavedu	Katrol	Kimmeridgian Corallian
Kota	Raghavapuram	Vemavaram	Sriperumbudur	Chari	Oxfordian Callovian
				Patcham	Bathonian
	Golapilli	Budavada			Lias
Maleri					Rhaetic
				Crinoidal dolomite	Keuper
				Bivalve beds	Muschelkalk
Mangli	Chintalpudi Sandstones			Ceratite beds	Bunter
Kamthi				Chidru Jabbi Kundghat	Thuringian
				Kalabagh Virgal	Saxonian
Barakar				Katta Amb	Artinskian
Talchir				Eurydesma & Conularia beds	Sakmarian
Boulder-bed				Boulder-bed	Uralian

from two horizons. These fossils need a critical study.

18 miles north-east of Anukpur (Sohagpur), Goraia (south of Pali in Rewa) and Kuppa (Sonada).

At Rikba and other places the following fossils have been found :—

Pteridospermæ	*Glossopteris indica*, *G. communis*, *G.* sp., *Gangamopteris cyclopteroides* var. *major*, *C. cyclopteroides*, *G angustifolia*, *G. buriadica*, *Vetebraria indica* (which is now believed to be the rhizome of *Glossopteris*).
Cordaitales	*Noeggerathiopsis hislopi*
Incertæ .	*Samaropsis* sp. (seeds.)

In the Panjab Salt Range area the Talchir boulder-bed is represented by the boulder-bed above the Salt Pseudomorph zone. Within a few feet of the base of the boulder-bed Gondwana fossil plants and spores have been discovered. From near Kathwai, from the shales immediately overlying the boulder-bed, several types of spores and cuticles have been discovered. The following fossils were also obtained from the same locality, about 25 ft. above the boulder-bed.

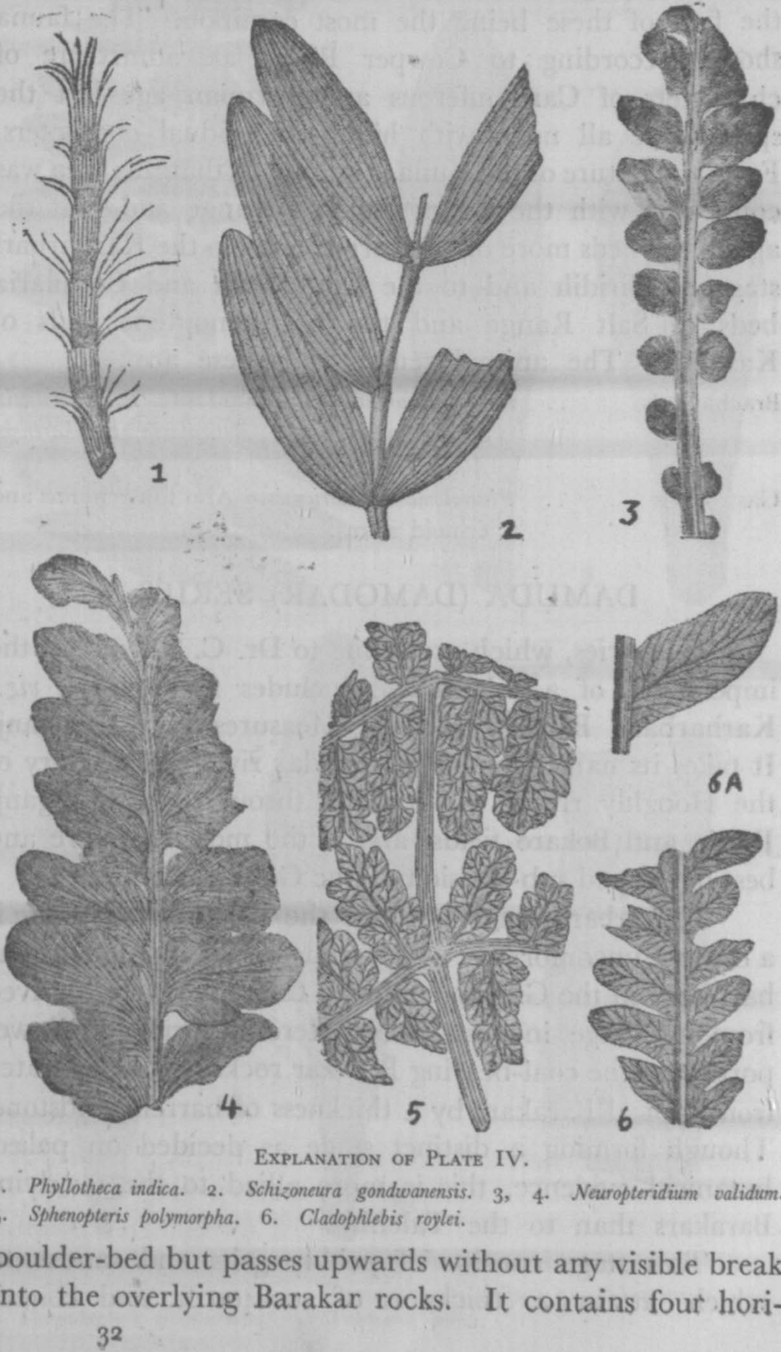
Equisetales ..	*Schizoneura* sp
Filicales? ..	*Alethopteris* sp
Pteridospermæ ..	*Glossopteris communis*, *G. indica*, *Gangamopteris buriadica*, *Vertebraria indica*, *Noeggerathiopsis* (*Cordaites*) sp.
Incertæ ..	*Ottokaria kathwaiensis*, *Samaropsis emarginata*, *Cordaicarpus sahnii*.

The Blaini boulder-bed of the Simla Hills, the Tanakki boulder-bed of Kashmir-Hazara and the Mandhali beds of Tehri-Garhwal are also considered to be their equivalents. The location of these may be taken as indicating the proximity of northern shore-line of Gondwanaland.

UMARIA MARINE BED.

An interesting discovery of recent years, by K. P. Sinor, is the occurrence of a highly fossiliferous marine band, about 10 ft. thick, in a railway cutting west of Umaria. This band unconformably overlies the Talchir

PLATE IV.
LOWER GONDWANA PLANTS I.



EXPLANATION OF PLATE IV.

1. *Phyllotheca indica.* 2. *Schizoneura gondwanensis.* 3, 4. *Neuropteridium validum.* 5. *Sphenopteris polymorpha.* 6. *Cladophlebis roylei.*

boulder-bed but passes upwards without any visible break into the overlying Barakar rocks. It contains four horizons packed with fossils, comprising only a few genera—*Productus*, *Spirifer*, *Reticularia* and a few small gastropods, the first of these being the most common. The fauna shows, according to Cowper Reed, an admixture of characters of Carboniferous and Permian age but the species are all new, with highly individual characters. From the nature of the fauna it is thought that this area was connected with the sea of the Salt Range and that the age of the beds more or less corresponds to the Karharbari stage of Giridih and to the Eurydesma and Conularia beds of Salt Range and the Gangamopteris beds of Kashmir. The animal remains in these are :—

Brachiopods	*Productus umariensis* (abundant), *P rewahensis*, *Spirifer narsarhensis*, *Reticularia barakarensis*, *Athyris* aff. *protea*
Gastropods ..	*Pleurotomaria umariensis*. Also fish remains and crinoid stems

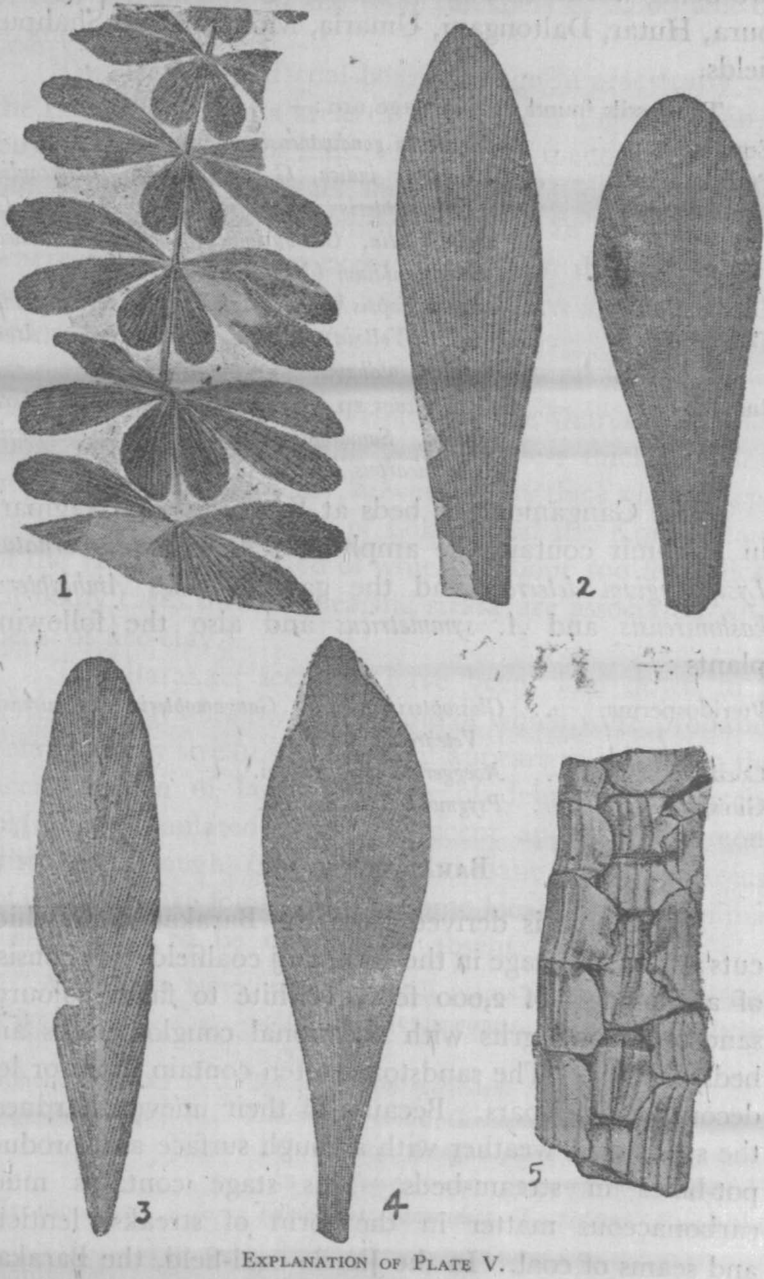
DAMUDA (DAMODAR) SERIES.

This series, which according to Dr. C. S. Fox has the importance of a sub-system, includes four stages, *viz.*, Karharbari, Barakar, Barren Measures and Raniganj. It takes its name from the Damodar river (a tributary of the Hooghly river) which flows through the Raniganj, Jharia and Bokaro fields, and is the most extensive and best developed sub-division of the Gondwana system.

Karharbari Stage.—Above the Talchir series there is a distinct unconformity which is succeeded by the Karharbari beds in the Giridih coalfield, the name being derived from a village in that area. Here it forms the lower portion of the coal-bearing Barakar rocks and is separated from typical Barakars by a thickness of barren sandstone. Though forming a distinct stage as decided on palæobotanical evidence, this is more allied to the overlying Barakars than to the Talchirs.

This stage consists of pebbly grits and sandstones which attain a thickness of 200-400 ft. and contain

PLATE V.
LOWER GONDWANA PLANTS II.



EXPLANATION OF PLATE V.

1. *Sphenophyllum speciosum.* 2. *Noeggerathiopsis hislopi.* 3. *Palaeovittaria kurzi.* 4. *Gangamopteris cyclopteroides.* 5. *Vetebraria indica.*

intercalated coal seams two of which are important and are being worked. It has been recognised in the Karanpura, Hutar, Daltonganj, Umaria, Mohpani and Shahpur fields.

The fossils found in this stage are .—

Equisetales	.	*Schizoneura gondwanensis, S wardi.*
Pteridospermæ		*Glossopteris indica, G. decipiens, G. longicaulis, Gangamopteris cyclopteriodes,* var. *major, G. angustifolia, G. buriadica, Vetebraria indica, Gondwanidium (Neuropteridium) validum.*
Cordaitales	..	*Noeggerathiopsis hislopi, N. stoliczkana, N. whittiana.*
Coniferales	..	*Buriadia (Voltzia) sewardi, Moranocladus (Araucarites) oldhami.*
Incertæ	.	*Callipteridium* sp , *Ottokaria bengalensis, Arberia indica, Samaropsis milleri, S. raniganjensis, Cordaicarpus indicus.*

The Gangamopteris beds at Khunmu and Nagmarg in Kashmir contain the amphibian *Archegosaurus ornatus*, *Lysipterygium deterrai*, and the ganoid fishes *Amblypterus kashmirensis* and *A. symmetricus* and also the following plants :—

Pteridospermæ	..	*Glossopteris indica, Gangamopteris kashmirensis, Vetebraria indica.*
Cordaitales	..	*Noeggerathiopsis hislopi.*
Ginkgoales ?	..	*Psygmophyllum haydeni.*

BARAKAR STAGE.

The name is derived from the Barakar river which cuts across this stage in the Raniganj coalfield. It consists of a thickness of 2,000 feet of white to fawn coloured sandstones and grits with occasional conglomerates and beds of shale. The sandstones often contain more or less decomposed felspars. Because of their uneven hardness, the sandstones weather with a rough surface and produce pot-holes in stream-beds. This stage contains much carbonaceous matter in the form of streaks, lenticles and seams of coal. In the Jharia coal-field, the Barakars include at least 24 seams of coal, each more than 4 feet in thickness, and it has been calculated that over 200 feet of coal are present in the total thickness of 2,000 feet of strata.

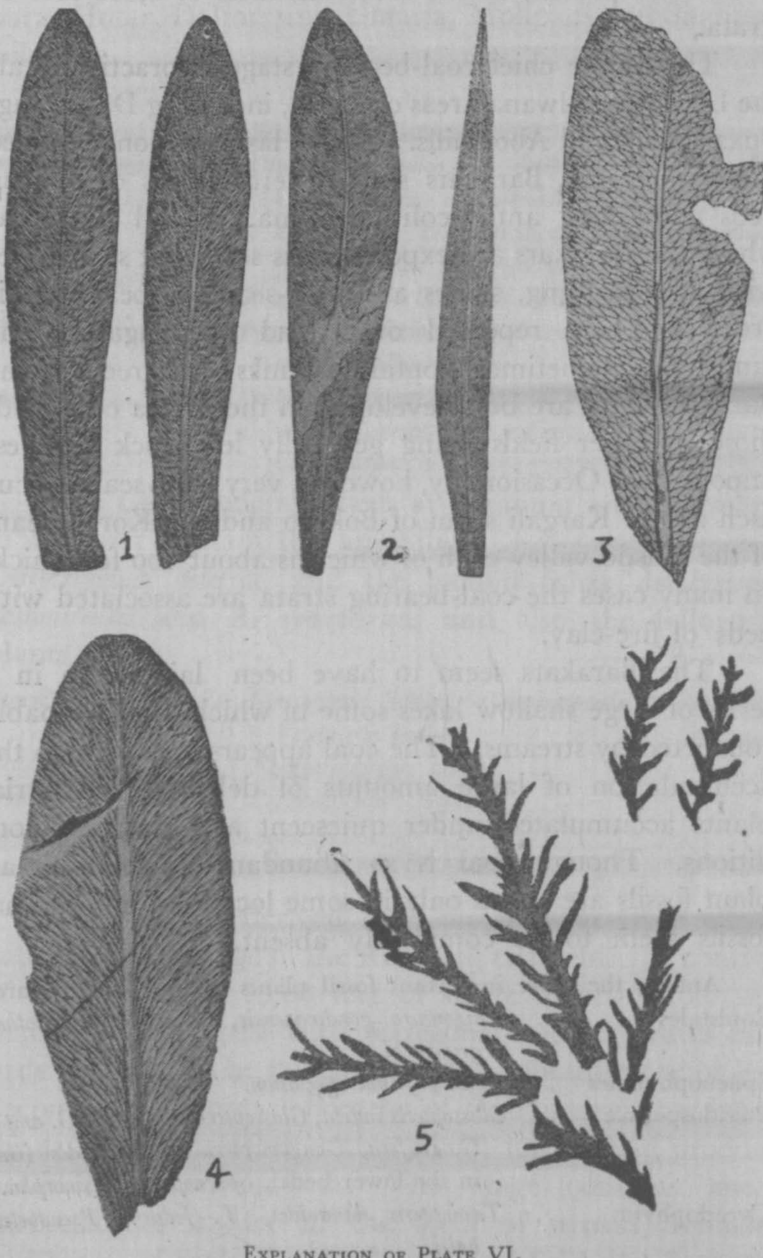
This is the chief coal-bearing stage in practically all the Lower Gondwana areas of India, including Darjeeling, Buxa Duars and Abor hills. In the last mentioned place the base of the Barakars show intercalations of marine beds containing anthracolithic fauna. In all the areas where the Barakars are exposed, it is seen that sandstones with false-bedding, shales and coal-seams appear in this order and are repeated over and over again. The sandstones sometimes contain trunks of trees. The Barakar seems are best developed in the Jharia coal-field, those in other fields being generally less thick and less important. Occasionally, however, very thick seams occur such as the Kargali seam of Bokaro and the Korba seam of the Hasdo valley each of which is about 100 feet thick. In many cases the coal-bearing strata are associated with beds of fire-clay.

The Barakars seem to have been laid down in a series of large shallow lakes some of which were probably connected by streams. The coal appears to be due to the accumulation of large amounts of debris of terrestrial plants accumulated under quiescent and stagnant conditions. Though coal is so abundant in some areas, plant fossils are found only in some localities, and animal fossils seem to be completely absent.

Among the more important fossil plants in the Barakars are :

Equistales		*Schizoneura gondwanensis, S. wardi, Phyllotheca griesbachi.*
Sphenophyllales	..	*Sphenophyllum speciosum.*
Pteridospermæ	..	*Glossopteris indica, Glossopteris communis, G. ampla, G retifera, Gangamopteris cyclopteroides* (only in the lower beds), *Sphenopteris polymorpha.*
Cycadophyta	..	*Tæniopteris danæoides, T feddeni, Pseudoctenis balli.*
Cordaitales	..	*Noggerathiopsis hislopi, N. whittiana, Dadoxylon indicum.*

PLATE VI.
LOWER GONDWANA PLANTS III.



EXPLANATION OF PLATE VI.

1. *Glossopteris decipiens.* 2. *Glossopteris indica* and *G. angustifolia.* 3. *Glossopteris retifera.* 4. *Glossopteris browniana.* 5. *Buriadia sewardi.*

Ginkgoales ? ..	*Rhipidopsis ginkgoides.*
Incertæ ..	*Barakaria dichotoma, Dictyopteridum sporiferum, Cordaicarpus* cf *cordai*

BARREN MEASURES (IRONSTONE SHALES).

The Barren Measures, which intervene between the Barakar and Raniganj stages in the Jharia coal-field, are about 2,000 feet thick and are entirely barren of coal-seams. They consist mostly of sandstones, which are somewhat less arenaceous than the Barakar type, and are represented in the Raniganj coal-field by the *Ironstone shales* whose thickness is about 1,400 feet. They consist generally of carbonaceous shales with clay-ironstone nodules which are sideritic at depth, but when oxidised at and near the surface become limonitic. These are in places rich enough to form workable iron ore, and formerly the nodules used to be collected at the surface or in shallow pits for use in the blast furnaces of the Bengal Iron Co. (since amalgamated with the Indian Iron & Steel Co.) situated at Kulti. The ironstone contains about 35-40 per cent. iron. The Barren Measures are seen in the Jharia-Karanpura field but when followed in the coal-fields further west, they merge more or less into the overlying Raniganj series which are also barren of coal seams in these western fields.

The fossil plants found in he Barren Measures are :

Lycopodiales	*Bothrodendron* sp.
Pteridospermæ	*Glossopteris indica, G ampla, Gangamopteris cyclopteroides*
Cordaitales	*Noeggerathiopsis hislopi*

Motur Stage.—In the Satpura area the Barren Measures seem to be represented by the Motur stage which is also devoid of coal. This consists of white sandstones with intercalated layers of red, yellow and carbonaceous shales as in the Pench valley. In the Tawa valley of the Betul district, the Moturs do not contain red clays but show brownish and greenish sandstones and buff to greenish buff clays which are often calcareous. In south Rewa the beds occurring between the Barakars and the Pali and Daigaon beds (Raniganj age) are apparently to be referred to the Barren Measures.

RANIGANJ STAGE.

This is typically developed in the Raniganj coal-field where it attains a thickness of over 3,000 feet. It is of about the same thickness in the Satpura area where it is known as the Bijori stage, but is thinner in the Jharia coal-field. In the type area it consists of sandstones, shales and coal-seams, the sandstones being definitely finer grained than those of the Barakar series. Valuable coal-seams occur in these only in the Raniganj coal-field. The coal is higher in volatiles and moisture than the Barakar coal, but there are certain seams, like the Dishergarh, Poniati and Sanctoria seams, which are excellent, long-flame, steam coals.

Fossil wood (*Dadoxylon*) has been found in the upper part of this stage both in the Raniganj and Jharia fields and in the Motur beds of the Pench and Tawa valleys.

Typical fossils of the Raniganj stage are —

Equisetales	..	*Schizoneura gondwanensis, Phyllotheca indica.*
Sphenophyllales	..	*Sphenophyllum speciosum.*
Filicales ?	..	*Alethopteris roylei.*
Pteridospermæ	..	*Glossopteris indica, G. communis, G. browniana, G. retifera, G. angustifolia, G. stricta, G. tortuosa, G. formosa, G. divergens, G. conspicua, Gangamopteris whittiana, Vertebraria indica, Sphenopteris hughesi, S polymorpha, Pecopteris phegopteroides.*
Cycadophyta	..	*Tæniopteris danæoides, T feddeni.*
Cordaitales	.	*Noeggerathiopsis hislopi.*
Ginkgoales ?	.	*Rhipidopsis densinervis.*
Coniferales	..	*Buriadia (Voltzia) sewardi.*
Incertæ	..	*Palaeovittaria kurzi, Belemnopteris wood-masoniana, Dictyopteridium sportiferum, [Actinopteris] bengalensis, Samaropsis raniganjensis.*

The Raniganj stage is represented by the Bijori stage in the Satpuras ; by the Kamthi beds of Nagpur and the Wardha valley in Chanda ; the Pali beds in South Rewah ; the Himgir beds in the Mahanadi and Brahmani valleys ; the Almod beds occurring just south of the Pachmarhi scarp ; and the Chintalpudi sandstones of the Godavari valley.

The Kamthi beds (named after Kamptee near Nagpur) comprise red argillaceous sandstones and conglomerates with interstratified shales. They extend down into the Wardha-Godavari valley where it is difficult to separate them from the lithologically similar Upper Gondwanas, and where this facies of rocks may include both Raniganj and Panchet stages. Their lithology has led to the confusion of correlating them with the Pachmarhi sandstones and the Supra-Panchets. The fossils found in the Kamthis are :—Equisetales : *Phyllotheca indica* ; Pteridospermæ : *Glossopteris indica, G. communis, G. browniana, G. stricta, G. ampla, Gangamopteris hughesi, Vertebraria indica ;* Cycadophyta : *Tæniopteris* cf. *macclellandi, T. danaeoides, T. feddeni* ; Cordaitales : *Næggerathiopsis hislopi.*

The Pali beds (named after Pali near Birsinghpur railway station on the Katni-Bilaspur line) consist of coarse felspathic sandstones associated with ferruginous and argillaceous bands, the latter yielding plant fossils of Raniganj age.

The Himgir beds of the Raigarh-Himgir coal-field are composed of red sandstones and shales of Kamthi facies which overlie the Barakars unconformably. They contain a Raniganj flora which includes :—Equisetales : *Schizoneura gondwanensis* ; Pteridospermæ : *Glossopteris indica, G. browniana, G. angustifolia, G. communis, Vertebraria indica, Pecopteris lindleyana,* and *Sphenopteris polymorpha.*

The Bijori beds in the Chhindwara district, which comprise sandstones, micaceous flags and shales which are sometimes carbonaceous, have been found to contain remains of the labyrinthodont *Gondwanosaurus bijoriensis* and the following plant fossils :—Equisetales : *Schizoneura gondwanensis* ; Sphenophyllales : *Sphenophyllum speciosum* ; Pteridospermæ : *Glossopteris communis*, *G. damudica*, *G. angustifolia*, *G. retifera*, *Gangamopteris sp.*, *Vertebraria indica* ; Incertæ : *Samaropsis* cf. *parvula*.

The Almod beds were originally referred to the Panchet by H. B. Medlicott, but are classified with the Bijoris by H. Crookshank.

THE PANCHET SERIES.

The Panchet series succeeds the Raniganj stage with a slight unconformity and sometimes overlaps on to the Barakars. The rocks of this series, which have a total thickness of 1,500 to 2,000 feet, rest upon the Raniganj stage of the Raniganj coal-field and constitute the Panchet hill which is a prominent landmark. They comprise greenish, buff and brownish sandstones and shales in the lower part, and greyish, micaceous and felspathic sandstones and shales in the upper part. The sandstones are often false-bedded and contain no coal-seams or carbonaceous matter. They are not known in the Jharia coal-field, but their equivalents are found in Bokaro and Auranga. The Almod beds in the Pachmarhi area may probably be of Panchet age in large part. The Mangli beds of the Wardha valley, composed of fine red and yellow sandstones and grits which are sometimes used as ornamental building stones and are more or less similar in appearance to the beds of Kamthi, are also referable to the Panchets on fossil evidence, since they contain *Brachyops laticeps* (a labyrinthodont) and *Estheria*. The lower part of the Panchet beds is found near Maitur, northwest of Asansol, where plant fossils (*Glossopteris*, *Schizoneura*, etc.) are found, with close Damodar affinities, and also *Pecopteris concinna* and *Cyclopteris pachyrachis*. A slightly higher horizon near Deoli, called the *Deoli beds* (also in the

Raniganj field on the Damodar river) has yielded the following fossils :—

Labyrinthodonts	..	*Gonioglyptus longirostris, G. huxleyi, Glyptognathus fragilis, Pachygonia incurvata, Pachygnathus orientale.*
Reptiles	..	*Dicynodon orientalis, Epicampodon indicus.*
Crustacea	..	*Estheria mangliensis.*

The Parsora Stage.—This stage is named after the deserted village of Parsora north of Pali in South Rewa. These beds consist of medium grained sandstone with micaceous and ferruginous bands. They overlie the Pali beds (of Raniganj age) with the intervention of several hundred feet of unfossiliferous strata. Some of the ferruginous bands contain fossil plants which have a distinctly younger aspect than the Damuda flora. *Glossopteris* appears to be absent but *Noeggerathiopsis* (*Cordaites*) *hislopi* and a few other forms persist. *Danaeopsis* (*Thinnfeldia*) *hughesi* and *Thinnfeldia odontopteroides* are abundant, which indicate a Triassic aspect. The beds of Chicharia (this village being 6 or 7 miles north of Parsora), which may be either of the same horizon or somewhat younger, contain *Thinnfeldia sahnii* which is referred to the Lower Triassic by Seward (*Rec.* 66, *pp.* 235-243). The age of the Parsora and Chicharia beds is still a moot question, but it may be said that it is somewhere between the Raniganj and Maleri stages.

MAHADEVA SERIES.

PACHMARHI STAGE.

This series is named after the Mahadeva hills on which is situated the celebrated Mahadeva temple near Pachmarhi, which latter place has given the name to the stage which forms its lower part. The upper portion includes both the Denwa and Bagra stages.

The Pachmarhi stage forms the magnificent scarp above which the town of Pachmarhi is situated, and attains a thickness of about 2,500 feet. It is of the nature of a huge lenticular mass of sandstone between the Denwa and Bijori beds, and consists of red and buff sandstones with some red clays near the base and top. There are layers of hæmatitic clay and platy veins of hard dense ferruginous matter which, on weathering, resemble broken pieces of pottery. The Pachmarhi and other stages of the Mahadevas are entirely devoid of carbonaceous matter, though the clayey layers sometimes show leaf impressions. The sandstones are generally somewhat coarse grained and tinted in various shades of red because of the disseminated ferric iron. Some of the Pachmarhi sandstones are of good quality for building and have been used at Pachmarhi, Warora and other places.

In the Damodar valley the Mahadeva series is known by the vague term *Supra-Panchet* which may also include the *Durgapur beds* of the Raniganj field. In the Rajmahal hills it is represented by the *Dubrajpur sandstone.*

MALERI (MARWELI) STAGE.

This stage, named after the village of Marweli near the Tandur coal-field in Asifabad district of Hyderabad State, consists of red clays and subordinate sandstones which are often calcareous. Here it rests on the Kamthis and is followed by the Kota beds seen near Sironcha. Reptilian and fish remains and coprolites have been got from the red clay beds.

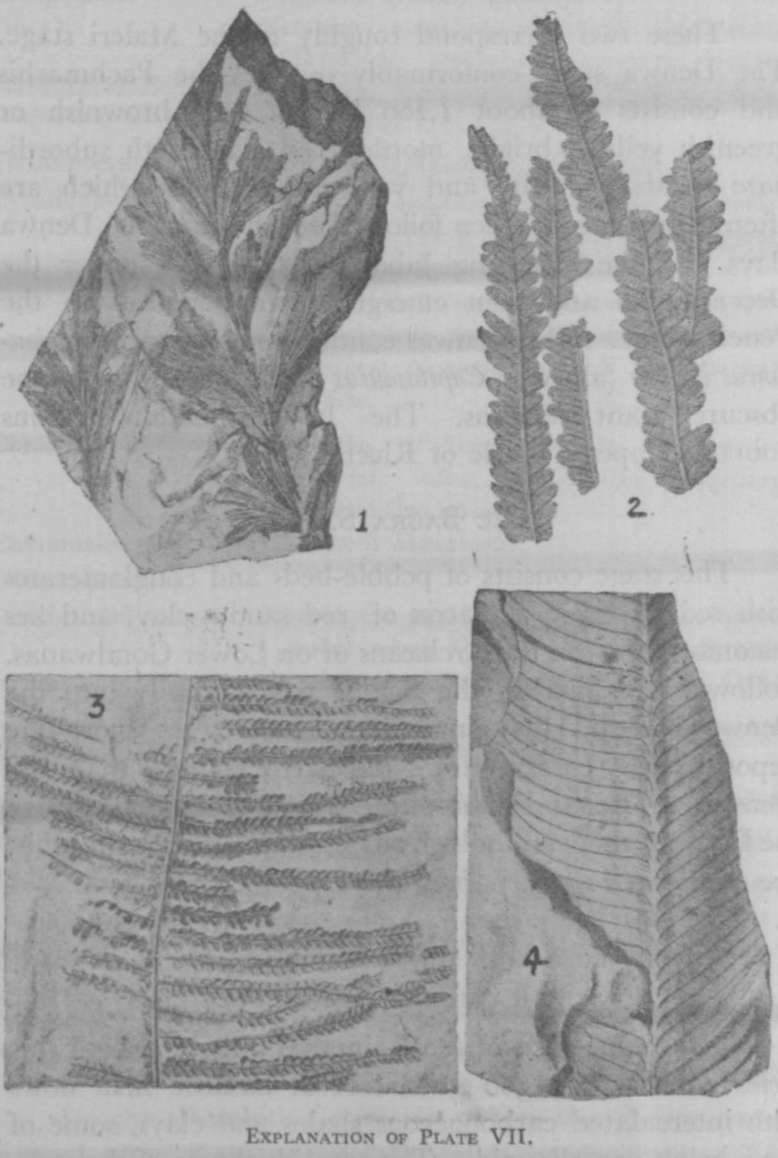
The same stage (called *Tiki beds*) is developed in South Rewa at and around Tiki near Beohari where also it has the same lithological characters as at Marweli. The vertebrate fossils found here include :—

Labyrinthodonts .	*Metoposaurids.*
Reptiles ..	*Hyperodapedon (Paradapedon) huxleyi, ? Paradapedon indicus, Belodon, Parasuchus.*
Saurischia ..	*Coelurosauria, Sauropodomorpha* cf. *massospondylus.*

Thecodont	..	*Brachysuchus maleriensis.*
Fishes	..	*Ceratodus hunterianus, C. hislopianus, C. virapa.*

PLATE VII.

UPPER GONDWANA PLANTS I.



EXPLANATION OF PLATE VII.

1. *Sphenopteris? hislopi.* 2. *Marattiopsis macrocarpa.* 3. *Gleichenites gleichenoides.* 4. *Ptilophyllum acutifolium.*

The reptilian fossils indicate an Upper Triassic age for these beds. There are also some fresh-water unionids and large trunks of fossil wood.

DENWA AND BAGRA STAGES.

These two correspond roughly to the Maleri stage. The Denwa stage conformably overlies the Pachmarhis and consists of about 1,200 feet of pale brownish or greenish yellow, bright, mottled red clays with subordinate bands of white and yellow sandstones which are often calcareous. When followed southwards, the Denwa clays and the overlying Jabalpur stage pass under the Deccan trap and then emerge as thinner beds in the Pench valley. The Denwas contain remains of *Mastodonsaurus indicus* (allied to *Capitosaurus* and *Metopias*) and some obscure plant remains. The labyrinthodont remains point to Upper Triassic or Rhætic age.

THE BAGRA STAGE.

This stage consists of pebble-beds and conglomerates with red jasper in a matrix of red sandy clay, and lies unconformably on the Archæans or on Lower Gondwanas. Followed southwards, the Bagras pass laterally into the Denwas so that they may be considered as shore-line deposits partly equivalent to, and partly younger than, the Denwas. The sandstones of the Tamia scarp lying above the Denwas, though lithologically similar to the Pachmarhis, are considered to be part of the Upper Denwa beds.

RAJMAHAL SERIES.

RAJMAHAL STAGE.

In the type area of the Rajmahal hills in Bengal this series consists of 1,500-2,000 feet of basaltic lava flows with intercalated carbonaceous shales and clays, some of these being porcellanoid. The total thickness of the sedimentary beds is only 100 feet. The inter-trappean sediments in the lower four or five flows contain plant remains, fossil wood and unionids. The more important plant fossils are :—

Equisetales	..	*Equisetites rajmahalensis.*
Lycopodiales	..	*Lycopodites gracilis, Lycoxylon* sp.
Filicales	..	*Marattiopsis macrocarpa, Gleichenites gleichenoides, Cladophlebis denticulata, Coniopteris hymenophylloides, Sphenopteris hislopi, Pecopteris lobata, Protocyathea rajmahalense.*
Pteridospermæ ?	..	*Danæopsis rajmahalensis, Thinnfeldia,* sp.
Cycadophyta	..	*Ptilophyllum acutifolium, P. cutchense, Otozamites bengalensis, Dictyozamites falcatus, D. indicus, Taeniopteris lata, T. spatulata, T. musæfolia, T. morrisii, T. ovata, T. crassinervis, Nilssonia (Pterophyllum) princeps, N. rajmahalensis, N. morrisiana, N. medlicottiana, N. bindrabunensis, N fissa*
Coniferales	..	*Elatocladus (Palissya) conferta, Retinosporites (Palissya) indica, Pagiophyllum peregrinum, Brachyphyllum expansum.*
Caytoniales	..	*Sagenopteris bhambhanii.*
Gymnospermous stems and cones	..	*Nipanioxylon guptai, Pentoxylon sahnii, Nipaniostrobus sahnii, Ontheodendron florini, Masculostrobus rajmahalensis, Sakristrobus sahnii, Carnoconites* sp.
Incertæ	..	*Rajmahalia paradoxa, Podozamites lanceolatus.*

The Rajmahals were regarded as Liassic by Feistmantel but Halle thinks they are middle Jurassic, while Du Toit suggests that the base of the series may extend down into the Rhætic. Prof. Sahni is of the opinion that none of the Rajmahal plants indicate a younger age than Upper Jurassic.

KOTA STAGE.

In the Pranhita-Godavari valley the Kota stage, named after Kota which is 5 miles north of Sironcha, which is about 2,000 feet thick, occurs above the Maleri beds probably with an unconformity. The constituent strata are mostly sandstones and grits of light to brown colour, with red clay bands and a few limestone beds. They sometimes contain carbonaceous clays and thin coal-seams.

Plant fossils have been found near Gangapur and Anaram :—

Cycadophyta	*Ptilophyllum acutifolium, Tæniopteris spatulata.*
Coniferales .	*Elatocladus (Palissya) jabalpurensis, E. conferta, E (Taxites) tenerrima, Retinosporites indica, Araucarites cutchensis.*

The Crustacean *Estheria* and also ganoid fish remains are found in a limestone exposure near Kota :—

Lepidotus deccanensis, L. breviceps, L. longiceps, Tetragonolepis oldhami, Dapedeus egertoni.

CHIKIALA STAGE.

This is named after a village some 10 miles north of Kota and consists of brown and buff sandstone, generally ferruginous, and some conglomerates, the thickness being 500 feet. It does not contain shale beds and the basal conglomerate seems to indicate an unconformity, though the junction between Kota and Chikiala is always covered by alluvium. Some unimportant coal beds are occasionally present in the Chikiala sandstones.

JABALPUR (JUBBULPORE) SERIES.

This series is divided into two stages, the lower called *Chaugan stage* and the upper *Jabalpur stage.* They consist of white and light coloured clays and massive soft sandstones. Some of the shales are carbonaceous, and such of the coal seams as occur (for example in the Hard and Morand rivers in the Satpura region) are not of economic importance. Plant fossils occur in both the stages, the Chaugan stage fossils resembling those of Kota. The two stages contain the following fossils ;—

Fossils of the Chaugan stage :—

Pteridospermæ ? ..	*Thinnfeldia* sp.
Cycadophyta ..	*Dictyozamites indicus*, *Tæniopteris spatulata*, *T. crassinervis*, *Anomozamites* cf. *nilssonia*, *Nilssonia prinseps*, *N. orientalis*, *N. rajmahalensis*.
Coniferales .	*Pagiophyllum divaricatum*.

Fossils of the Jabalpur stage :—

Filicales ..	*Gleichenites gleichenoides*, *Cladophlebis medlicottiana*, *Eboracea lobifolia*.
Cycadophyta ..	*Ptilophyllum acutifolium*, *Otozamites hislopi*, *Williamsonia indica*.
Coniferales ..	*Elatocladus jabalpurensis*, *E. plana*, *Brachyphyllum expansum*, *Pagiophyllum* cf. *peregrinum*, *Retinosporites indica*, *Araucrites cutchensis*, *A macropterus*, *A. latifolius*.
Ginkgoales ? ..	*Ginkgoites lobata*, *Phoenicopsis* sp.
Incertæ ..	*Podozamites lanceolatus*.

THE COASTAL DEVELOPMENT OF THE GONDWANAS.

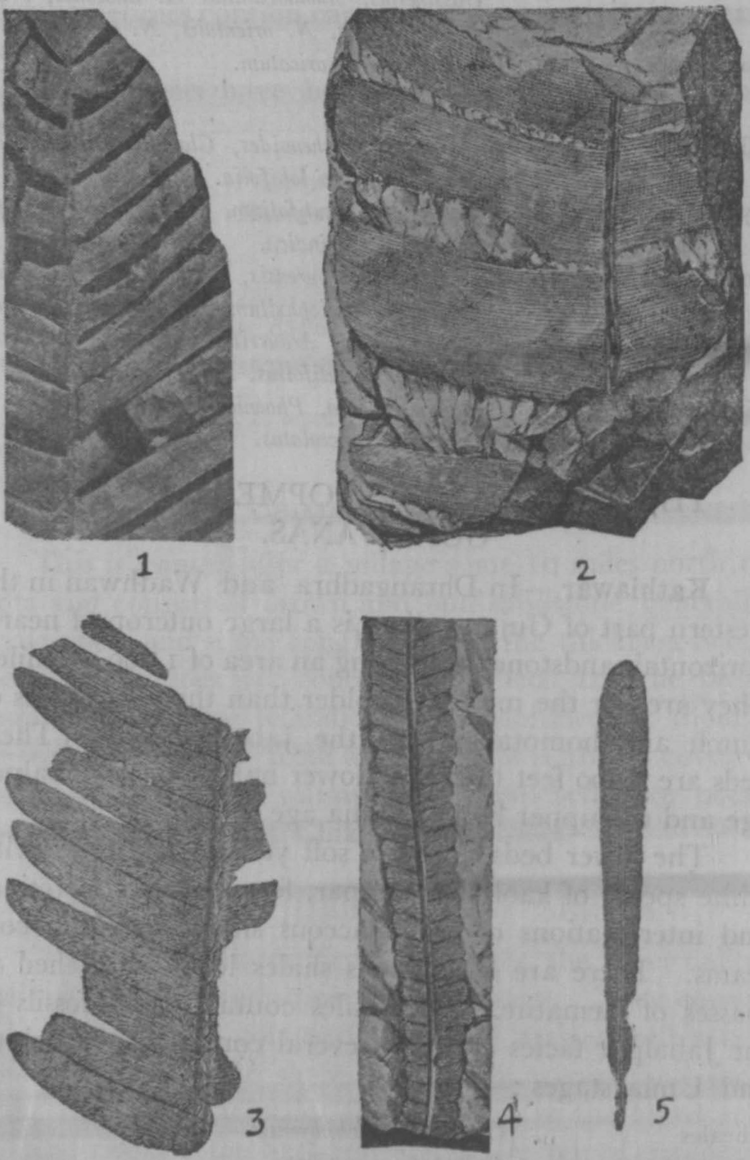
Kathiawar.—In Dhrangadhra and Wadhwan in the western part of Gujarat there is a large outcrop of nearly horizontal sandstones occupying an area of 1,000 sq. miles. They are, for the most part, older than the Umia beds of Cutch and homotaxial with the Jabalpur beds. These beds are 1,000 feet thick, the lower half being of Jabalpur age and the upper half of Umia age.

The lower beds comprise soft yellow sandstones with white specks of kaolinised felspar, ferruginous concretions and intercalations of carbonaceous shales and thin coal seams. There are ferruginous shales locally enriched to masses of hæmatite. The shales contain plant fossils of the Jabalpur facies and also several common to Jabalpur and Umia stages :—

Filicales .	*Cladophlebis whitbyensis*.
Cycadophyta ..	*Ptilophyllum cutchense*.
Coniferales ..	*Elatocladus jabalpurensis*, *E. tenerrima*, *Araucarites cutchensis*.
Incertæ ..	*Podozamites lanceolatus*.

PLATE VIII.

UPPER GONDWANA PLANTS II.

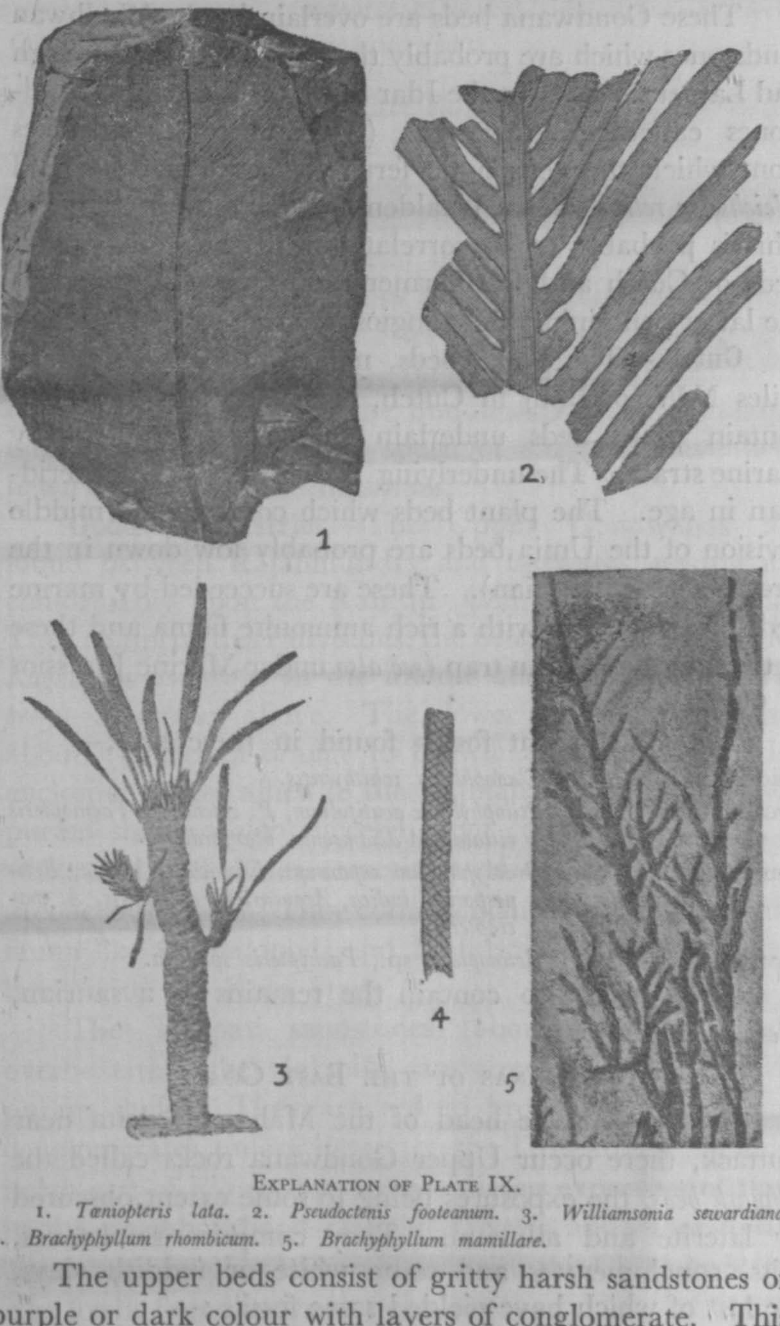


EXPLANATION OF PLATE VIII.

1. *Nilssonia morrisiana.* 2. *Nilssonia princeps.* 3. *Dictyozamites falcata.* 4. *Otozamites bengalensis.* 5. *Taeniopteris spatulata.*

PLATE IX.

UPPER GONDWANA PLANTS III.



EXPLANATION OF PLATE IX.

1. *Tæniopteris lata.* 2. *Pseudoctenis footeanum.* 3. *Williamsonia sewardiana.* 4. *Brachyphyllum rhombicum.* 5. *Brachyphyllum mamillare.*

The upper beds consist of gritty harsh sandstones of purple or dark colour with layers of conglomerate. This upper division is probably equivalent to the Umia beds of Cutch and the Tirupati sandstones.

These Gondwana beds are overlain by the Wadhwan sandstones which are probably the equivalents of the Bagh and Lameta beds. In the Idar State there are some sandstones called Himmatnagar (Ahmednagar) sandstones from which the xerophytic ferns—*Matonidium indica* and *Weichselia reticulata*—of Wealden age, have been obtained. This is probably to be correlated with the Umia plant beds of Cutch and the Barmer sandstone of Rajputana, the latter containing some angiosperms.

Cutch.—The Umia beds, named after a village 50 miles N.W. of Bhuj in Cutch, are 3,000 feet thick and contain plant beds underlain as well as overlain by marine strata. The underlying Katrol stage is Kimmeridgian in age. The plant beds which come in the middle division of the Umia beds are probably low down in the Cretaceous (Barremian). These are succeeded by marine beds of Aptian age with a rich ammonite fauna and these in turn by the Deccan trap (*see also* under Marine Jurassics of Cutch).

The Chief plant fossils found in these are :—

Filicales	.. *Cladophlebis whitbyensis.*
Cycadophyta	.. *Ptilophyllum acutifolium, P. cutchense, Taeniopteris vittata, Williamsonia blanfordi.*
Coniferales	.. *Brachyphyllum expansum, Elatocladus plana, Retinosporites indica, Araucarites cutchensis, A. macropterus.*
Incertæ	.. *Actinopteris* sp., *Pachypteris specifica.*

These beds also contain the remains of a saurian, *Plesiosaurus indica.*

GONDWANAS OF THE EAST COAST.

Orissa.—At the head of the Mahanadi delta near Cuttack, there occur Upper Gondwana rocks called the *Athgarh beds*, the exposures being to some extent obscured by laterite and alluvium. They comprise sandstones, grits, conglomerates and some white or reddish clays, the last of which have yielded some fossils ;—

Filicales	..	*Marattiopsis macrocarpa, Gleichenites gleichenoides, Cladophlebis indica, C. whitbyensis, Rhizomopteris balli* (probably the rhizome of a fern).
Coniferales	..	*Retinosporites indica.*

The first four of these are Rajmahal species and therefore these beds are referred to that age.

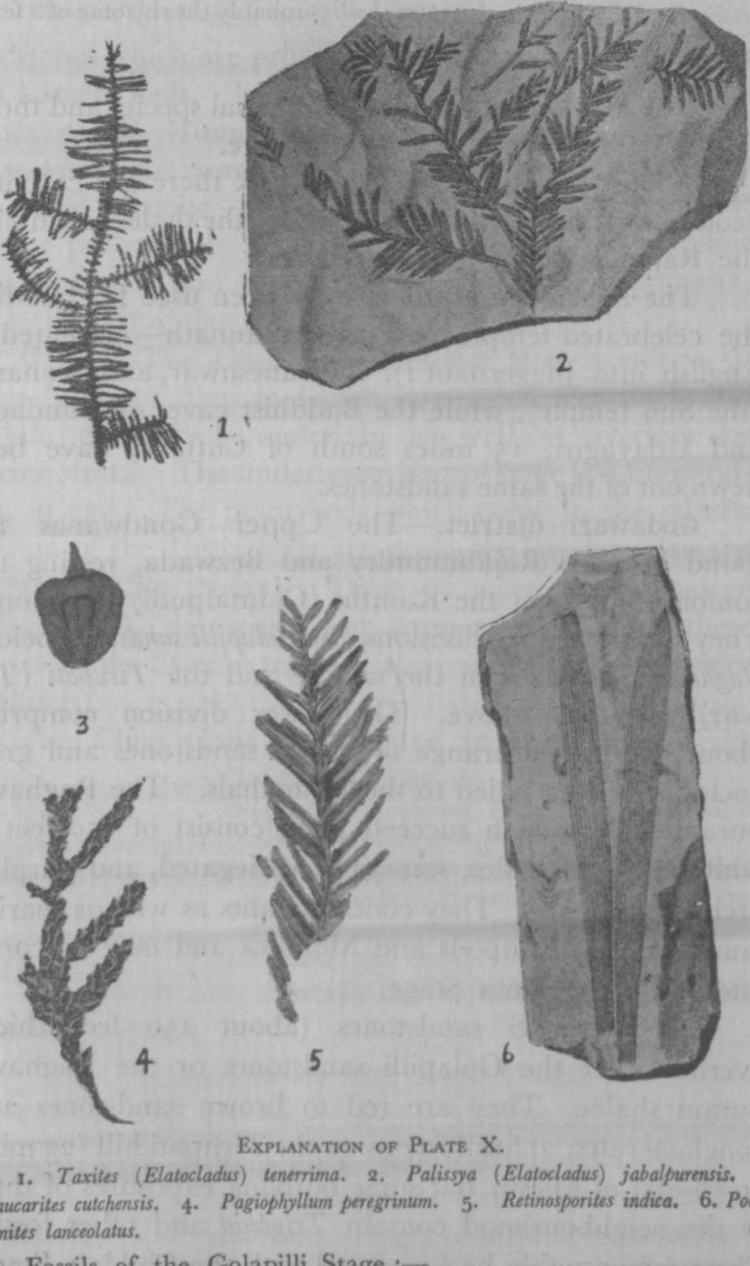
About five miles west of Cuttack there are carbonaceous shales traversed by basalt dykes, the shales resembling the Rajmahal inter-trappean beds.

The Athgarh sandstones have been used for building the celebrated temples of Puri (Jagannath—mutilated in English into Juggernaut !), Bhuvaneshwar, and Konarak (the Sun temple), while the Buddhist caves at Kandagiri and Udayagiri, 15 miles south of Cuttack, have been hewn out of the same sandstones.

Godawari district.—The Upper Gondwanas are found between Rajahmundry and Bezwada, resting unconformably upon the Kamthi (Chintalpudi) sandstones. They comprise three divisions, the *Golapilli sandstones* below, *Raghavapuram shales* in the middle and the *Tirupati* (*Tripetty*) *sandstones* above. The lower division comprises about 350 feet of orange to brown sandstones and grits, enclosing a flora allied to the Rajmahals. The Raghavapuram shales which succeed them consist of 150 feet of white and buff shales, sometimes variegated, and purplish arenaceous shales. They contain plants as well as marine fauna like Cephalopods and Molluscs and may be correlated with the Kota Stage.

The Tirupati sandstones (about 150 feet thick) overlie either the Golapilli sandstones or the Raghavapuram shales. They are red to brown sandstones and conglomerates, unfossiliferous on the Tirupati hill (23 miles north-east of Ellore) but some outlying exposures of these in the neighbourhood contain *Trigonia* and other fossils. These may roughly be correlated with the Chikiala Stage. The fossils found in these stages are :—

PLATE X.
UPPER GONDWANA PLANTS IV.



EXPLANATION OF PLATE X.

1. *Taxites* (*Elatocladus*) *tenerrima*. 2. *Palissya* (*Elatocladus*) *jabalpurensis*. 3. *Araucarites cutchensis*. 4. *Pagiophyllum peregrinum*. 5. *Retinosporites indica*. 6. *Podozamites lanceolatus*.

Fossils of the Golapilli Stage :—

Filicales .. *Marattiopsis macrocarpa*, *Cladophlebis* (*Alethopteris*) *indica*.

Cycadophyta	.. *Ptilophyllum acutifolium, P. cutchense, Taeniopteris ensis, Dictyozamites falcata, Nilssonia (Pterophyllum) morrisiana, Williamsonia* sp.
Coniferales	.. *Elatocladus (Palissya) conferta, Retinosporites (Palissya) indica, Araucarites macropterus.*

Fossils of the Raghavapuram Stage :—

Filicales	.. *Cladophlebis (Pecopteris) reversa.*
Cycadophyta	.. *Ptilophyllum acutifolium, ? Pterophyllum* sp , *Otozamites abbreviatus, Taeniopteris spatulata, T. macclellandi.*
Coniferales	.. *Elatocladus (Taxites) tenerrima.*
Ginkgoales ?	.. *Ginkgo crassipes.*
Incertæ	.. *Pachypteris ellorensis, Podozamites lanceolatus.*

Amongst the animal fossils found in these beds are fish scales and several mollusca including—*Leda, Mytilus, Trigonia interlævigata, Solen, Tellina, Pecten,* etc.

Fossils of the Tirupati (Tripetty) Stage :—

Several fossils have been found in this stage, mostly mollusca amongst which are some ammonites and belemnites.and also *Trigonia ventricosa, T. smeei, Inoceramus, Pseudomonotis, Lima* and *Pecten.*

Ongole Area.—In this region there are four patches in which Upper Gondwanas are found. They are near Kandukur, Ongole, Vemavaram and Guntur. The best Upper Gondwana exposures are found near Budavada 24 miles N. by E. of Ongole. The lower beds, *i.e., Budavada sandstones,* are buff coloured, and are the marine equivalents of the Golapilli Stage. They are succeeded by thin-bedded, fissile, purplish, variegated shales, called the *Vemavaram shales* containing an abundant flora closely related to the Raghavapuram shales (Kota stage). Overlying these are the *Pavalur sandstones* which are brown and red sandstones apparently unfossiliferous.

In the vicinity of Pavalur occur large blocks of sandstones containing marine fossils belonging to the genera *Belemnites, Cerithium, Ostrea, Rhynchonella,* etc., but the stone is dissimilar to the Pavalur sandstone and may possibly be younger.

The Budavada sandstones have yielded the following plant fossils (all cycads) :—*Ptilophyllum acutifolium, Tæniopteris (Angiopteridium) spatulata, Otozamites* sp. and *Dictyozamites indicus.*

The Vemavaram shales have yielded a fairly rich assemblage of fossils amongst which are :—

Filicales	..	*Cladophlebis (Alethopteris) indica, Sphenopteris* sp., *Dicksonia* sp.
Cycadophyta	..	*Tæniopoteris spatulata, T. ovata, Ptilophyllum acutifolium, P. cutchense, Pterophyllum distans, Zamites proximus, Dictyozamites indicus.*
Coniferales	..	*Retinosporites indica, Brachyphyllum rajmahalensis Araucarites* sp.

Dr. L. F. Spath examined, a few years ago, the collections of ammonites made from near Budavada by Foote, from Raghavapuram by King and from Raghavapuram, Vemavaram and Budavada by L. A. N. Iyer (*Pal. Ind., N. S.* IX, *Mem.* 2, pp. 827-829, 1933). From the first two collections he has described *Pascoeites budavadensis* and *Gymnoplites simplex* respectively, both being new fossils (genera as well as species) referred to Lower Cretaceous from their evolutionary characteristics. Dr. Iyer's collections contained poorly preserved fossils in variegated shales having a non-marine aspect and sometimes containing *Otozamites* in association. The collection consisted of mostly new genera and species and not particularly well suited for satisfactory determination.

Reviewing the collections, Dr. Spath says that the assemblage of ammonites consisting of the following, points to an Upper Neocomian age :—

Holcodiscus cf. *perezianus, H.* cf. *caillaudianus, Hoplites* cf. *borowæ, H.* cf. *beskidensis, H. codazzianus, Lytoceras, sp.* cf. *vogdti, Pascoeites budavadensis, P. crassus,* and *Gymnoplites simplex,* etc.

The floras described by Feistmantel from the East Coast Gondwana strata are of Rajmahal (Jurassic) age. However, it may be mentioned here that these floras need a critical revision. It is also necessary to make careful field studies and collections of both plant and animal fossils from each fossiliferous horizon and study them in conjunction with field data before we can assert whether the beds are Jurassic or Cretaceous or grade from the one into the other.

Madras.—There are two occurrences near Madras which are referable to the Upper Gondwanas. The lower stage is called after *Sriperumbudur* (Sripermatur) 25 miles W.S.W. of Madras and consists of sandstones, buff shales and clays containing marine animals and plant remains, especially in the eastern part of the basin. The invertebrate fossils found here are *Leda*, *Yoldia*, *Tellina*, *Lima*, *Pecten*, etc. One or two ammonites similar to those in the Raghavapuram shale are also said to have been found by Bruce Foote from loose boulders here, but a recent search did not reveal any animal fossils except mollusca, nor the boulders referred to. The plant fossils found are :—

Filicales	..	*Cladophlebis whitbyensis*, *C. indica*, *C. reversa*.
Pteridospermæ ?	..	*Thinnfeldia* sp.
Cycadophyta	..	*Tæniopteris spatulata*, *T. macclellandi*, *Ptilophyllum acutifolium*, *P. cutchense*, *Dictyozamites indicus*, *Otozamites abbreviatus*, *O bunburyanus*, *Pseudoctenis* (*Pterophyllum*) *footeanum*.
Coniferales	..	*Pagiophyllum* (*Pachyphyllum*) *peregrinum*, *Brachyphyllum rajmahalensis*, *B rhombicus*, *Elatocladus conferta*, *E. plana*, *Araucarites cutchensis*, *A. macropterus*.
Ginkgoales ?	..	*Ginkgo crassipes*.

The upper stage is found in the *Satyavedu* (Sattivedu) beds about 35 miles N.W. of Madras, consisting of purple mottled ferruginous sandstones and conglomerates which contain fragmentary plant fossils. They are underlain by the Sriperumbudur beds and therefore thought to be the equivalents of the Tirupati stage.

Trichinopoly.—Small exposures of Upper Gondwana beds are also found near the Uttatur village in the Trichinopoly district where they consist of micaceous shales, grey sandstones and grits containing calcareous concretions. They rest on Archæan gneisses and are overlain by marine Cenomanian beds, and contain :—

Filicales	..	*Cladophlebis indica, ? Actinopteris.*
Cycadophyta	..	*Ptilophyllum acutifolium, Otozamites* sp., *Dictyozamites indicus, Tæniopteris spatulata.*
Coniferales	..	*Elatocladus conferta, Retinosporites indica, Araucarites cutchensis.*

These indicate the same horizon as the Vemavaram beds.

Madura-Ramnad.—Bruce Foote mentions the find of buff and yellow shales resembling the Upper Gondwana shales of Uttatur and Vemavaram at Ammersanpatti (near Moodechempatti) 10 miles north-east of Sivaganga. Similar material was seen a mile south-east of the above village in scrub-jungle, and also 2 miles north of Sivaganga. No fossils were however found in them. Some boulder beds resembling those at the base of the Upper Gondwanas of Uttatur were also found on the high ground north-east of Sivaganga and north-west of Seruvayal.

CEYLON.

Upper Gondwana strata, called the *Tabbowa series*[1], are found to occupy an area of about 1 square mile north and east of the Tabbowa tank, 8 miles N.E. of Puttalam. They consist of sandstones, conglomerates, shales and nodular limestones. The strata are apparently faulted into the gneiss, but generally covered by alluvium so that their actual extent is not known. The same rocks have recently been found[2] near Andigama some 16 miles south of Tabbowa and are believed to continue further south.

The sandstones and shales contain plant impressions, with occasional Carbonaceous material. The plant fossils were examined and described by Seward and Holttum[3] in 1922 and a further collection has recently been studied by K. Jacob[4] who states that the following have been identified :—

---

[1] E J Wayland · The Jurassic rocks of Tabbowa. *Ceylon, Jour Sci.* XIII, B Pt. 2, 1924

[2] P Deraniyagala : *Proc Ind. Sci Congress*, 1940, Pt. 4, p. 77.

[3] A.G Seward and R E. Holttum Jurassic plants from Ceylon. *Q.J G.S.*, LXXVIII, Pt. 3, 1922

[4] Personal communication.

Filicales	.. *Sphenopteris* sp., *Coniopteris* sp., *Cladophlebis* sp., *C.* cf. *browniana*, *C. reversa*.
Cycadophyta	.. *Taeniopteris spatulata*, *Nilssonia* cf. *schaumburgensis*.
Coniferales	.. *Araucarites cutchensis*, *Brachyphyllum mamillare*, *Elatocladus plana*, *E.* sp, *Desmiophyllum* (? *Podozamites*) sp.

Several of the species agree with those described by Feistmantel from the East Coast Gondwanas of Madras, which are referred to the Kota stage. Seward and Holttum agree with this, but Dr. Jacob thinks that the age may be slightly younger, particularly as the presence of *Cladophlebis* cf. *browniana* and *Nilssonia schaumburgensis* give the assemblage a newer aspect than Kota. A final decision on the age of the Upper Gondwanas of Ceylon and Madras must however await the results of further detailed work.

IGNEOUS ROCKS IN THE GONDWANAS.

Dolerite and Basalt.—Most of the Gondwana coalfields are traversed by hypabyssal basic intrusives—dolerites and basalts, which may be sometimes olivine-bearing—as dykes and sills. Some of these are affected by faults while others pass through them without interruption, so that in general they may be regarded as later in age than the faults. They occasionally form thick sills, especially in Rewa and Satpura regions, usually at the junction of dissimilar formations like shales and sandstones. Dykes are also known to pass into sills in the Satpura area.

These basic dykes and sills are common in the Satpura, Son-Damodar, Assam and other fields north of the Satpura axis and are comparatively rare in the Godavari and Mahanadi valleys.

The intrusives of the Satpura and Rewa areas are undoubtedly of Deccan trap age, while those of the Damodar valley and Assam are thought to be of Rajmahal age, though evidence on this point is not clear. In the Rajmahal area the traps are dolerites, basalts and andesites, very similar to the Deccan traps, and they are not younger than Lower Oolite. The upper flows of Rajmahal may however be of Middle Jurassic age.

Mica-Peridotite.—Another type of igneous rock is also found as dykes and sills in the fields of the Damodar valley, Giridih and Darjeeling foot-hills. This is the mica-peridotite, a lamprophyric or mica-rich ultrabasic rock containing altered olivine, calcite (or dolomite), mica and much apatite. Fresh and unaltered type of this rock is rather rare even at depth, being dark grey, hard and tough. At the surface as commonly seen, it is buff coloured and soft, containing nests of mica. Mica-peridotite dykes are generally of small thickness (3 to 6 ft.) and have a tendency to form anastomosing veins, lens-like masses and thin flat sheets at the junction of coal seams and sandstone or in the coal seams themselves. The rock gives evidence of high fluidity and high temperature, as it has destroyed, coked, or otherwise rendered the coal useless. Alongside some of the sills the coal has been affected and converted into a kind of coke (*jhama*) for a distance of as much as 6 feet from the contact. The high fluidity of the intrusive is evidenced by the intricate ramifications of the veins and sheets, which may often be less than an inch thick, traversing the cracks amidst the *jhama* which has developed columnar structure. The rock seems also to have spread out into sheets more in the lower seams than in the upper, in the same area. In contrast with these, the dolerite dykes are scarcely harmful to the coal.

The mica-peridotites are seen only in the Damodar valley and in the Himalayan region. They seem to be nearly of the same age as the dolerites.

Features of Gondwana areas.—The Gondwana strata, formed of alternations of sandstones and shales, show the sandstones forming ridges and shales the valleys. But it is usually only the Barakar, Kamthi, Mahadeva and Upper Gondwanas which are particularly hard. The

Talchir and part of the Damuda sandstones are often too soft to form prominent topography. Some of the best scenery in Central Provinces is due to the fine scarps of the Pachmarhi and Kamthi sandstones. Because of differences in hardness, the Gondwana exposures constitute important hydrographic basins.

The Talchirs and Barakars form poor soils and generally support only a sparse vegetation. The under-scarps of the sandstones and the shales support good vegetation and may be forest-clad. The ferruginous sandstones of the Kamthi and Mahadeva series form more or less flat-topped hills on which a fair amount of vegetation flourishes.

Climate and Sedimentation.—The Gondwana era was initiated by a glacial climate during which an ice-sheet may have covered Rajputana and Central India highlands. Glaciers appear to have flowed out towards the Salt Range where the boulder bed contains rocks whose source was undoubtedly Rajputana in part. The boulder beds in other areas are also glacial materials but probably re-worked by water action. During the Talchir period the climate gradually warmed up as seen from the appearance of a flora towards the top. The prevailing green tints and the presence of unaltered felspars in the Talchir strata point to a cold climate which prevented the oxidation of the iron in the rocks.

The Damuda (Damodar) period was one of warm humid climate in which a luxuriant flora flourished over the land, and an enormous amount of vegetation drifted into the swamps and lake basins to form the coal beds. This marked the zenith of development of the Glossopteris flora. Warm conditions are also evidenced by the presence of kaolinised felspars in the sandstones. The sandy sediments point to estuarine conditions and the shales to lacustrine (fresh-water) conditions. The repetition of the succession—sandstone, shale, coal—points to repeated oscillations of level of the basins of deposition, probably in some measure through repeated sinking of the faulted trough, or a series of tilts. In the Barakars of the Jharia coal-field there are as many as 25 coal seams which point to as many repetitions of the cycle of sedimentation. While the eastern portion of the Damodar valley shows moist conditions, as seen from the excellent development of coal seams, there seems to have been a gradual desiccation further west heralding the appearance of a dry climate. This is seen in the red Kamthi facies of the Raniganj stage and in the Motur-Bijori strata containing remains of amphibians and reptiles.

The Kamthi, Panchet and Pachmarhi stages and their equivalents, of Permo-Trias age, are deposits of an arid climate. They are characterised by prevailing red tints and contain remains of reptiles and amphibians.

After this there is again a return to more favourable moist conditions. The *Glossopteris flora* practically died out during the Permo-Triassic period and a new one, the *Ptilophyllum* flora, began to establish itself in the Rajmahal times. The Rajmahal hills and the neighbourhood constituted a focus of volcanic activity and dykes and sills connected with this invaded the coal-fields of the Damodar valley and further east. The humid conditions seem to have persisted, with slight variations, during the rest of the Gondwana era, but the coal seams formed during this period are of very minor importance.

World distribution of the Gondwana System.—Rocks similar to the Gondwanas and containing very closely related flora occur in regions now lying so far away from each other as Australia, South Africa, South America and Antarctica. There are the same plants, even the species being identical, in Indian Barakar rocks as in Argentina and New South Wales. It is therefore deduced that these lands lay close together so that the flora could migrate freely. *Glossopteris* being its most important element, the flora is known by that name. At the same time there were also other floras in the lands of the Northern Hemisphere, indicating that they were separated from the Gondwana province by effective barriers.

TABLE 19.—THE GONDWANA SYSTEM AND ITS FOREIGN EQUIVALENTS (AFTER C. S. FOX).

INDIA Gondwana system.	SOUTH AFRICA Karroo system.	S. E. AUSTRALIA. Carbonaceous system	SOUTH AMERICA Santa Catharina system.
Umia	Uitenhage	Rolling Downs Formation	
Jabalpur			Volcanics (basalt) Serra Geral eruptives
Kota	Stormberg: Karroo and Drakensburg dolerites	Hawkesbury: Artesian and Talbrager series	
Rajmahal with lavas	Cave sandstones		
Maleri	Red Beds Molteno Beds	Wianamatta stage	Sai Bento series: Sao Bento beds Rio do Rasto beds
Pachmarhi	Beaufort: Up Beaufort	Hawkesbury stage	
Panchet	Mid Beaufort	Narrabeen stage	
Raniganj	L. Beaufort	Maitland: Newcastle series	
Barren Measures	Ecca: Up. Ecca	Dempsey series	
Barakar	Mid. Ecca	Tomaco series	
Karharbari	L. Ecca		
Umaria (marine)	Mesosaurus bed	Murree: Up Marine series Greta beds	Passa Dios: Rochina limestone Iraty shale with Mesosaurus bed
Talchir	Dwyka: Upper shale Eurydesma bed	L. Marine series with Eurydesma	Rio Tubarao: Rio Bonito series
Boulder bed	Boulder bed	Glacial beds	Itarare boulder bed.

The similarity of stratigraphy persists all over Gondwanaland (*i.e.*, the southern continents) through the greater part of the Gondwana era but the distinctness of the flora is to a large extent lost in Upper Gondwana times. There is evidence that the southern continents gradually drifted away in the Mesozoic era and that they followed individual lines of development during the Tertiary. Table 19 shows the succession in the equivalents of the Gondwana system in South Africa, Australia and Brazil.

PERMO-CARBONIFEROUS FLORAS.

The Lower Carboniferous period seems to have supported a flora with *Rhacopteris* and allied plants which had a uniform distribution over the world, since it is found in Europe, in India (Spiti area) and in Australia. The Hercynian revolution of the Upper Carboniferous period seems to have separated the Gondwana continent from the rest. Glacial conditions prevailed over the southern continent, during which the previous flora was almost completely destroyed, and with the amelioration of climate, the Glossopteris flora began to flourish. In Europe, however, the old flora continued to develop and was represented by the familiar Coal Measure flora with *Lepidodendron*, *Sigillaria*, etc. There is little in common between these two floras. The Glossopteris flora is essentially a cold temperate one, having few species, with a scarcity of arboreous forms, the trees however showing sharply marked growth rings. The European flora on the other hand was a tropical one of the rain-forest type rich in species and in tree-ferns, the trees being characterised by indistinct growth rings.

At the same period there were two other great floral groups. The *Gigantopteris flora* flourished in China and Western North America, this region being now split into two by the Pacific Ocean. The *Angara flora* flourished in the Angara continent comprising Siberia and the adjoining countries lying to the north of India, separated by the ocean called Tethys. But since there are some elements common between the Glossopteris and Angara floras, there was probably a connecting archipelago through Kashmir and the Pamir region which are known to have been dry land during the Permo-Carboniferous. It is an interesting fact that the Gondwana flora of Kashmir shows better affinities with the Angara flora than does the Gondwana flora of Peninsular India, which is of course to be expected.

The Glossopteris and Gigantopteris floras are quite distinct from each other though India now adjoins China and Indo-China. The extensive changes which took place in late Mesozoic and early Tertiary eras caused India to drift and wedge itself into the Chinese region. The line of separation is well marked along the Burma Malay arc. Just as Gondwanaland now lies scattered over the whole of the southern hemisphere, the land of the European flora lies on both sides of the Atlantic and the land of the Gigantopteris flora on both sides of the Pacific. These facts are best explained by the theory of continental drift associated with the name of Alfred Wegener.

STRUCTURE OF THE GONDWANA BASINS.

The Gondwana rocks occupy tectonic troughs with faulted boundaries arranged in a rough linear fashion, the magnitude of the faults along the two longer sides being unequal. This produces a dip of the strata towards the side with the greater throw. Thus, in the chief Gondwana blocks in the Damodar valley, the faults run roughly east to west and the strata generally dip towards the more faulted southern boundary. In the Pranhita-Godavari basin the prevailing strike is roughly N.W.-S.E., the general dip being towards the more faulted boundary on the north-east. In the Chhattisgarh-Mahanadi basin the trend of the main fault is N.W.-S.E.; the Gondwana outcrops of the Chhattisgarh basin lie to the north-east of this fault, the strata dipping therefore towards the south-west, while those of the Mahanadi basin are exposed on the southern side of the fault and dip towards the north-east. It is noteworthy that the faulting of these troughs is parallel to the strike of foliation of the contiguous metamorphic terrain.

In addition to the main faults which form the boundaries of the troughs there are also cross or oblique faults. The main faults seem to have been formed simultaneously with the deposition in the basins. It is often seen that the stages or beds which appear to be perfectly conformable in the centre of the basins become unconformable near the faulted boundary. It would appear that some of these basins mark the limits of original deposition and are not necessarily to be interpreted as faulted remnants of more widespread ones. The sediments are generally gently dipping except near faults or intrusions. The faults are in most cases of the normal type but some tear- or sag-faults have been noted, especially in the Jharia field.

Age of faults.—Most of the faults in the Damodar valley fields are older than the intrusions of dolerite and mica-peridotite but there is some evidence in the Rajmahal area that the traps are affected by the faults. In the Karanpura field there are two sets of faults some being pre-Mahadeva and some post-Mahadeva. There are post-Deccan Trap faults in the Satpura area where the dykes are of Deccan trap age. Hence it may be said that there were two main periods of faulting, one pre-Mahadeva and the other post-Rajmahal.

Folds.—In general much of the Gondwana area is free from folding disturbances, though occasionally these are to be found. In the Eastern Himalayan area, however, the Gondwanas have been severely affected by the Tertiary mountain building movements which have folded, overthrust and even inverted them.

Thermal springs.—The faulted zones are sometimes marked by thermal springs and silicified breccias, the silicification being attributable to water circulating in the fault zone.

PALAEOGEOGRAPHY OF THE GONDWANA ERA.

The similarity of the Gondwana deposits is so great that it has been suggested by Wegener that South Africa, Madagascar, India, Australia, Antarctica and South America formed parts of a continent which probably lay in the Indian Ocean around what is now South Africa. India then lay alongside South Africa and Madagascar, and Australia to the east of India. South America was joined to South Africa, Argentina curving round the Cape of Good Hope. The southern part of this continent was Antarctica. Australia seems to have drifted apart in the Jurassic when the Bay of Bengal more or less took its present shape. India began to drift northward or north-eastward perhaps in the late Cretaceous. The different phases of the Himalayan upheaval may be looked upon as active phases of this drift and underthrust of India into the Tethyan region. South America is supposed to have drifted westward from Africa. These drifts may have been accompanied by the breaking off of some portions of the crust which foundered into the under-crust. Though there are gaps in our knowledge and certain details difficult of explanation, yet Wegener's conception of continental drift gives a remarkably interesting explanation of the geology and the subsequent history of Gondwanaland. For discussions of the various phases of this subject, the works of Wegener, Du Toit, Fox and others may be consulted.

At the commencement of the era, in the Indian region, there must have been two elevated regions from which glaciers radiated. These were the Aravalli range and the Eastern Ghats, for both of these were apparently uplifted in post-Vindhyan times, since the Vindhyans of Rajputana and Central India as well the Cuddapah basin of the Chhattisgarh region have both suffered compression and disturbance in pre-Gondwana times. Moreover

Gondwana rocks overlap the faulted Cuddapahs and Vindhyans in the Godavari valley. From the Rajputana highlands glaciers carried boulders to the Salt Range, Hazara and Kashmir. The boulder beds of Eastern India should have similarly derived their materials from the Eastern Ghats.

A series of parallel fault zones seem also to have been developed in pre-Gondwana times along the Godavari valley and the Mahanadi valley. These, it will be noticed, are parallel to and lie amidst ancient rocks having the same strike as the Dharwars of South India. Another line of faults seems to have stretched from Rewa eastwards to Bengal, as well as W.S.W.-wards in the direction of Gujarat.

Dr. Fox has shown that the drainage in the Godavari and Mahanadi basins was north-westward, and that in the Damodar valley eastward. The one to the west of Rewa may have had an outlet towards Gujarat, roughly along the present Narbada valley. This and the Damodar basin are roughly parallel to the Satpura strike. If such were the case, this trough would have extended across the southern end of the Aravallis to Kathiawar and Cutch. To the south and west of the Deccan plateau was the land mass directly connected with Madagascar and South Africa. Western Rajputana and Western Punjab may have been a marine area connected to the Salt Range and Umaria where, as we have seen, there are *Productus*-bearing marine beds of Lower Permian age.

Fox has postulated, at the suggestion of Fermor (*Mem.* 58, Plate 10), a marine connection of the Salt Range through the Ganges-Jumna valley and Bundelkhand to Umaria. This seems difficult to accept in view of the fact that this connection lies right across the northern Aravallis, the Bundelkhand plateau and the Kaimur ranges all of which remain as elevated land to this day, and which show no traces of rocks younger than the Vindhyans. Hence the more probable connection appears to be through the Narbada valley, Cutch and Western Rajputana. All this area is now covered by rocks younger than the Lower Gondwana and there seems to be a likelihood of yet finding marine Permian beds at the base of the Barakars in the Narbada drainage region of Jubbulpore and possibly in south-western Rajputana.

It is known that the Conularia and Eurydesma beds of Kashmir have their counterpart in Eastern Australia which shows that the two areas must have had direct marine connection. Fox has suggested that this might have been through Eastern Nepal and the present Ganges valley (*Mem.* 58, Plate 10). This appears unsatisfactory for the following reason. At this period there was a sea right along the site of the present Himalayan axis, with which the Salt Range sea was apparently connected. Now, boulder-beds of Talchir age occur as the Tanakki beds of Kashmir, Blaini beds of Simla, and Mandhali beds of Garhwal. Lower Gondwana rocks occur in the Darjeeling area and further east along the Himalayan foot-hills. It is not known to what extent Lower Gondwanas are developed in the Nepal Himalayas, but since Auden has noted Semri-like (Lower Vindhyan) rocks in his traverses in Nepal it is clear that land existed a little beyond the border of the present Siwalik zone. Moreover an effective barrier must have extended from Central India through Hazaribagh to the Assam plateau which forms the Satpura protaxis. Hence the probability of the connection of Salt Range with Australia through the Central Himalayan zone and the Shan area in Burma seems to be the only possibility, remembering that Australia at that time was not far from the Bay of Bengal region and that there was no Assam wedge to distort the eastern end of the Tethys.

To the east and south-east of the Eastern Ghats there was presumably land. But what gap there was between these and Australasia is not known. It may however be conceded that in Damuda times there was an arm of the sea somewhere in the region of Northern Bay of Bengal into which the rivers of the Damodar basin found an outlet.

The Permo-Trassic period was one of extensive land conditions, and though the seas to the north-west, north (? and east) of India must have contracted, shallow arms might still have extended along the Narbada valley and in Lower Bengal region. In the Jurassic era extensive faulting (and perhaps some uplift) occurred along the eastern coast of India giving this coast more or less the present configuration. For, marine and lacustrine Jurassic deposits occur at several places between Cuttack and Trichinopoly. The coast line, it will be noticed, is parallel to the strike of the rocks of the Eastern Ghats between the Mahanadi and the Kistna, and of the Dharwarian rocks of the Nellore-Madras region, but perpendicular to the strike in the southern end of the Peninsula.

There was at this time a large sea occupying Kathiawar, Cutch and Western Rajputana and continuous with the Baluchistan and Salt Range Sea which however seems to have been fairly distinct from the Himalayan Tethys. For, we find one facies of rocks in the Salt Range, Cutch and Baluchistan but a different facies in spiti, Kashmir and in parts of Hazara. In the main Gondwana basins, Jurassic rocks (Jabalpur series) are the latest rocks exposed. It is probable that the lakes in these basins dried up at the end of the Jurassic.

In Upper Jurassic times (Callovian) there was a great retreat of the sea which continued till the sea advanced again in the Cenomanian (Cretaceous). On the East Coast a stratigraphical gap marks this regression. The callovian unconformity is well marked also in the Baluchistan arc, and to some extent in the Tethyan area.

There now remains the Nepal-Kumaon Himalaya to consider. The shape of the Vindhyan outcrops north of the Son-Narbada valleys suggests that the Vindhyan sea extended northwards into the Simla-Garhwal-Nepal region. Its deposits are the Simla States and certain rocks in Nepal.

The boulder beds of Talchir age (Blaini) suggest that in Upper Gondwana times the shore line was somewhere in the Lesser Himalaya region. The post-Blaini rocks are the Infra-Krol and Tal series which may represent any age between Upper Carboniferous and Triassic. The Krol limestones are undoubtedly marine and often dolomitic while the Tals consist of current-bedded quartzites which are shore line deposits, overlain by sandy limestones with fragmentary molluscan remains. So far as known, similar rocks have not been found in Sikkim, where we see the Tibetan facies beyond the broad Archæan zone. It would appear that the post-Vindhyan sea contracted into a basin occupying parts of the Lesser Himalaya. The practically unfossiliferous nature of the beds, amidst which are found foetid limestones, dolomites, gypseous limestones and pyritous shales, seems to indicate that this sea was more or less cut off from the Tethys (the deposits of the latter being fossiliferous) and was under conditions somewhat similar to those existing in the present day Black Sea where the sea-bottom is devoid of life. The barrier between this sea and the Tethys may have been thrown up by the Hercynian revolution. This sea probably disappeared in the Triassic or Jurassic. The history of the area is very obscure because of the unfossiliferous nature of the beds and the stupendous changes in the Tertiary when the strata were jumbled up by thrusts and nappes and intruded by igneous rocks.

ECONOMIC MINERALS IN THE GONDWANAS.

Clays.—The main importance of the Gondwana system centres around coal, but there are also deposits of various types of clays. The coal seams are often associated especially in the Barakar stage with important beds of fire-clay which are worked for the manufacture of refractory bricks. Other types of clay available from the Gondwana strata are useful for making bricks, pottery, terra cotta and china-ware. Factories utilising clay of various descriptions are situated in the Raniganj, Jharia Jubbulpore areas.

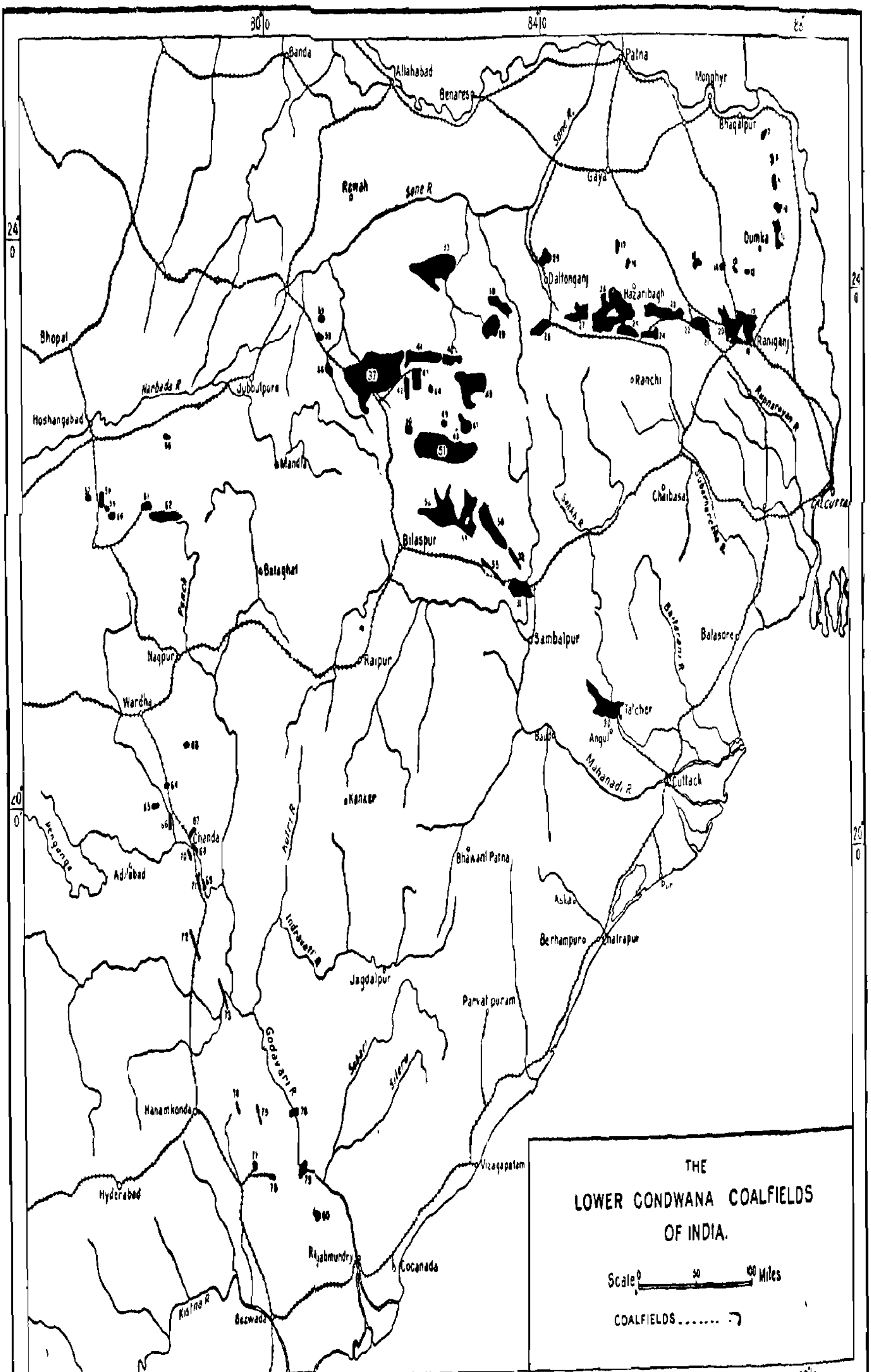
Sandstones.—The Barakar, Raniganj, Kamthi and Pachmarhi sandstones are used locally as building material, though they are not, in general, comparable in quality to Vindhyan sandstones. The Ahmednagar sandstone of Idar State has been used in the delicate tracery that adorns the mosques of Ahmadabad. A sandstone of great beauty and durability is the Athgarh sandstone which has been employed in the magnificent temples of Puri, Bhuvaneshwar and Konarak. It is fine grained and has retained the sharpness and delicacy of carved work very well through more than ten centuries. It is in these same sandstones that the caves at Kandagiri, some 15 miles south of Cuttack, have been carved out. The Tirupati sandstones and the Satyavedu sandstones have also been used for building purposes.

The Barakar sandstones are also, in places, suitable for making millstones and abrasive stones. They may occasionally also serve as sources of good quartz sand if the impurities are small or could be easily separated.

Irone-ore.—The beds of sideritic iron-ore and their oxidised outcrops occurring in the Ironstone shales of the Raniganj coal-field have been worked as iron-ore for the Barakar Iron Works and its successor the Bengal Iron Co. Pockets of limonitic iron-ore and of ochre are also found in the red sandstones, *e.g.*, Kamthi and Mahadeva age.

Coal.—By far the greater amount of coal in the Gondwanas is found in the Damuda (Damodar) Series, *i.e.*, both in the Barakar and Raniganj stages, the former stage being the more important one. Coal seams occur also in the Kota, Chikiala, Jabalpur and Umia stages but they are of local development and generally of inferior quality.

Coal seams are developed in practically all the areas where the Barakar stage occurs. Raniganj stage coal is


THE
LOWER GONDWANA COALFIELDS
OF INDIA.
Scale 0 50 100 Miles
COALFIELDS
Patna
Allahabad
Benares
Banda
Monghyr
Bhagalpur
Gaya
Rewah
Sone R
Dumka
Daltonganj
Hazaribagh
Raniganj
Bhopal
Narbada R
Jubbulpore
Hoshangabad
Ranchi
Mandla
Calcutta
Chaibasa
Bilaspur
Balaghat
Sambalpur
Balasore
Nagpur
Raipur
Wardha
Talcher
Angul
Mahanadi R
Cuttack
Kanker
Chanda
Adilabad
Bhawani Patna
Jagdalpur
Berhampur
Chatrapur
Godavari R
Parvatipuram
Hanamkonda
Vizagapatam
Hyderabad
Rajahmundry
Cocanada
Kistna R
Bezwada

important only in the Raniganj coalfield though occurring in Jharia, Bokaro and a few neighbouring fields. Coal of Jabalpur age is found as rather unimportant seams in the valley of the Hard river, and of Kota and Chikiala age in the Godavari drainage area. Thin seams occur also in the Umia beds of Cutch.

Coal consists of carbonised remains of vegetation accumulated either *in situ* or transported by water and deposited. Practically all Indian coal seems to be of the latter type. Chemically it consists essentially of carbon and hydrogen with subordinate amounts of oxygen and nitrogen. These are combined in very complex ways. Coal is usually banded, the bands being dull and bright. The dull bands are composed of *durain* which is organic matter mixed with extraneous mineral matter which latter constitutes the ' ash ' of coal. The bright bands known as *vitrain* are much purer and are high in volatiles. There are two other constituents also, one being *clarain,* a silky or satiny looking material, and the other *fusain* which looks like soft friable charcoal and soils the hands when handled.

For ordinary commercial purposes it is necessary to have a knowledge of the proximate composition of coal, determined according to certain standardised empirical procedure. In this the moisture, volatile matter, fixed carbon and ash are determined. The calorific value, either in British Thermal Units (per lb.) or in Calories (Per lb. or kilogram) is also generally found, as well as the caking tendency. The colour of ash gives an idea of the amount of the iron present and indirectly its tendency to clinker on grates when burnt. It is necessary also to know the percentage of phosphorus and sulphur present, and the form (pyritic, sulphate or organic) in which the sulphur occurs.

The ultimate analysis determines the percentage of elements present (O,H,C,N) and is useful in evaluating

37

the suitability of the coal for certain purposes, particularly in the chemical industry.

The general characters of coal of Barakar and Raniganj stages are shown below :—

Barakar.	*Raniganj.*
Low moisture (1 to 3 per cent.)	High moisture (3 to 8 per cent. or more)
Low volatile (20 to 30 per cent.)	High volatile (30 to 36 per cent.)
High fixed carbon (56 to 65 per cent.)	Medium fixed carbon (50 to 60 per cent.)
Excellent steam coal, often excellent coking coal.	Generally poorly caking, though some are moderately so; good gas coal and long flame steam coal.

The classification adopted by the Coal Grading Board in India is used for trade purposes. The scheme in use is shown in Table 20.

It may be said that most of the Gondwana coals are good steam and gas coals, none being anthracitic. In the Himalayas, however, the coal is crushed and is in consequence low in moisture and volatiles, but very friable.

The best coking coals are practically confined to Jharia, Giridih and Bokaro fields while some from the Raniganj

TABLE 20.—COAL CLASSIFICATION (INDIAN COAL GRADING BOARD).

Grade.	Low volatile	High volatile.
Selected	Up to 13 per cent. ash Over 7,000 cal.	Up to 11 per cent. ash Over 6,800 cal. Under 6 per cent moisture
Grade I	13 to 15 per cent. ash Over 6,500 cal.	11 to 13 per cent ash Over 6,300 cal Under 9 per cent. moisture.
Grade II	15 to 18 per cent. ash Over 6,000 cal.	13 to 16 per cent. ash Over 6.000 cal. Under 10 per cent. moisture.
Grade III	Inferior to the above.	Inferior to the above.

field are semi-coking and can with advantage be blended with Jharia coal to yield good coke. A part of the coal in Giridih is exceptionally good, being very low in phosphorus and useful for the manufacture of ferro-alloys like ferro-manganese.

In the Bengal and Bihar fields, where a large number of seams lie one over the other, it is found that the lower seams are generally higher in fixed carbon and lower in moisture and volatiles than the ones above, which may be explained as due to the effect of pressure and compaction. When a region is subjected to folding, as in the Mohpani field of the Central Provinces, these effects are still more marked in comparison with a neighbouring field.

GONDWANA COALFIELDS OF INDIA.

As already mentioned, the coalfields are arranged along certain definite lines and can be divided into groups. The names of the fields given below are those shown on the map accompanying Dr. Fox's 'Lower Gondwana Coalfields of India' (*Mem.* 59).

Himalayan area.—Abor, Miri, Daphla and Aka, Bhutan hills, Buxa Duars and Darjeeling. These fields are of little economic importance as they are inaccessible and the seams folded, faulted and crushed.

North-Bengal.—Hura, Gilhuria, Chuparbhita, Pachwara and Brahmani. These are all small and unimportant.

Damodar valley.—The northern group includes Kundit Kuraia, Sahajuri, Jainti, Giridih (Karharbari), Chope, Itkhuri and Daltonganj. This is much less important than the southern group which includes Raniganj, Jharia, Bokaro, Ramgarh, North and South Karanpura, Auranga and Hutar.

Central Provinces (Eastern group).—In this area the middle divisions of the Gondwana system are well developed and the coalfields appear from beneath them and include Tatapani, Ramkola, Singrauli, Korar, Umaria, Johilla, Sohagpur, Sanhat and Jhilmili.

Between the extensive Sohagpur field and the northern border of the Chhattisgarh area there is a large spread of Talchir rocks so that some of the following appear as outliers on the Talchirs : Jhagrakhand, Kurasia, Koreagarh, Bisrampur (Sirguja), Bansar, Lakhanpur, Panchbhaini, Damhamunda and Sendurgarh.

Mahanadi valley.—Hasdo-Rampur (Sirguja), Korba, Mand river, Raigarh (N. and S.), Himgir, Ib river (Rampur) and Talchir. Some of these are potentially important.

Central Provinces (Western or Satputra).—Mohpani, Sonada, Shahpur, Dulhara, Patakhera, Kanhan valley and Pench valley. Of these, Mohpani is an isolated field lying north of the Satpuras, the others lying along their southern border. Pench valley is being actively exploited at the present time.

Wardha-Godavari valley.—Bandar, Warora, Wun, Ghughus-Telwasa, Chanda, Ballarpur, Wamanpalli, Sasti-Rajura, Antargaon, Tandur, Sandrapalli, Kamaram, Bandala-Allapalli, Lingala, Singareni, Kottagudem, Damarcherla, Ashwaraopeta and Bedadanuru.

In this area there is an extensive development of Kamthi and younger rocks, the coal measures appearing as isolated patches separated by the younger rocks. There is every probability that several of these coalfields are much more extensive than they appear and extend underneath the younger rocks. The possibilities of the Godavari valley fields are therefore probably considerable.

THE RANIGANJ COALFIELD.

This is the easternmost field in the Damodar valley and is situated around Asansol, about 130 miles north-west of Calcutta. It covers about 600 square miles of proved coal-bearing area. It is surrounded on three sides by

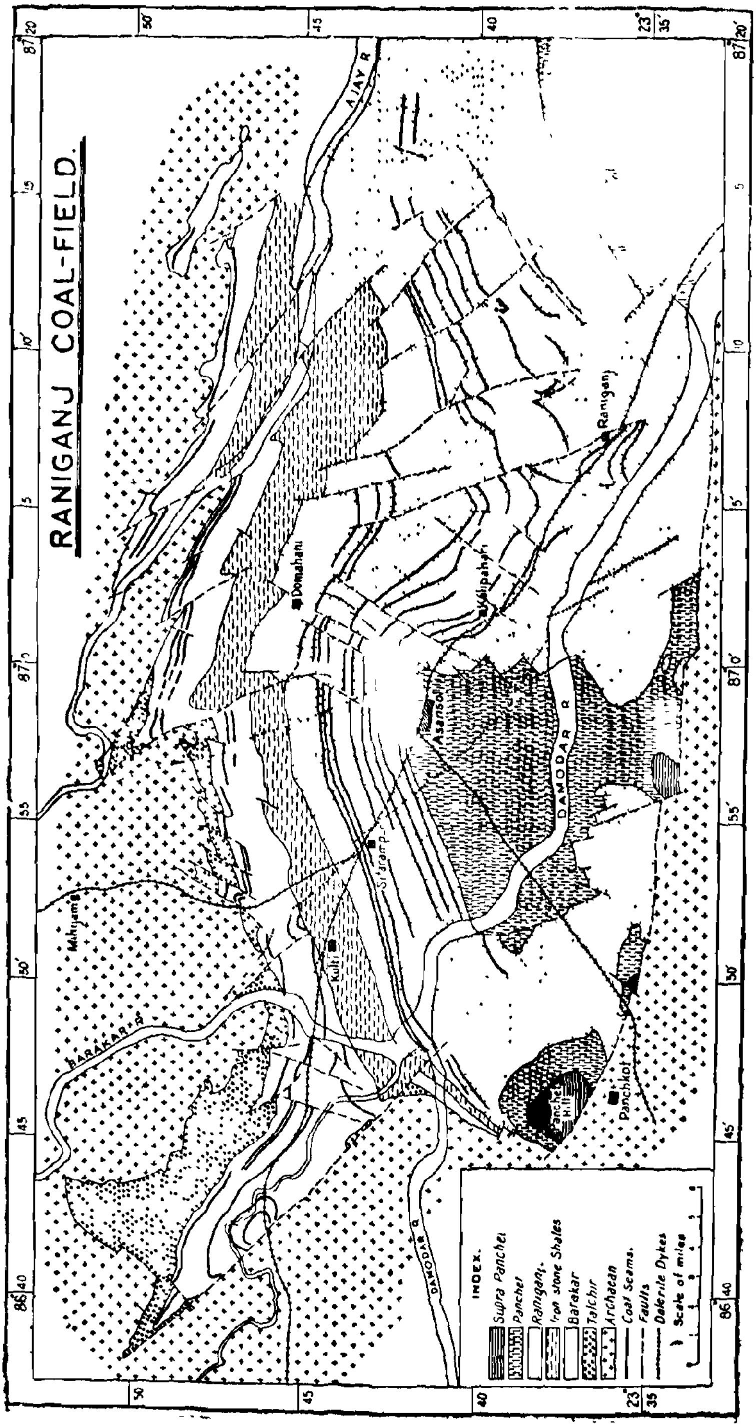
Archæan rocks but on the east it passes beneath alluvium and laterite where its extension is a matter of speculation.

The formations exposed in the field are shown below :

Formation	Description.	Maximum thickness.
Supra-Panchets	Red and grey sandstones and shales ..	1,000 ft.
Panchet .	Micaceous yellow and grey sandstones, red and greenish shales	2,000 ft.
Raniganj .	Grey and greenish soft felspathic sandstones, shales and coal seams .	3,400 ft.
Ironstone shales ..	Dark carbonaceous shales with ironstone bands .	1,200 ft.
Barakar ..	Coarse and medium grey and white sandstones, shales and coal seams ..	2,100 ft.
Talchir with boulder bed at the base	Coarse sandstones above and greenish shales and sandy shales below	900 ft.

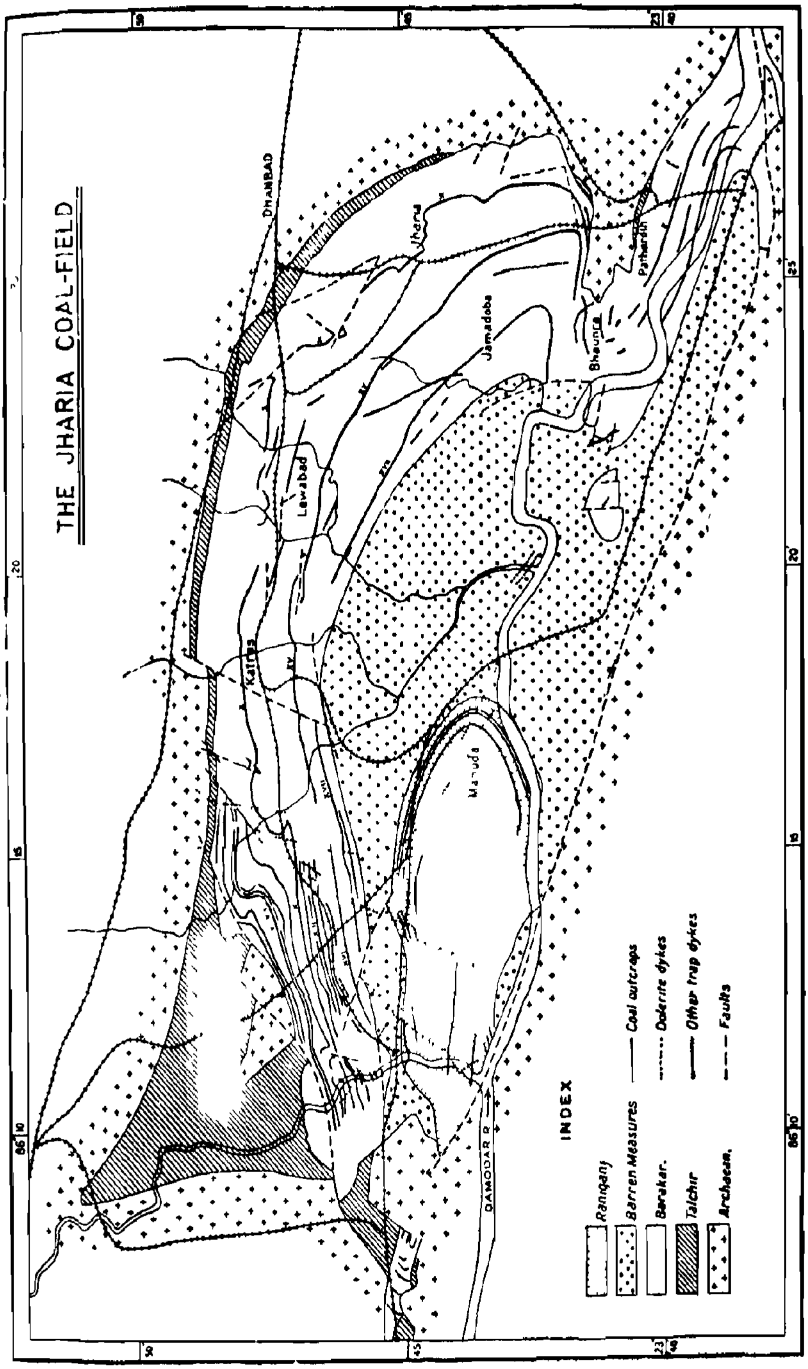
The Raniganj coalfield is faulted on the south and west, the southern boundary being a series of faults, running *en echelon*, indicating a throw of 9,000 feet near the Panchet hill. Over the greater part of the northern side, the Gondwana boundary is one of original deposition, modified of course by later erosion. The oldest beds are found in the north, and are overlapped by younger beds in a southward direction, the general dip being also southward. Besides the boundary faults, there are also oblique and cross faults in the field. The main dislocation probably took place in the Jurassic. The field is traversed by many dolerite and mica-peridotite dykes, the latter having produced much damage to coal. The intrusives are later than the faults and may be of Rajmahal or Deccan trap age.

Coal.—Coal seams occur both in the Barakar and Raniganj stages. The seams of the Barakar Series are named as follows from below upwards :—Damagaria, Salanpur, Kasta, Laikdih, Ramnagar, Chanch-Begunia seams. The seams in the Raniganj stage are, from below upwards :—Taltore, Sanctoria-Poniati, Hatinal-Koithi, Dishergarh-Samla, Bara Dhemo-Raghunathbati, Lower Dhadka-Nega-Jambad, Ghusik-Searsole-Upper Kajora,


RANIGANJ COAL-FIELD.
INDEX.
Supra Panchet
Panchet
Raniganj
Iron stone Shales
Barakar
Talchir
Archaean
Coal Seams.
Faults
Dolerite Dykes
Scale of miles
AJAY R
DAMODAR R
BARAKAR R
Domahani
Raniganj
Asansol
Kulti
Panchkot
Panchet Hill

MAP VII.

MAP VIII


THE JHARIA COAL-FIELD
DHANBAD
Jharia
Jamadoba
Patherdih
Bhaunra
Lowabad
Katras
Mahuda
DAMODAR R.
INDEX
Raniganj
Barren Measures
Barakar.
Talchir
Archaean.
Coal outcraps
Dolerite dykes
Other trap dykes
Faults

Upper Dhadka-Satpukhuriya, and Narsamuda-Bharat Chak. These seams have local names in different areas and there are also less important intervening seams.

Of the above, the Ramnagar, Laikdih, Begunia, Sanctoria-Poniati and Dishergarh are caking coals, but they are not as good as Jharia coals. They might however be used for blending with the latter. Recent estimates of the coal reserves by the Geological Survey of India in this field are :—

Kinds of coal.	Million tons	
	1,000 ft. depth.	2,000 ft depth.
Coking	82	250
Non-coking, superior	964	1,570
Inferior	4,631	6,860
Total	5,677	8,680

The above are the estimates of the quantities still available for exploitation. This coalfield has been worked since about 1800 the amount raised to the end of 1937 being over 230 million tons.

JHARIA COALFIELD.

This is the most important coal-field of India, being responsible for something like 40 per cent. of the total Indian production, besides being the most important storehouse of the best coking coal. It is situated about 170 miles west of Calcutta, the town of Dhanbad lying on its north-eastern corner. The field is roughly sickle-shaped, being about 12 miles N.-S., and 24 miles E.-W. The total area of Gondwana rocks exposed is 175 square miles of which Barakars occupy 84 square miles, and Raniganj series 21 square miles. The other strata exposed are Talchirs and Barren Measures. The Talchirs are found along the northern and western margins with a maximum thickness of 800 feet, the boulder-bed being 50 feet thick. The Barakar series and the Barren Measures have each a thickness of 2,000 feet while the Raniganj series is 1,840 feet thick, the former exposed in the north and east of the field. The Raniganj measures form an elliptical outcrop in the south-western part of the field.

The Jharia coalfield is faulted against the Archæans along the southern margin, but the strata dip inward towards the centre of the field. Two small horsts of gneiss are found, one in the north-eastern and the other in the north-western part. There are also faults on the other sides as well as cross-faults within the field, most of them being of the 'sag-fault' type. A large number of dykes of dolerite and mica-peridotite traverse the field.

Though coal seams occur in both the Barakar and Raniganj stages, those in the Barakars are by far the most important. This stage contains more than 25 seams, the more important of which are numbered I to XVIII from below upwards, seams X and above being of good quality. The best seams in this field (indeed in India) are XI, XIV, XIV-A, XV, XVII and XVIII.

The total available reserves now present in the Jharia field have been calculated by the Geological Survey of India as follows :—

	Million tons	
	to 1,000 ft.	to 2,000 ft.
Raniganj stage	90	90
Barakar stage	3,032	4,147
	3,122	4,237

The field has been exploited since about 1895, the amount raised up to 1938 being 370 million tons. Out of the total reserves within 1,000 feet depth, about 800 million tons are high quality coking coal.

SELECTED BIBLIOGRAPHY.

Cotter, G. de P. A revised classification of the Gondwana system. *Rec.* 48, 23-32, 1917.

Foote, R.B. Geology of Madras. *Mem.* 10 (1), 1873.
Fox, C.S. The Jharia coalfield. *Mem.* 56, 1930.
Fox, C.S. Natural history of Indian coal. *Mem.* 57, 1931.
Fox, C.S. The Gondwana system and related formations. *Mem.* 58, 1931.
Fox, C.S. Lower Gondwana coalfields of India. *Mem.* 59, 1934.
Gee, E.R. Geology and coal resources of the Raniganj coalfield. *Mem.* 61, 1932.
Holland, T.H. Highly phosphatic mica-bearing periodotites intrusive into the Lower Gondwana rocks of Bengal. *Rec.* 27, 127-141, 1894.
King, W. Coastal region of the Godavari district. *Mem.* 16 (3), 1880.

FOSSILS.

Huxley, T.H. *et al.* Vertebrate fossils from the Panchet and Kota-Maleri rocks ; Labyrinthodonts of the Bijori group ; Reptilia and Amphibia of the Maleri-Denwa groups. *Pal. Ind. Ser. IV, Vol. I,* (1-5), 1865-85.
Feistmantel, O. Fossil flora of the Gondwana system. *Pal Ind. Ser. II, XI, XII, Vol. I-IV,* 1863-1886.
Seward, A.C. Lower Gondwana plants from Golabgarh Pass, Kashmir. *Pal. Ind. N.S. IV,* (3), 1912.
Seward, A.C. and Sahni, B. Revision of Indian Gondwana plants. *Pal. Ind. N.S. VII,* (1), 1920.
Sahni, B. Revision of Indian Fossil plants—*Coniferales. Pal. Ind. N.S. XI,* 1928-31.
Reed, F.R.C. Permo-Carboniferous marine fauna from the Umaria coalfield. *Rec.* 60, 367-398, 1928.

CHAPTER XI.

UPPER CARBONIFEROUS & PERMIAN SYSTEMS

THE UPPER PALAEOZOIC UNCONFORMITY.

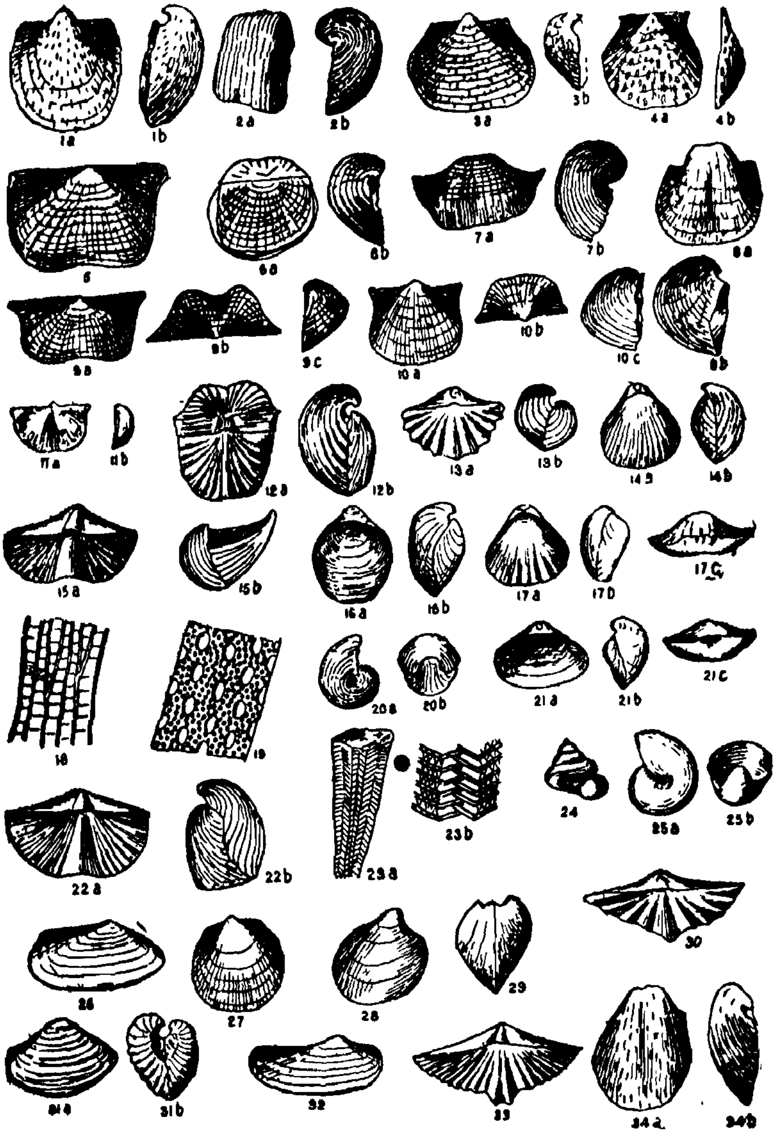
The Upper Carboniferous was a period of stupendous changes on the surface of the globe, brought about by what is known to geologists as the Hercynian revolution It brought into existence a great central ocean which extended, so far as we know, from China to Spain and in which sediments were deposited continuously from the Upper Carboniferous or Permian to the Eocene. This ocean spread over not only the area of the present Mediterranean but extended north and south beyond its present shores. The deposits laid down in its waters are recognised in the Alps, Carpathian and Caucasus mountains, and in Asia Minor, Iran, Baluchistan, Afghanistan and Tibet. This central ocean has been called the Tethys. To its north lay Angaraland comprising parts of Northern Asia. To its south was a great southern continent,—Gondwanaland—which comprised India, South Africa, South America, Australia and parts of the East Indian Archipelago. These lands, which are now separated by large stretches of oceanic waters, seem to have formed a more or less continuous land mass through the great part of the Mesozoic. This Gondwanaland was characterised by fluviatile and continental deposits, laid down apparently in faulted troughs which sank while deposition was going on. It is in these areas that we see the deposits of the Gondwana System which include most of the important coal deposits of the Southern Hemisphere.

The Upper Carboniferous revolution therefore brought about a renewal of deposition of sediments in Peninsular India which continued up to the Lower Cretaceous. The sea which had receded in the Middle and Upper Palæozoic in the northern Himalayan (Tibetan) region again transgressed over the land, with the birth of the Tethys. Only in Kashmir did land conditions prevail for a time, accompanied by the volcanic activity which extended from the Upper Carboniferous to well into the Triassic period. This area perhaps acted as a land-bridge between Gondwanaland and Angaraland during this span of time, for we have evidences in this region of a certain amount of intermingling of the two characteristic floras. The Tethyan deposits of the end of the Carboniferous times are found to begin with a conglomerate which indicates the cessation of land conditions and the commencement of a period of sedimentary deposition.

The region of the Lesser Himalayas—Hazara, Simla and Garhwal—was also affected by the revolution, since here also there are relics of glacial deposits which characterise the commencement of the Gondwanas in the Peninsula. But the deposits following this have local characters of their own, being practically unfossiliferous and showing evidences of sedimentation in enclosed basins. These basins dried up later in the Mesozoic, probably in Jurassic or Cretaceous times.

The Upper Palæozoic unconformity in the Himalayan area is of varying magnitude in different places. In Spiti it is of very short duration since the Po series of Lower to Middle Carboniferous age is followed by Permian deposits including the Productus shales. In Kumaon the Carboniferous strata are missing, the eroded surface of the Muth Quartzite being overlaid by Permian rocks. Parts of Kashmir show the presence of the Syringothyris limestone or Fenestella shales under the Agglomeratic Slates. In other places the unfossiliferous Tanawal series are seen below the deposits of the Permo-Carboniferous. Beyond the syntaxis, in Hazara, the Dogra slates are often overlain, with marked unconformity, by the glacial boulder bed called the Tanakki conglomerate. In Chitral also there is an unconformity at the top of the Carboni-

PLATE XI.
PERMOCARBONIFEROUS FOSSILS.



EXPLANATION OF PLATE XI

1. *Productus spitiensis* (1/3) 2 *P cora* (1/3). 3 *P. abichi* (2/3). 4 *P. pustulosus* (2/3). 5 *P semireticulatus* (1/4). 6 *P. indicus* (1/4) 7. *P. spiralis* (1/4) 8 *P. gangeticus* (1/3) 9 *Marginifera himalayensis* (1/3) 10 *Marginifera vihiana* (1/3) 11. *Chonetes lissarensis* (2/3). 12 *Spirifer* (Spiriferella) *rajah* 1/3). 13. *Spiriferina cristata* (1/2). 14. *Uncinella middlemissi* (1/2). 15. *Syringothyris cuspidata* (1/3). 16. *Dielasma lidarense* (1/3). 17. *Camarophoria purdoni*

ferous, the Carboniferous strata being followed by the Infra-Trias and Trias. The Salt Range, as already seen, shows a hiatus between the Salt Pseudomorph shales and the Talchir boulder bed, the latter being followed by the Speckled sandstone and this by a fine development of the marine Permian.

UPPER CARBONIFEROUS AND PERMIAN SYSTEMS.

SPITI—THE KULING SYSTEM.

The Upper Carboniferous of Spiti, as already noted, is marked by an unconformity conglomerate. This conglomerate rests on the Po series or earlier rocks and is followed by Permian strata constituting the Kuling system.

Calcareous sandstone.—The lowest members of the Kuling system are grits and quartzites, overlain by calcareous sandstones having a thickness of about 100 ft., and containing fossils which have affinities with those of the Middle Productus Limestones :

Productus sp , *Spirifer fasciger*, *S. nitiensis*, *S. marcoui*, *Dielasma latouchei*, *Aulosteges gigas*, *Spirigera gerardi*.

Products shales.—The calcareous sandstones are succeeded by a group of brown or black carbonaceous and siliceous shales called the Productus Shales which have a thickness of 100 to 200 ft. and form a fairly persistent horizon in Kashmir, Spiti, Kumaon and Nepal. They enclose, especially in the lower part, a rich and characteristic Permian fauna of the same age as the Middle and Upper Productus beds of the Salt Range, but yet of a different facies. About 30 ft. below the top, there is a

(1/3). 18. *Fenestella* aff *fossula* (3). 19. *Protoretepora ampla* (6). 20. *Euphemus urei* (2/3). 21. *Martinia dispar* (1/4). 22. *Spirifer fasciger* (1/3). 23. *Conularia warthi* (1). 24. *Pleurotomaria nuda* (2/3) 25 *Bucania warthi* (2/3). 26. *Sanguinolites tenisoni* (1/3) 27. *Discinisca warthi* (2/3). 28. *Eurydesma globosum* (1/6). 29. *Eurydesma ellipticum* (1/4). 30. *Spirifer nitiensis* (1/6). 31. *Palæocorbula difficilis* (1/4). 32. *Sanguinolites kashmiricus* (1/3). 33. *Syringothyris nagmargensis* (1/3). 34. *Productus* (Tæniotherus) *permixtus* (1/4).

horizon having a thickness of barely 1 foot, from which concretions containing cephalopods have been obtained, this being in fact the only cephalopod yielding horizon in the shales. Amongst the fossils of the Productus shales are :

Brachiopods	..	*Productus purdoni, P. abichi, P. gangeticus, Spirifer rajah, S. fasciger, Spirigera gerardi, Marginifera himalayensis, Chonetes lissarensis.*
Cephalopods	..	*Xenaspis carbonaria, Cyclolobus oldhami, C. kraffti, C. haydeni.*

HUNDES.

The Tibetan facies of the Permian is seen in the peaks of Chitichun I and Malla Sangcha where a limestone facies prevails. These are large blocks (the exotic blocks) which have been brought into their present position by volcanic floods or by thrust movements. The limestone blocks contain a rich Permian fauna comprising :

Trilobites	..	*Phillipsia middlemissi, Cheiropyge himalayensis.*
Brachiopods	..	*Productus semireticulatus, P. chitichunensis, P. gratiosus, P. abichi, Marginifera typica, Lyttonia nobilis, spirifer fasciger, S. wynnei, Martinia* cf. *glabra, M. elegans, Reticularia lineata, Spirigerella grandis, S. derbyi, Athyris roysii, A. sub-expansa, Enteletes waageni, Camarophoria purdoni, Hemiptychina himalayenis, Dielasma elongatum, Notothyris triplicata, Richthofenia* sp.
Cephalopods	..	*Nautilus hunicus, Xenaspis carbonaria, Cyclolobus walkeri.*
Anthozoa	..	*Amplexus coralloides, Zaphrentis beyrichi, Clisiophyllum* sp., *Lonsdaleia indica.*

KUMAON—GARHWAL.

The Productus shale facies continues into Painkhanda and Byans south-east of Spiti, where some of the fossils found in Spiti have been recognised, especially *Chonetes lissarensis, Spirifer nitiensis* and several Productids.

MOUNT EVEREST REGION.

The several Everest expeditions have gathered a considerable amount of information on the geology of North Sikkim and the neighbourhood of Mt. Everest. The top of Mount Everest is composed of massive, arenaceous limestone dipping gently towards the north and continuing laterally into North Sikkim. This is called the *Mount Everest Limestone*, whose thickness must be 1000 to 2000 ft. It is well bedded and contains felspathic sandy bands. Its age is Carboniferous in the main and possibly Permo-Carboniferous in part.

The Mount Everest Limestone is underlain by the *Everest Pelitic Series* of 4000 ft. thickness, consisting mainly of shaly and slaty rocks with calcareous and sandy bands. It is injected profusely by granitic rocks. Its age is probably Carboniferous or earlier.

The Everest Limestone is overlaid conformably by the *Lachi Series* which covers a large area of north Everest and in North Sikkim. It has an aggregate thickness of 2000 ft. and contains a lower fossiliferous limestone bed 50 ft. thick and an upper fossiliferous calcareous sandstone (300 ft. thick) containing upper Permian fossils. It is overlain by the *Tso Lhamo Series* of Triassic age.

The fossils in the Lachi series include :—

Lower Horizon	..	Several corals including *Straparollus lachiensis.*
Upper horizon	..	(Calcareous sandstone)—
Bryozoa	..	*Fenestrinella internata*, *Goniocladia* sp.
Brachiopods	..	*Spirifer* (*Spiriferella*) *rajah* (numerous), *spirifer* (*Neospirifer*) *musakheylensis*, *Marginifera himalayensis*, *Productus* (*Waagenoconcha*) *purdoni*, *Uncinunellina jabiensis*, *Syringothyris lydekkeri*.
Lamellibranchs	..	*Parallelodon* aff. *tenuistriatum*, *Pleurophorus* sp., *Aviculopecten hyemalis*.
Gastropod	..	*Pleurotomaria* aff. *orientalis*.

The succession in the Everest region is shown below :

Tso Lhamo Series	Dark limestones and shales (Triassic). Quartzites and shales (400 ft.).

Lachi Series ..	Calcareous sandstones (300 ft.) with Upper Permian fossils. Pebble beds (600 ft.). Limestones and shales (50 ft.). Quartzites, silts and shales (600 ft.).
Mt. Everest Limestones	Massive arenaceous limestones (1000-2000 ft) Carboniferous.
Mt. Everest Pelitic Series	Slaty rocks with bands of limestone and sandstone, injected by granite (4000 ft.).
Lower calcareous series	Limestones, shales, etc., extensively injected by granite.

ASSAM HIMALAYA.

Our knowledge of Assam Himalaya is very fragmentary and is derived from two or three traverses in connection with military expeditions into the mountainous areas. The presence of Permian rocks in the Assam Himalaya is inferred from fossiliferous pebbles and boulders brought down by the Subansiri river.

KASHMIR—PANJAL VOLCANIC SERIES.

The great revolution of the Upper Carboniferous age converted a large part of Kashmir into a land area with volcanic conditions reigning. The volcanic activity was at first of the explosive type and contributed fragmentary products which were deposited as agglomerates and pyroclastics. The later activity was mainly in the form of lava flows. It reached its climax in the early Permian ; then waning gradually, it died off finally in the Upper Triassic. While the igneous action was prevalent in certain areas, the sea was encroaching in others, so that we find marine sediments of Permian and Triassic ages side by side with products of volcanism.

Distribution.—The volcanic series is extensively developed in the Pir Panjal range whence its name is derived ; to the west of the Zanskar range up to Hazara ; in Ladakh and Baltistan; also in many areas around the Jhelum valley.

Varying age.—The earliest manifestations of volcanism seem to be of Middle to Upper Carboniferous age, *e.g.*, as early as the latter part of the Moscovian in the Lidar valley and Upper Carboniferous near Nagmarg. The trap is seen to overlap beds of various ages and its upper limits are different in different areas. In some places it underlies the Gangamopteris or Zewan beds. Near Sonamarg it is higher up in the Permian, while north and west of the Wular lake it extends to Lower, Middle and Upper Triassic and is intercalated with beds of the respective ages.

The Agglomeratic Slates.—The volcanic agglomerates are gritty or greywacke-like and grade frequently into slates. They contain angular fragments of quartz, felspar, quartz-porphyry, granite, limestone, devitrified glass, etc. They were once regarded as of glacial origin. But the absence in them of ice-scratched pebbles and boulders and the presence of devitrified glass fragments and volcanic material, have tended to support the view that they are pyroclastic and derived from volcanic explosions and rearranged by subaerial agencies.

The Agglomeratic slates are generally unfossiliferous but well-preserved fossils have been obtained from them in about half a dozen localities, the most important of which are: (1) Near Kismar hamlet at Nagmarg where they overlie the Silurian and are succeeded by the Panjal traps, the upper portion being fossiliferous; (2) in the anticline of the Marbal valley overlying the Fenestella shales; (3) in the Kolahoi-Basmai anticline where they overlie the Syringothyris Limestone, the higher beds being interbedded with the trap; (4) in the Golabgarh pass in Pir Panjal overlying the Fenestella shales.

The fossils found the these areas are :—

Brachiopods	..	*Spirifer nitiensis, S. Kismari, S fasciger, Productus cora* var. *lineatus, P. scabriculus, P. undatus, Dielasma* sp., *Chonetes* sp , *Syringothyris cuspidata, S. nagmargensis, Derbyia regularis, Camarophoria dowhatensis.*
Bryozoa	..	*Protoretepora ampla, Fenestella* sp.
Lamellibranchs	..	*Lima* sp., *Pinna* sp.

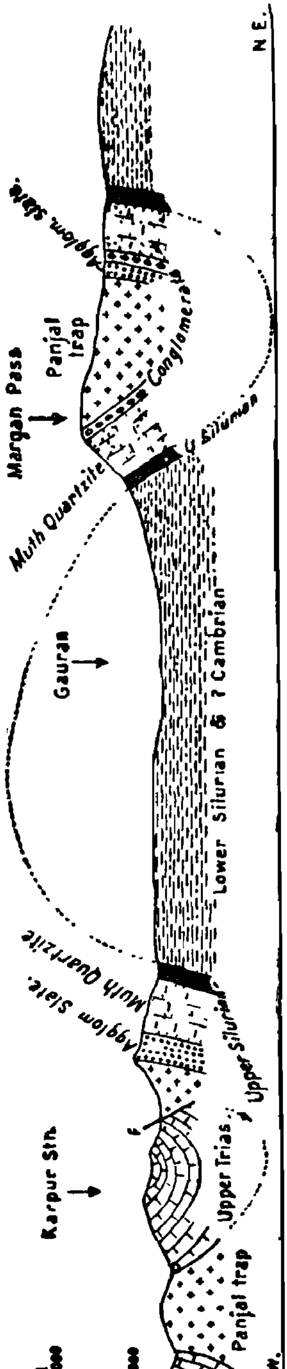


FIG. 6.—SECTION THROUGH THE NAUBUG VALLEY AND MARGAN PASS. (AFTER C. S. MIDDLEMISS, *Rec.* 40.)

Panjal Trap.—The Panjal trap consists of bedded flows of green, purple and dark colours. The lavas are sometimes amygdaloidal or porphyritic though compact fine-grained varieties are the most common. Interbedded with them are pyroclastics and occasionally sedimentary strata. The flows vary in thickness up to 20 or 30 feet and are generally lenticular. Locally they attain an enormous thickness, the maximum being estimated at 7000 feet in the Uri district.

The lavas are andesitic to basaltic in composition, but acid and ultrabasic varieties have also been found. The ferromagnesian minerals and felspars are generally seen to have been chloritised and epidotised.

Gangamopteris beds.—Beds containing Lower Gondwana plants occur intercalated with pyroclastics in several places and are overlain by the Panjal Traps. The following localities are well known as yielding typical flora; Golabgarh pass (Pir Panjal), Gulmarg, Khunmu and Risin, Nagmarg, Bren and Marahom. Near Nagmarg on the Wular lake, the soft arenaceous beds underlying these plant beds contain *Productus cora*, *P. scabriculus*, *Spirifer nitiensis*, *Derbyia*, *Syringothyris cuspidata* and *Fenestella* which given an unmistakable indication of Uralian to Lower Permian age of the fauna. The slaty plant beds contain *Gangamopteris kashmirensis*, *Glossopteris indica*, *Psygmophyllum haydeni*, *Vertebraria*; also the amphibian *Archegosaurus ornatus* and the fishes *Amblypterus kashmirensis* and *A. symmetricus*. These beds are therefore of Lower Permian (Karharbari) age.

The Apharwat ridge near Gulmarg has yielded *Gangamopteris*, *Glossopteris*, *Alethopteris*, *Cordaites* and *Psygmophyllum* from beds underlying the lava flows and overlying the Tanawal series. At Bren, near Srinagar, a *Eurydesma*-bearing horizon is just below the Gangamopteris bed. At Risin and Zewan in the Vihi district, the Gangamopteris bed underlies fossil-bearing Permian limestone and contains the amphibian *Actinodon risinensis* and the fish *Lysipterigium deterrai.*

The Gangamopteris beds have different positions with reference to the volcanics—above the volcanics at Khunmu and Gołabgarh pass, below them at Nagmarg and Bren, or intercalated with them in one or two places—and their fossil content points to the same age as that of the Talchir and Karharbari beds. The point of importance is that at the Golabgarh pass and Marahom the plantbeds underlie the Zewan beds of Middle Permian age. Their age is therefore Upper Carboniferous to Lower Permian.

ZEWAN BEDS.

The Zewan beds take their name from Zewan, a village in the Vihi district. They extend also into the Sind and Lidar valleys. At Zewan they lie on a silicified limestone (novaculite), the basal portion being a crinoidal limestone overlain by beds containing the bryozoa *Protoretepora ampla.* This horizon is well exposed in the Golabgarh pass, Zewan spur, Guryal ravine, etc. and contains, besides numerous colonies of *P. ampla*, *Lyttonia nobilis*, *Spiriferina zewanensis* and *Derbyia* sp. Above these come shales and thin limestones, about 400 to 500 ft. thick, with a rich Permian fauna. The Upper Permian beds are missing at Zewan but are well seen at Barus, a short distance away. The fauna includes :

Brachiopods	*Productus cora*, *P. indicus*, *P. spiralis*, *P. gratiosus*, *P. abichi*, *Spirifer rajah* (abundant), *S nitiensis*, *S fasciger*, *Marginifera himalayensis* (abundant) *M. vihiana*, *Spirigera gerardi*, *S. subexpansa*, *Dielasma latouchei*, *Dielasma hastatum*, *Camarophoria purdoni*, *Chonetes lissarensis*, *C. laevis*, *Spiriferina cristata*, *Lyttonia nobilis*
Bryozoa ..	*Protoretepora ampla*, *Fenestella* aff. *fossula*
Corals ..	*Amplexus*, *Zaphrentis*.

The fauna of the Zewan beds shows that they correspond to the Middle and Upper Productus Limestones of the Salt Range and to the Chitichun Limestone.

The succession in Kashmir is summarised below :

Zewan beds with *Protoretepora ampla* bed near the base.	Middle and Upper Permian.
Gangamopteris beds Agglomeratic Slates with Panjal Trap	Permo-Carboniferous to Upper Carboniferous.
Fenestella shales	Middle Carboniferous.
Syringothyris limestone ..	Lower Carboniferous.
Muth Quartzite ..	Devonian.

THE SALT RANGE.

GLACIAL BOULDER BED.

The Lower Palæozoic of the Salt Range culminates in the Salt Pseudomorph shales of presumably Cambrian age. Overlying this, with the intervention of an unconformity, is found a boulder bed of glacial origin which lies on one of the stages of the Cambrian succession. It is heterogeneous in composition, being composed of a mixture of boulders and pebbles in a matrix of fairly comminuted rock flour. The boulders are of various sizes upto 2 ft. or more across and consist of Malani rhyolite and crystalline rocks from Rajputana and Southern Punjab, which are often striated and facetted by ice action. The boulder bed attains a maximum thickness of 200 fit. Both in constitution and stratigraphical position it resembles the Talchir boulder bed of the Peninsula. The presence in it of rocks from Rajputana is proof that the boulders were derived from that region and transported by glaciers in Upper Carboniferous times.

The age of the boulder bed is indicated by the presence of spores, leaf impressions and other remains of Lower Gondwana plants in the beds immediately overlying it.

THE OLIVE SERIES.

EURYDESMA HORIZON.—The Upper Palæozoic in the eastern end of the Salt Range is represented by the Olive Series, consisting of dark greenish, yellow and white, or spotted sandstones and having a thickness of 150 ft. At its base is the boulder bed which, in certain cases, may represent re-sorted and re-deposited glacial material. Near Pidh (in the Eastern Salt Range) the sandstones immediately overlying the boulder bed contain numerous casts of marine bivalves belonging to the genus *Eurydesma* and other fossils, *viz*: *Eurydesma cordatum*, *E. hobartense*, *E. punjabicum*, *E. subovatum*, *Pterinea* cf. *lata*, *Nucula pidhensis*, *Aviculopecten* sp., *Astartila* cf. *ovalis*, *Cardiomorpha penguis*; (Brachiopod) *Dielasma dadanense*: (Bryozoa) *Fenestella fossula*.

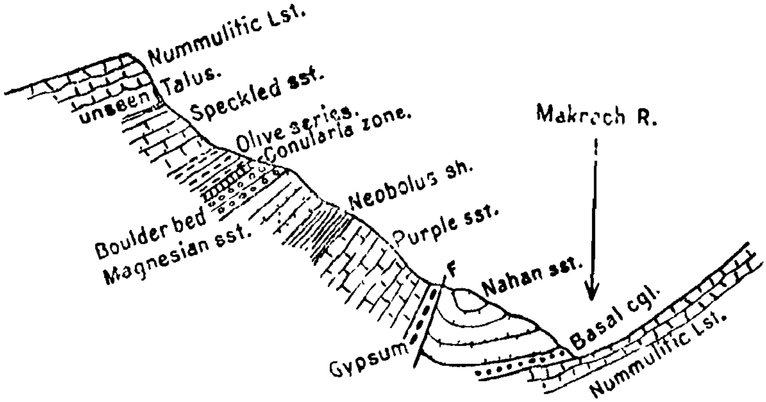


FIG. 7.—SECTION ACROSS THE MAKRACH VALLEY, SALT RANGE.
(AFTER C S. MIDDLEMISS, *Rec.* 24).

A similar Eurydesma-bearing zone is associated with the Upper carboniferous or lowermost Permian in Kashmir. The fossil contents of these two horizons show a great deal of similarity as will be seen from the following:

Salt Range.	Kashmir.
Fenestella fossula	F. fossula.
Dielasma dadanense	D. lidarense.
Aviculopecten cunctatus	A cunctatus
Cardiomorpha penguis	C. sp
Astartila cf. ovalis	A. ovalis
Eurydesma cordatum var mytiloides	E cordatum var. mytiloides.
E subobliqua	E. cordatum var subquadrata.
E punjabicum	E. globosum.

In New South Wales, Australia, two *Eurydesma* horizons are known ; the lower one with *E. hobartense* occurs just below the Gangamopteris bed and is Upper Carboniferous ; the upper one with *E. cordatum* is assigned a Permian age. Similar beds also occur associated with the Dwyka conglomerate of South Africa. The Kashmir *Eurydesma* horizon is closely allied to the Lower Permian of the Kolyma Province in Siberia, the brachiopod fauna of the two being related.

Conularia zone.—The boulder bed passes upwards, in certain places, into a calcareous sandstone and black shales containing concretions enclosing well preserved fossils among which *Conularia* is the most abundant. The *Conularia* horizon is about a foot thick and a few feet above the boulder bed and thus also slightly younger than the Eurydesma horizon. It is well seen near Choya Saidan Shah, Mt. Chel, Ratuchha, etc. The fossils in this horizon include :

Gastropods ..	*Conularia laevigata, C. warthi, C. punjabica, C. salaria, Pleurotomaria nuda, Bucania warthi.*
Lamellibranchs .	*Pseudomonotis subradialis, Sanguinolites tenisoni.*
Vermes	*Serpulites warthi.*
Brachiopods .	*Spirifer vespertilio, Martiniopsis darwini, Chonetes cracowensis, Discinisca warthi.*

Near Kathwai, the Conularia beds yielded *Glossopteris* and *Gangamopteris* impressions and the following bivalves :

Palaeomutela oblonga, Palaeonodonta salaria, P. subquadrata P. singularis. These indicate, according to Cowper Reed, a Lower Permian horizon. The Conularia fauna is also represented in the marine beds intercalated with Upper Palæozoic glacial beds in Australia.

THE SPECKLED SANDSTONE GROUP.

Boulder-bed.—West of the Nilawan ravine, the position of the Olive series is taken by the Speckled Sandstones. In their typical development they include a basal portion comprising the *Boulder-bed*, a middle portion with *Speckled Sandstones*, and an upper portion with *Lavender clays*. The boulder bed has the same stratigraphical position as that under the Olive series, and fine exposures are seen near Makrach and to its west. It is seen also near the western end of the Salt Range.

Speckled Sandstones (*sensu stricto*).—These are 200 to 400 feet thick and consist of reddish to brownish sandstone with green and purple patches. Numerous small concretionary masses are seen on the weathered surface. They contain thin intercalations of shales of purple, lavender and grey colours and also gypseous bands. The shale bands become prominent and thick in the upper part which is spoken of as Lavender clays.

Lavender Clays.—These lavender coloured shaly rocks and associated sandstones display current bedding, ripple marks and other evidences of shallow deposition. They are well seen in many places west of Nilawan and up to the Indus, beyond which they become mainly calcareous.

The Olive Series and the Speckled Sandstones are to be regarded as two facies of the same strata. They seem to be the equivalents of the Schwagerina beds of Russia and may be referred to the Upper Uralian or the lowermost Permian. The Eurydesma and Conularia beds are the equivalents of the Nagmarg beds of Kashmir and the Rikba plant beds of the Karanpura coalfield in Bihar which are all correlated with the Sakmarian stage of Russia. There is some difference of opinion amongst geologists whether to include the Sakmarian in the Upper Carboniferous or Lower Permian, but C. S. Fox is in favour of its inclusion in the Carboniferous.

THE PRODUCTUS LIMESTONE SERIES.

One of the best developed normal marine Permian areas in the world is in the Salt Range so that the Middle Permian is often referred to by the name Panjabian, after the Province in which the Salt Range lies. The Permian succession met with in this area is shown in Table 21.

TABLE 21.—PERMIAN OF THE SALT RANGE.

	Division.	Stage.	Age.
Productus Limestone Series. PERMIAN.	UPPER 100'-150'	CHIDRU (Sandstones and marls) JABBI (Sandstones and marls with Cephalopods) KUNDGHAT (Sandstones containing *Bellerophon*, etc)	Thuringian (Zechstein).
	MIDDLE 200'400'	KALABAGH (Limestones and marls with Crinoids, etc) VIRGAL (Siliceous Limestones)	Panjabian or Saxonian (Rothliegendes).
	LOWER 200'	KATTA (Calcareous sandstones and arenaceous limestones) AMB (Calcareous sandstone and limestones with *Fusulinae*)	Artinskian.
SPECKLED SANDSTONES 300'-500'		LAVENDER CLAY (50'-100') SPECKLED SANDSTONE (100'-300') *Eurydesma* and *Conularia* beds) BOULDER BED (100'-200')	Lower Permian to Uralian.

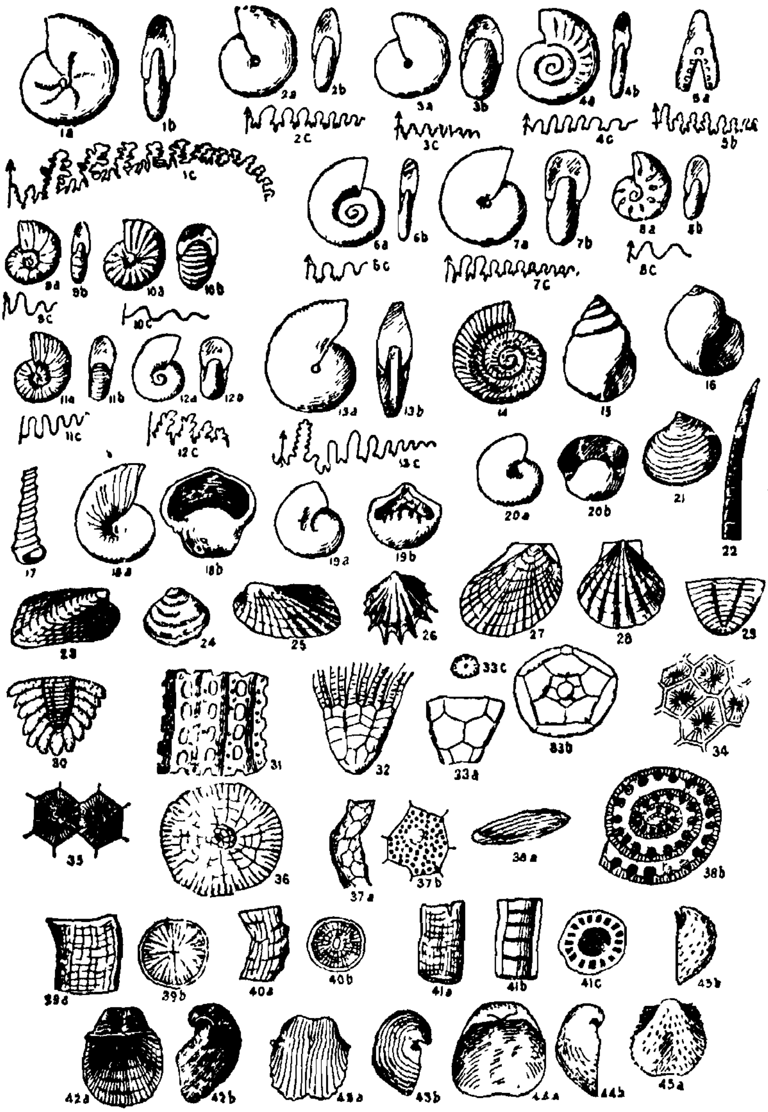
Amb.—The lowest beds of the Permian succession constitute the Amb stage which is made up of course yellowish and greenish calcareous sandstones with a few layers of coaly shales, well exposed in the Nilawan ravine. Continued westwards, they become gradually more calcareous.

Katta.—The Katta stage forms a transition between the Amb beds and the Middle Productus Limestones. It contains arenaceous limestones, Fusulinids being abundant in this as well as in the upper part of the preceding Amb stage.

Middle Productus Beds.—The most important part of the succession is the Productus Limestone proper, which forms the crags of the outer escarpment in the Salt Range.

PLATE XII.

PERMIAN FOSSILS (I).



EXPLANATION OF PLATE XII

1. *Cyclolobus oldhami* (1/6). 2. *Arcestes antiquus* (1/3) 3. *A. priscus* (1/2) 4. *Xenodiscus carbonarius* (1/4). 5 *Sageceras primas* (1/4). 6 *Xenaspis carbonaria* (1/3) 7 *Stacheoceras trimurti* (1/3). 8. *Gastrioceras* aff. *marianum* (3/2) 9. *Nomismoceras smithii* (1). 10 *Branchoceras* sp (3/2). 11 *Adrianites* (*Hoffmannia*) sp (3/2) 12 *Hyattoceras aff. cumminsi* (3/2). 13. *Sageceras* (*Medlicottia*) *wynnei* (1/4) 14. *Euomphalus parvus* (3). 15 *Macrocheilus avellanoides* (2/3).

It contains dolomite in addition to limestone, but the dolomitisation has been responsible for a good deal of obliteration of the enclosed fossils. The limestones are bluish grey to grey in colour while the dolomites are cream coloured. The limestones, which include crinoidal and coralline ones, show fossils on the weathered surfaces, while the intercalated marls contain abundant and easily extractable fossils.

The Productus Limestone proper is divided into two stages, the lower one named after Virgal and the upper after Kalabagh.

The equivalents of these beds are found in the Chitichun limestone in Northern Himalaya, in the Brachiopod beds of the Vladimir region in Russia, and the Productus limestone of the Timor region.

Upper Productus beds.—The Upper beds are to a large extent arenaceous in character and consist of three stages, Kundghat, Jabbi, and Chidru. The Kundghat stage contains abundant fossils, especially in the upper part, amongst which *Bellerophon* and *Euphemus* are important. The topmost stage, the Chidru, consists of marls and limestones which, though only 20 to 25 ft. thick, contains abundant lamellibranchs in concretions scattered through the formation. This indicates an important change in faunal characters, since the earlier stages are rich in brachiopods ; such a change may be due to a regression and shallowing up of the sea.

---

16. *Phasianella aranicola* (3) 17 *Murchisonia conjugens* (2/3). 18 *Bellerophon jonesianus* (1/3). 19. *Euphemus indicus* (2/3) 20 *Stachella bifrons* (1/3). 21 *Lucina progenetrix* (1/3). 22 *Entalis herculea* (1/12) 23 *Pleurophorus complanatus* (3/2). 24. *Gouldia primava* (3). 25. *Macrodon geminum* (1/3) 26 *Oxytoma atavum* (1/3). 27 *Lima footei* (1/3). 28. *Pecten flemingianus* (1/3) 29 *Phillipsia middlemissi* (1/3) 30. *Cheiropyge himalayensis* (1/2) 31 *Fenestella perelegans* (7) 32 *Philicrinus cometa.* 33. *Cyathocrinus indicus* (*a*, lateral view , *b*, basal, *c*, transverse section of stem). 34. *Lonsdaleia wynnei* 35 *Lonsdaleia salinaria* 36 *Lonsdaleia indica* (7). 37 *Hexagonella ramosa* (*b*, part of surface enlarged) 38 *Fusulina kattaensis* (*b*, transverse section) 39. *Zaphrentis beyrichi* (*b*, transverse section). 40. *Dibunophyllum sp.* (*b*, transverse section) 41 *Amplexus coralloides* (*a*, longitudinal and *b*, transverse sections) 42. *Productus lineatus* (1/4). 43. *P. gratiosus* (1/4) 44 *P Purdoni* (1/3). 45. *Strophalosia horrescens* (1/3).

The Ch.dru beds pass upwards into unfossiliferous marls and sandstones which contain some coaly matter. In places, an erosion unconformity is indicated by the presence of a conglomerate at the top of the Chidru stage. The Triassic beds appear above this and the passage beds are thought to represent the *Otoceras* zone of Spiti.

FAUNA OF THE PRODUCTUS LIMESTONE SERIES.

The Productus Limestone is rich in fossils, both in species and individuals. The majority are brachiopods which are abundant in all the divisions and especially in the Middle one. Lamellibranchs appear in large numbers in the Upper part of the Upper Productus Limestone, this division being characterised also by the presence of a number of cephalopods. The more important fossils of the three divisions are shown below :

LOWER PRODUCTUS BEDS ·

Brachiopods .. *Productus (Dictyoclostus) spiralis, Marginifera vestita, Strophalosia tenuispina, Aulosteges trimuensis, Dielasma trimuense, D elongatum, Hemiptychina (Beecheria) sublaevis, Spirifer (Neospirifer) marcoui, S. (N.) kimsari, Spirifer (Fusella) niger, Martinia semiglobosa, Athyris (Cleiothyridina) roissyii.*

Lamellibranchs . *Parallellodon trimuensis, Cardiomorpha sublimosa, Anodontophora purdoni.*

Gastropods .. *Bucania kattaensis, Naticopsis sessilis.*

MIDDLE PRODUCTUS BEDS .

Brachiopods .. *Orthis indica, Enteletes waageni, Streptorhynchus pelargonatus, Derbyia hemispherica, Kiangsiella Pectiniformis, Productus (Dictoyoclostus) indicus, P. (D.) transversalis, P. (Linoproductus) lineatus, P (Waagenoconcha) abichi, Marginifera typica, Camarophoria purdoni, Terebratuloidea depressa, Dielasma truncatum, Oldhamina decipiens, Richthofenia lawrenciana, Hemiptychina inflata, Spirifer (Anelasma) wynnei, Athyris (Cleiothyridina), capillata, Martiniopsis punjabica, Spiriferina*

		(Spiriferellina) cristata, Spirigerella grandis, S. derbyi.
Lamellibranchs	..	*Allorisma waageni, Schizodus dubiformis, Pseudomonotis waageni, Aviculopecten regularis.*
Gastropods	..	*Pleurotomaria (Mourlonia) punjabica.*
Cephalopods	..	*Metacoceras goliathus, Solenocheilus peregrinus, Xenaspis carbonaria.*

UPPER PRODUCTUS BEDS :

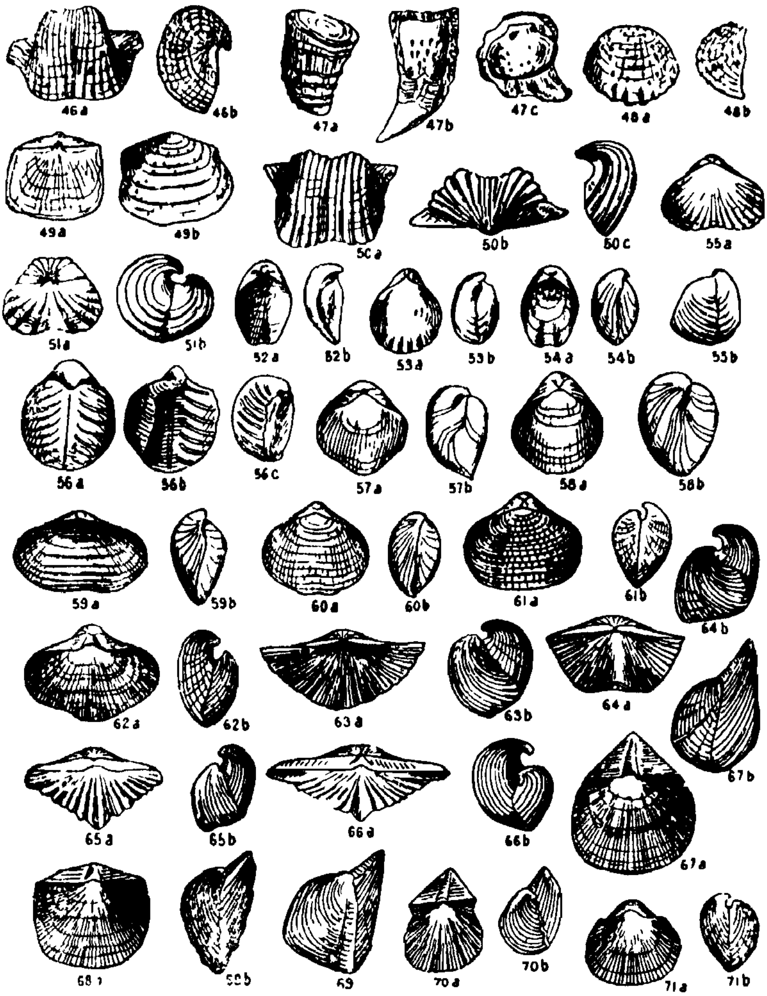
Brachiopods	..	*Schizophoria juresanensis, Enteletes sulcatus, Productus (Dictyoclostus) indicas, P. (D.) spiralis, Tschernyschewia typica, Productus (Dictyoclostus aratus, Productus (Linoproductus) cora, Strophalosia horrescens, Chonetes squamulifer, Camarophoria superstes, Lyttonia nobilis, Hemiptychina himalayensis, spirifer (Neospirifer) warchensis, Spirigerella grandis, S. praelonga.*
Lamellibranchs	..	*Schizodus emarginatus, Solemya biarmica, Aviculopecten morahensis.*
Gastropods	..	*Pleurotomaria (Worthenia) durga, Bellerophon equivocalis, B. jonesianus, Naticopsis sessilis.*
Cephalopods	..	*Foordiceras oldhami, Planetoceras postremum, Episageceras wynnei, Waagenoceras* cf. *oldhami, Xenodiscus plicatus.*

Dr. F. R. Cowper Reed, after examining the recent extensive collections from the Salt Range, states that there are no grounds, based on faunal characters, for subdividing the three major divisions of the Productus Limestones into stages as was done by Waagen. Even on purely lithological grounds, such a sub-division cannot be sustained. Even the separation of Middle and Upper Productus Limestone is difficult, for the brachiopod faunas are for the most part common to the two. However, the Upper Productus beds are more arenaceous and contain a number of lamellibranchs and cephalopods not present in the Middle division.

The Lower Productus beds are characterised by the presence of *Productus spiralis, Spirifer marcoui* and *S. niger.* The subgenus *Tæniotherus* of *Productus,* and the genus *Aulosteges* appear also to be confined to them. Many of

PLATE XIII.

PERMIAN FOSSILS II.



EXPLANATION OF PLATE XIII.

46. *Marginifera typica* (1/3) 47. *Richthofenia lawrenciana* (1/4). (*a*, large valve, *b*, section of a; *c*, small valve). 48 *Strophalosia indica* (2/3). 49 *Aulosteges medlicottianus* (1/2). 50 *Chonetes grandicosta* (1/4) 51. *Enteletes sublaevis* (1/3). 52. *Dielasma biplex* (1/3). 53. *Hemiptychina himalayensis* (2/3) 54. *Notothyris simplex* (2/3). 55 *Uncinulus theobaldi* (1/3) 56 *Oldhamina decipiens* (1/3) (*a* ventral and *b*, dorsal valves; *c*, side view) 57 *Spirigerella derbyi* (1/2) 58. *S. grandis* (1/3). 59. *Athyris subexpansa* (2/3) 60 *A ryossii* (2/3). 61. *Reticularia lineata* (2/3). 62 *Spirifer striatus* (1/3). 63. *S. musakheylensis* (1/3). 64. *S. marcoui* (1/4). 65 *S niger* (1/3). 66. *S. alatus* (1/3). 67. *Streptorhynchus pelargonatus* (3/2). 68 *Derbyia grandis* (1/6). 69 *Derbyia hemisphaerica* (1/3) 70. *Streptorhynchus pectiniformis* (2/3). 71. *Orthis indica* (2/3).

the species found in the Lower Productus beds do not seem to extend into the higher division.

The Middle Productus beds are very rich in brachiopods. The subgenera *Haydenella* and *Cancrinella* of *Productus*, and also *Ricnthofenia* are confined to them. The upper division is characterised by *Tschernyschewia* and *Cryptacanthia* and several cephalopods.

Faunal Affinities.—The lower Productus beds have affinities to the Agglomeratic Slates of Kashmir and to the Permo-Carboniferous of Western Australia. The Middle and Upper divisions correspond to the Chitichun limestone and the Zewan beds of Kashmir. The Kuling shales (Productus shales of Spiti) seem to be the equivalents of Upper Productus Limestones while the sandstones underlying the Kuling shales correspond to the Middle Productus. The Anthracolithic of Shan States show some general resemblance, though few fossils are identical. The Middle and Upper divisions are equivalent to the Lopingian of China which contains several identical species of brachiopods.

The Lower Productus beds contain a strong element of the Pacific fauna which is developed in Australia, while the Middle and Upper divisions show a similar relationship with the boreal or Russian fauna. However, mingled with these, there is a strong local or endemic fauna showing that the Indian region was a distinct life province with its own special characters.

FAUNAL CHARACTERS AND EVOLUTION.

The fauna of the Productus Limestones bears some resemblance to that of the European Carboniferous so that Dr. W. Waagen did at first correlate the two. But later studies and the discovery of marine fauna in Sicily and the Urals showed that it was really Permian. It was also realised that the Salt Range Permian rocks represent a complete succession of normal marine Permian in the world.

The fauna includes all sub-divisions of the animal world except reptiles and the higher vertebrates. Fusulinids are found in large numbers in the lower Productus beds. Crinoids, Hydrozoa and Bryozoa are plentiful ; the crinoids are all of the Palæozoic type such as *Cyathocrinus* and *Philocrinus*, and in certain places they must have been extremely abundant as they make up large masses of limestone.

The Chitichun limestone contains two trilobites, *Phillipsia middlemissi* and *Cheiropyge himalayensis* which are amongst the last of this extinct order of animals.

The extraordinary richness of the fauna in brachiopods and other fixed forms of life (crinoids and bryozoa) shows that these must have constituted veritable submarine forests at the bottom of the relatively shallow seas, and that the conditions were eminently suitable for luxuriant development of organisms. In addition to many normal forms, there were also various aberrant brachiopods. One of the most remarkable of these was *Richthofenia* (which bears a resemblance to the form assumed at a later period by the lamellibranchs classed under the *Hippuritidae*) which occurs in the Lower and Middle Productus beds. The aberrant forms *Lyttonia* and *Oldhamina* occurring in the Middle and Upper beds have dorsal valves resembling a midrib to which are attached a number of linear processes. Noetling (*Palaeontographica*, Vol. 51, 1908) regarded them as representing a specialised branch of the *Productidae*. These very specialised forms had naturally a very brief range in geological time and died off as soon as the favourable conditions of life were disturbed. The higher organised brachiopods such as the Terebratulids and Rhynchonellids survived the changes at the end of the Palæozoic era and continued to flourish in the Mesozoic.

The gastropods and lamellibranchs, which are of subordinate importance in the Himalayan Permian and in the Lower and Middle Productus beds of the Salt

Range, attain great prominence in the Upper Productus beds, and probably indicate the shallowing of the ocean basin. Amongst the gastropods, a large number belong to types in which the outer lip is notched by a slit. The most important gastropods of the Upper Productus beds are *Bellerophon* which is represented by over 20 species, *Euphemus indicus* of which an enormous number of individuals occurs, and the large tooth-shell *Entalis herculea.* The lamellibranchs are more or less concentrated in the Chidru beds; some of them (*Schizodus*, *Pleurophorus*, *Allorisma*) are typically Permian while a few precursors of the Mesozoic genera, *Mytilus* and *Septifer*, also occur.

The Cephalopods are represented by Nautiloids and early Ammonoids, the latter being abundant in the Upper Productus Limestones. The Ammonoids are easily distinguished from the Nautiloids by reason of the complicated patterns of the sutural lines. They are divided into three groups—the Goniatites, typical examples of which have rounded saddles and angular lobes; the Ceratites in which both the saddles and the lobes are generally rounded; the Ammonites in which both the saddles and lobes develop highly irregular and involved patterns.

Each of these groups has shells of various thickness in different species. At a certain stage of development there is a tendency to bifurcation of character of the shell in order to strengthen it; in the one case the shell becomes corrugated and sculptured and in the other the sutural line (*i.e.*, the line of junction of septa and the shell) becomes complicated. These two lines of development are particularly well exemplified in the Ammonites, but the Goniatites and Ceratites also show them to a somewhat limited extent. As the specific characters diverge more and more from the normal, the organism becomes delicate and any sudden changes in the environment have a disastrous effect on it. It is thus that we find these groups dying off in large numbers at the end of each geological period. Each of these groups has a limited distribution in geological time, the Goniatites being essentially Palæozoic, the Ceratites characteristic of the Triassic and the Ammonites particularly abundant in the Jurassic and Cretaceous. It was therefore that the announcement, in 1872, of Waagen's discovery of Ceratites and especially of the Ammonites in the ' Carboniferous ' strata of India came as a surprise to Palæontologists.

The species now known as *Cyclolobus oldhami* was first described by Waagen under the name of *Phylloceras oldhami* as it was believed to belong to the Ammonite group on account of the serrated outline of its sutural inflections. It was later recognised that the Goniatites and Ceratites had also the same types of developmental stages as the Ammonites. Waagen's diagnosis of *Xenodiscus* as a member of the Ceratite group proved to be correct. *Cyclolobus oldhami* is now regarded as a highly specialised member of the Goniatite group and the anomaly of a ' Carboniferous ammonite ' has been explained.

KASHMIR—HAZARA.

THE INFRA-TRIAS.

Unfossiliferous Upper Palæozoic rocks are developed in the Lesser Himalayan zone which would include the Simla, Garhwal and the Kashmir—Hazara regions, all of which seem to have some general resemblance.

The Tertiary (Murree) zone of Kashmir contains inliers of dolomitic limestone in which no fossils have been found. This is called the *Great Limestone*, and is regarded as the upper part of the Infra-Trias series of Hazara.

In western Kashmir and Hazara the Tanawal series is overlain by a boulder-conglomerate containing ice-striated boulders. This formation is probably the equivalent of the Talchir boulder-bed. Over this are found purple sandstones and shales which are in turn followed by 2000 feet of unfossiliferous dolomitic limestones. This group of rocks is known as the Infra-Trias series as it underlies Triassic formations. The dolomitic rocks are, in places (*e.g.*, in Kaghan) intercalated with flows of the Panjal trap. Their age is therefore, at least in part, Upper Carboniferous to Permian.

SIMLA-GARHWAL.

INFRA-KROL AND KROL SERIES.

The Upper Palæozoic unconformity in the Simla region is probably indicated by the presence of the Blaini boulder-bed which may be correlated with the Tanakki conglomerate of Hazara. The Blainis contain also some pink limestones and slates, the latter resembling the slates of the Infra-Krols. The Infra-Krols consist of dark slaty shales with thin bands of quartzite. The Infra-Trias is presumably represented here by the Infra-Krol and Krol series, but it must be pointed out that there is little lithological similarity between the rocks of the two areas.

In the Krol belt of the Sirmur State the Krol series is well developed. Its basal beds are Krol sandstones, orange to brown in colour, generally soft, and containing fragments of shale. They are followed by limestones which show five sub-divisions with an aggregate thickness of 2000 feet.

Krol E.—Massive cream coloured limestone, calcareous sandstone and brown shales.
„ D.—Cherty limestone, dark limestone, bleached shales and quartzites.
„ C.—Massive crystalline limestone, often sulphurous.
„ B.—Red and green shales with dolomitic limestone.
„ A.—Thin bedded blue limestone, shaly limestone, calcareous and carbonaceous shales.

In Garhwal, the Lower Krols (A) are slaty, the Middle Krols (B) being represented by purple shales and the Upper Krols (C, D, E) by massive limestone as seen around Mussoorie and further east. The Krols of the two areas are compared below :

		Simla.		Garhwal.
Krol E, D, C	Upper Krol .	Limestone		Massive limestone.
,, B	Middle Krol :	Red Shales		Purple Shales.
,, A	Lower Krol :	Limestone		Slates.

There are two great overthrusts in the Krol belt, the Giri thrust which brings the Blainis and Jaunsars over the Krol series, and the Krol thrust which brings the Infra-Krols over the Kasauli (Tertiary) beds. In the Chakrata area the Krol thrust brings the Krol and older rocks on to the Subathu beds. The Krol series is seen to be highly folded in the area between these two thrusts.

The Krols show signs of rather shallow water deposi tion and only rarely contain fragmentary and undeterminable fossils. The foetid limestones occurring in them may be taken as indicating that the basin of deposition was far from favourable for the habitation of organisms.

In the Simla region there are also the *Shali Limestones*, dolomites and slates whose age is unknown, but from whose resemblance to the Krols, the two might perhaps be correlated. The Shali limestones are overlain by the *Madhan Slates* and these in turn by the Subathu and Dagshai beds.

The Blainis may be roughly correlated with the Permo-Carboniferous, and the Infra-Krol and Krol beds with the Permian. This is however a mere conjecture.

EASTERN HIMALAYA.

In the Lesser Himalayas of Darjeeling, Buxa Duars, Bhutan and some other places further east, the Upper Carboniferous and Permian are represented by the Gondwanas in which typical Barakar rocks with carbonaceous shales and poor coal seams have been recognised. The Gondwanas are generally thrust over the Siwaliks to their south.

SELECTED BIBLIOGRAPHY.

PERMO-CARBONIFEROUS AND PERMIAN.

Auden, J.B. Geology of the Krol belt. *Rec* 67, 357-454, 1934.

Bion, H.S. and Middlemiss, C.S. Fauna of the Agglomeratic Slates of Kashmir. *Pal. Ind. N.S. XII*, 1928.

Diener, C. Geological structure of the Chitichun region. *Mem. 28*, Pt. I, 1898.

Diener, C. Anthracolithic fossils of Kashmir and Spiti. *Pal. Ind. Ser. XV, Vol. I* (2), 1899.

Diener, C. Permo-carboniferous fauna of Chitichun I. *Op cit.* Pt. 3, 1897.

Diener, C. Fossils of Productus shales of Kumaon and Garhwal. *Op. cit.* Pt. 4, 1897.

Diener, C. Permian fossils of the Central Himalayas. *Op. cit.* Pt. 5, 1903.

Diener, C. Anthracolithic fossils of Shan States. *Pal. Ind. N. S. III*, 4, 1911.

Diener, C Anthracolithic faunae of Kashmir, Kanaur and Spiti. *Pal. Ind. N.S. V.* 2, 1915.

Dunbar, C.O. Fusulinids of Lower Productus limestones. *Rec. 66*, 405-413, 1933.

Griesbach, C.L. Notes on the Central Himalayas. *Rec.* 26, 19-25, 1893.

Reed, F R.C. Upper Carboniferous fossils from Chitral and the Pamirs. *Pal. Ind. N.S. VI*, 4, 1925.

Reed, F. R. C. Fauna of the Agglomeratic slates of Kashmir. *Op. cit. XX*, 1, 1932.

Reed, F. R C. Fossils from the Productus limestone of the Salt Range, *Op. cit. XVII*, 1931

Reed, F R C Fossils from the Eurydesma and Conularia beds of the Salt Range. *Op cit. XXIII*, 1, 1936.

Reed, F. R. C. Brachiopoda and Mullusca from the Productus Limestones of the Salt Range, *Op. cit., XXIII*, 2, 1944

Reed, F. R. C. Anthracolithic faunas of S. Shan States. *Rec.* 67, 357-454, 1934

Seward, A C and Smith Woodward, A. Permo-carboniferous plants and vertebrates from Kashmir. *Pal. Ind N. S II*, 2, 1905.

Waagen, W. Salt Range Fossils (Productus Limestone). *Pal. Ind. Ser. XIII*, Vol. I, 1-7, 1879-1887.

Waagen, W. Salt Range Fossils—Geological results. *Pal. Ind. Ser. XIII*, Vol. IV, 1889-1891.

Wager, L R. The Lachi series of N. Sikkim. *Rec.* 74, 171-188, 1939.

Wynne, A.B. Geology of the Salt Range in the Punjab. *Mem. 14*, 1878.

CHAPTER XII.

THE TRIASSIC SYSTEM.

The marine Triassic is well developed in the northern Himalayan zone in the classic area of Spiti and its subdivisions are easy of correlation with those of the Mediterranean region of Europe. This belt extends into Garhwal-Kumaon, there being some differences in the lithology near the Nepal border. To the west, in Kashmir, the strata are thicker, but they have not been studied in as much detail as in Spiti, though several important zones have been identified. The Triassic of the Cis-Indus Salt Range is incompletely developed, only the lower division and the lowest part of the middle division being seen. The upper division is, however, seen in the Trans-Indus portion.

The Upper Trias is seen as a thick series of argillaceous rocks in the Zhob-Pishin region of Baluchistan on the west and in the Arakan region on the east. The Triassic rocks assume the red sandstone facies beyond and east of the Irrawaddy, as in parts of Yunnan and Szechuan, bearing some resemblance to the Gondwana strata of the same age. A marine facies is however to be seen in the areas bordering on the 'Red basin' of China and in Tonkin in Indo-China. The Tethyan facies is developed in the Malay Archipelago and in New Zealand through which apparently there was communication with the Pacific (American) basin of sedimentation. To the west of the Himalays, the Triassic rocks have been recognised in several places between them and the Alps. Indeed there is a remarkable similarity between the calcareous Tibetan facies and the Hallstatt marble facies in the Eastern Alps not only in fauna but also in lithology.

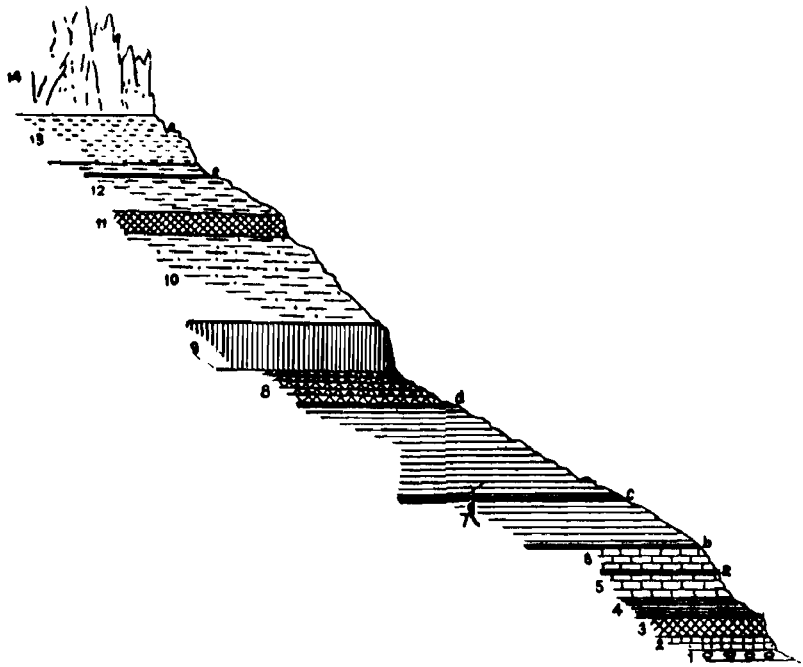


FIG. 8.—GENERALISED SECTION NEAR LILANG, SPITI
(AFTER A. VON KRAFFT. AS IN DIENER, *Mem.* 36, PT. 3).

1 Productus shales 2 Lower Trias 3 Muschelkalk 4. Daonella shales. 5. Daonella limestone 6. Halobia limestone. 7. Grey beds. 8. Tropite shales. 9. Dolomite with *Lima austriaca.* 10 Juvavites shales. 11. Coral limestone. 12 Monotis beds. 13. Quartzite series. 14. Megalodon limestone. *a.* Zone of *Joannites thanamensis.* *b.* Zone of *Joannites cymbiformis* *c* Brachipod layer (Grey beds). *d* Zone of *Tropites sub-bullatus.* *e.* Zone of *Monotis salinaria.*

SPITI: THE LILANG SYSTEM.

The most complete section of the Trias is exposed in the Spiti-Kumaon belt of the Himalaya north of its main axis where it forms immense escarpments rising often to a height of 10,000 feet from the level of the adjoining valleys. Deriving its name from the type section of Lilang in Spiti, the system is seen to comprise black limestones with shale intercalations and to attain a thickness of nearly 4,000 feet. It is entirely marine in character and is fossiliferous except

TABLE 22—TRIAS OF SPITI.

(After Hayden, *Mem*, XXXVI. Pt. 1, and Diener, *Ibid.*, Pt 3).

Divisions.		Name of beds.	Description of beds	Thickness. Ft
LIAS		Kioto (=Megalodon)	Massive limestone and dolomite (with *Stephanoceras coronatum* 350 ft below the top)	1600
UPPER TRIAS.	Noric.	limestone	Massive limestone and dolomite (with *Spirigera noetlingi*, *Megalodon ladakhensis* and *Dicerocardium himalayense* 300 to 400 ft above base)	800
		Quartzite series	White and brown quartzites with grey limestones and black shales (with *Spirigera maniensis*)	300
		Monotis shales	Sandy and shaly limestone with brown-weathering shales and sandstones (with *Monotis salinaria* and *Spiriferina griesbachi*).	300
		Coral limestone	Limestones (with *Spiriferina griesbachi*, and coral and crinoid remains).	100
		Juvavites beds	Brown-weathering shales, limestones and sandstones (with *Juvavites angulatus*)	500
	Carnic	Tropites beds	Dolomitic limestones (with *Dielasma julicum*) Shales and dark limestones with ammonite bed (*Tropites subbullatus*) 400 ft. above base.	300 600
		Grey beds	Grey shales and shaly limestones with a bivalve bed 300 ft above base, and an ammonite bed 50 ft above base (*Spiriferina shalshalensis* and *Joannites cymbiformis*)	500
		Halobia beds	Dark splintery limestone (with *Halobia cf comata*). Bed with *Joannites thanamensis* near base	140
MIDDLE TRIAS.	Ladinic	Daonella Limestone	Hard dark limestone (with *Daonella indica*).	150
		Daonella shales.	Black limestone, shaly limestone and shale (with *Daonella lommeli* and *Ptychites gerardi*).	160
	Muschelkalk.	Upper Muschelkalk	Concretionary limestone with shale bands (*Ptychites rugifer*)	20
		Lower Muschelkalk.	Dark shales and grey limestones (with *Keyserlingites dieneri*, *Sibirites prahlada*, *Spiriferina stracheyi*	6
		Nodular limestone	Hard nodular limestone with few fossils.	60
		Basal Muschelkalk	Shaly limestone (with *Rhynchonella griesbachi*)	3

Divisions		Name of beds	Description of beds	Thickness. Ft.
LOWER TRIAS.	Bunter	Hedenstroemia beds.	Limestone with *Pseudomonotis himaica*. Shaly limestones and shales alternating (unfossiliferous)	3 24
			Thin-bedded limestones and shales (with *Hedenstroemia mojsisovicsi*, *Flemingites rohilla* and *Xenodiscus nivalis*)	7
		Meekoceras Zone	Thin-bedded limestones and shales with *Meekoceras varaha* and *Meekoceras lilangense*.	3
		Ophiceras zone	Grey limestone with *Ophiceras sakuntala* and *Pseudomonotis griesbachi*	1
		Otoceras zone.	Brown limestone with *Otoceras woodwardi*.	2
PERMIAN		Productus shales	Dark shales with Permian fossils	?

in the topmost division which grades imperceptibly into the Lower Jurassic without any change in lithology.

As in Europe, it is divisible into three series, but the divisions are of very unequal thickness. The Lower Trias is only 40 ft. and the Middle 400 ft., while the Upper Trias attains a thickness of 3,500 ft.

The Himalayan Trias has been studied in Spiti, Johar, Painkhanda and Byans. Superb sections are seen in the neighbourhood of Lilang and other places in Spiti and in the Bambanag and Shalshal cliffs further east, though, unfortunately, these are difficult of access from the plains. Table 22 gives details of the general section at Lilang.

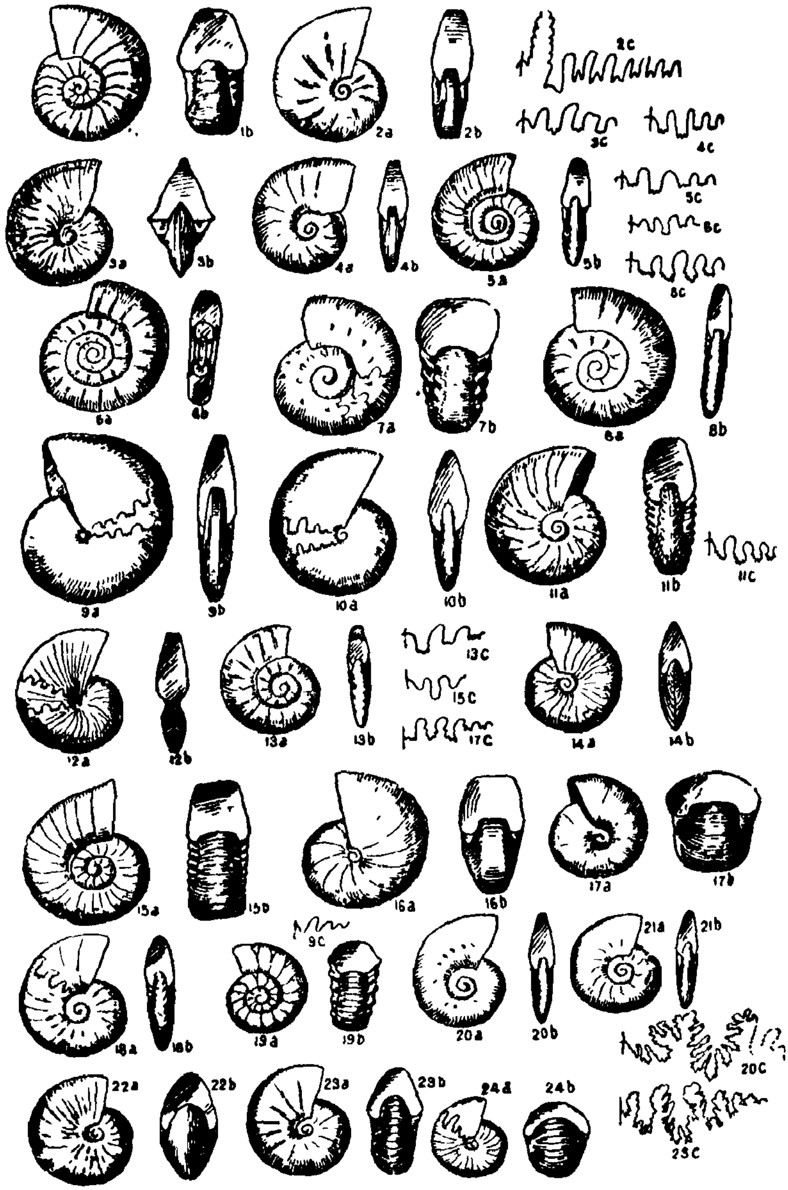
LOWER TRIAS.

The Lower Trias follows conformably on the Productus shales and consists of limestones and intercalated shales. The basal 10 feet contain rich fossiliferous zones showing at least three distinct faunal assmblages, *viz.*, *Otoceras-Ophiceras*, *Meekoceras* and *Hedenstroemia-Flemingites* faunas. The Chief fossils in these zones are :

Otoceras zone .. *Otoceras woodwardi*, *O.* cf. *undatum*, *Ophiceras sakuntala*, *Pseudosageceras dalailamae*.

PLATE XIV.

TRIASSIC FOSSILS I.



EXPLANATION OF PLATE XIV.

1 *Nautilus brahmanicus* (1/3) 2 *Medlicottia dalailamæ* (1/4). 3. *Otoceras woodwardi* (1/6). 4 *Meekoceras varaha* (1/4). 5. *Ophiceras sakuntala* (1/3). 6. *Danubites himalayanus* (1/3). 7. *Ceratites subrobustus* (1/8). 8. *Flemingites rohilla* (1/4). 9. *Hedenstroemia mojsisovicsi* (1/6) 10. *Aspidites superbus* (1/12). 11.

Ophiceras zone .. *Ophiceras sakuntala, O. tibeticum, Xenodiscus radians, Pseudomonotis griesbachi.*

Meekoceras Zone .. *Meekoceras varaha, M. markhami, M. hilangense, M. johnkense, Aspidites spitiensis, Koninckites haydeni, Xenodiscus radians*

The three above-mentioned zones are close together and separated from the *Hedenstroemia beds* by 2 to 4 feet of unfossiliferous rock. The Hedenstroemia beds contain some 30 species of cephalopods including *Hedenstroemia mojsisovicsi, Sibirites spitiensis, Pseudosageceras multilobatum, Xenodiscus nivalis, Flemingites rohilla, Aspidites muthianus, Meekoceras* cf. *joharense, Koninckites giganteus.*

These are followed by similar but unfossiliferous beds having a thickness of about 24 ft., above which a fossiliferous 3-foot bed occurs, containing *Pseudomonotis himaica* and *P. decidense.*

MIDDLE TRIAS.

The Muschelkalk.—Within 2 to 3 feet of the last mentioned bed, there is another horizon which yielded *Rhynchonella griesbachi* and *Retzia himaica* which are referable to the basal Muschelkalk. It is followed by hard, nodular limestone, about 60 ft. thick, similar in lithological characters and stratigraphical position to the Niti limestone of the Niti Pass in Kumaon, and containing only a few fossils. The over-lying beds, consisting of dark shales and limestones, constitute a typical Lower Muschelkalk horizon, with an ammonite-rich lower part and a brachiopod-rich upper part. They contain :

Cephalopods .. *Keyserlingites (Durgaites) dieneri, Danubites kansa, Dalmatites ropini, Monophyllites hara, M. confucii Sibirites prahlada.*

Brachiopods .. *Spiriferina stracheyi, Rhynchonella dieneri.*

Ceratites thuilleri (1/4). 12 *Aspidites spitiensis* (1/3) 13 *Xenodiscus radians* (1/4). 14 *Hungarites middlemissi* (1/3) 15 *Kashmirites blaschkei* (1/3) 16. *Gryphoceras whiteanum* (1/3) 17 *Isculites middlemissi* (1/3) 18 *Ceratites (Hollandites) voiti* (1/4). 19 *Sibirites prahlada* (2/3). 20. *Gymnites jollyanus* (1/4) 21. *Gymnites (Buddhaites) rama* (1/4) 22 *Ptychites gerardi* (1/4). 23. *Ptychites rugifer* (1/6) 24. *Lobites oldhamianus* (2/3).

The Upper Muschelkalk.—This consists of a concretionary limestone and contains a large number of cephalopods and a few brachiopods and mollusca. Amongst the fossils are :

Brachiopods ..	*Coenothyris* cf. *vulgaris*, *Mentzelia koeveskalliensis*.
Cephalopods ..	*Ptychites rugifer*, *P. gerardi*, *Ceratites thuilleri*, *C. trinodosus*, *C.* (*Hollandites*) *ravana*, *C.* (*H.*) *voiti*, *Beyrichites khanikoffi*, *Sturia sansovinii*, *Buddhaites rama*, *Gymnites jollyanus*, *Orthoceras spitiensis*, *Joannites* cf. *proavus*, *Proarcestes* aff. *bramantei*.

LADINIC STAGE.

Daonella Shales.—The Upper Muschelkalk bed shows a gradual passage to the Ladinic stage, there being no noticeable change in the stratigraphical unit ; that is to say, the Ladinic begins somewhere in the middle of the concretionary limestone. The lower part of the Ladinic is the Daonella shales, about 160 ft. thick, consisting of shaly limestones and shales. The passage beds contain *Spirigera hunica*, *Arpadites* cf. *lissarensis*, *Protrachyceras spitiense*, *Rimkinites nitiensis*, *Ptychites gerardi*, *Jaonnites kossmati*, *J. praovus*, *Proarcestes* cf. *balfouri*, etc. Many of the fossils are common to both the Upper Muschelkalk and the Daonella shales.

The Daonella shales enclose a typical Ladinic fauna amongst which may be mentioned : *Daonella lommeli*, *D. indica*, *Spirigera hunica*, *Hungarites pradoi*, *Rimkinites nitiensis*, *Protrachyceras spitiense*, *Pinacoceras* sp., *Ptychites gerardi*, *Joannites* cf. *proavus*, *Proarcestes* aff. *bramantei*.

Daonella Limestone.—The Daonella shales are overlaid by a mass of homogeneous splintery limestone, 280 ft. thick, but this is divided into two stages by a band of black limestone with shale intercalations in the middle. The portion (160 ft.) below this dark band contains *Daonella indica* throughout, the lower part containing also *Daonella* cf. *lommeli*. The portion containing *D. lommeli* is included in the Ladinic stage while that above is assigned to the Carnic stage. Hence, on palæontological grounds, the line of division between the Middle and Upper Trias passes halfway through the Daonella limestone. The Daonella limestone contains, besides species of *Daonella*, the cephalopods *Rimkinites nitiensis*, *Joannites kossamti*, *Celtites trigonalis*, *Monophyllites* cf. *wengensis* and the brachiopod *Rhynchonella rimkinensis*.

UPPER TRIAS: CARNIC STAGE.

The Upper Trias, which attains a huge thickness, is divisible into two main divisions, the lower mainly shaly and the higher mainly calcareous. They correspond more or less with the faunistic division as in the case of the Alps where a lower (Carnic) stage is distinct from an upper (Noric) stage. The Carnic stage in Spiti comprises the beds upwards from the upper part of the Daonella limestone to the base of the Juvavites beds.

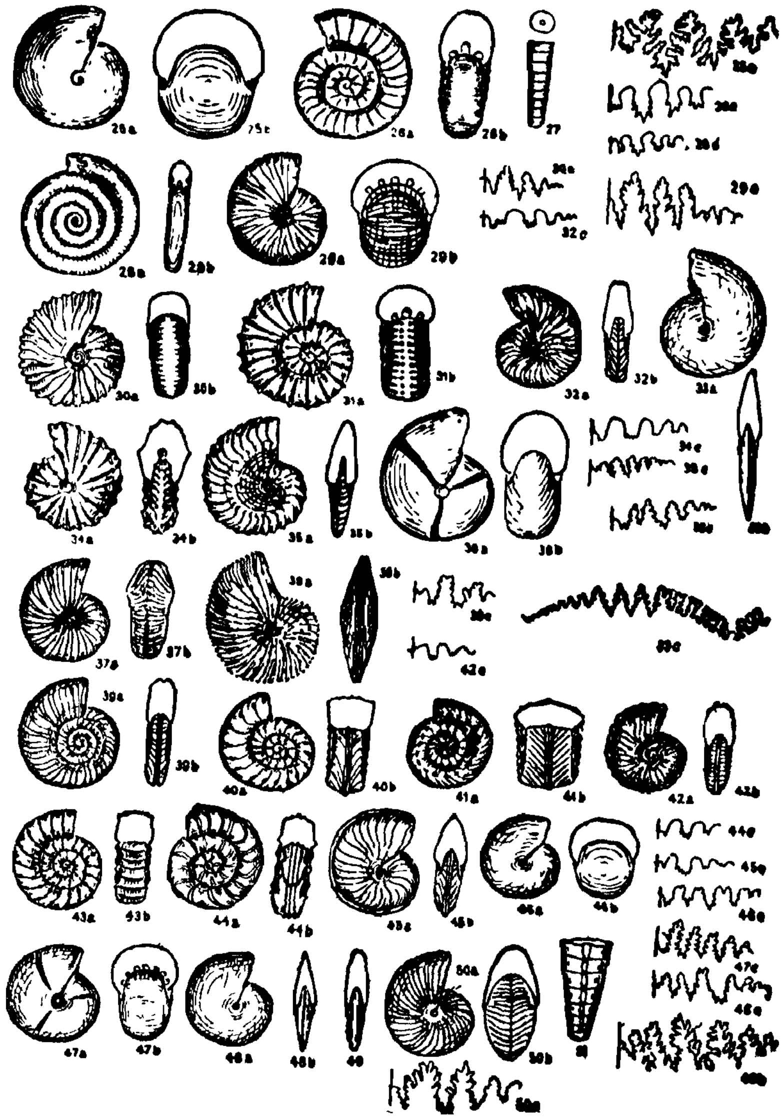
Halobia Limestone.—The dark limestone bed just above the Daonella limestone is the zone of *Joannites thanamensis*. The limestone overlying this is the Halobia limestone characterised by *Halobia* cf. *comata* which is a typical European fossil of the Julic substage of the Carnic.

Grey shales.—The Halobia limestone is overlain by the Grey shales which have a thickness of 500 feet and consist of shales with intercalations of shaly limestone. They show fossil horizons a little above the base and again at 300 ft. above the base. The lower horizon contains *Trachyceras* aff. *ariae*, *Joannites* cf. *cymbiformis*, *Monophyllites* cf. *simoyni*, etc. The upper horizon yielded only one ill-preserved ammonoid (*Paratropites* sp.) and several brachiopods and bivalves:

Brachiopods .	*Rhynchonella laucana*, *R. himaica*, *Spiriferina shalshalensis*, *S. gregaria*, *Mentzelia mentzelii*, *Dielasma julicum*.
Bivalves	*Lilangina nobilis*, *Pomarangina haydeni*, *Lima* sp.

Tropites beds.—The Grey shales are overlaid by the Tropites beds, the lower 600 feet of which are calcareous shales with limestone intercalations. About 400 ft. above the base of these there is a nodular limestone containing

PLATE XV.
TRIASSIC FOSSILS II.



EXPLANATION OF PLATE XV

25. *Proarcestes balfouri* (1/4) 26 *Danubites kansa* (1/4) 27 *Orthoceras* cf. *campanile* (1/3). 28. *Monophyllites confucii* (1/3) 29 *Halorites procyon* (1/4). 30 *Parajuvavites feistmanteli* (1/3). 31 *Clionites woodwardi* (1/3) 32. *Dittmarites hindei* (1/3). 33. *Pinacoceras parma* (1/3) 34 *Tibetites ryalli* (2/3) 35. *Bambanagites dieneri* (1/3). 36. *Joannites cymbiformis* (1/4) 37 *Juvavites angulatus* (1/3) 38. *Sirenites elegans* (1/3) 39. *Distichites sollasii* (1/8) 40. *Margarites georgi* (2/3). 41. *Tropites sub-bullatus* (1/3). 42. *Sandlingites oribasus* (1/6). 43.

a rich, but badly preserved, cephalopod fauna which includes *Tropites* cf. *subbullatus*, *T. discobullatus*, *Clydonautilus acutilobatus*, *Jovites spectabilis*, *Sandlingites* aff. *reyeri*, *Proarcestes* cf. *gaytani*.

The upper part of the Tropites beds are dolomitic limestones, with a thickness of 300 ft. also containing Carnic fossils—*Dielasma julicum*, *Spiriferina* aff. *shalshalensis* ; *Lima* cf. *austriaca*, *Halabia* aff. *superba*, *Daonella* aff. *styriaca*.

The Carnic beds, which end with this limestone, have a total thickness of 1,600 ft.

NORIC STAGE.

Juvavites Beds.—The Tropites beds are followed conformably by brown-weathering limestone with shale and sandstone beds having a total thickness of 500 ft. Their characteristic fossil is *Juvavites angulatus* which is associated with others, such as—

Juvavites aff. *ehrlichi*, *Anatomites* aff. *melchioris*, *Tibetites* cf. *ryalli*, *Pinacoceras* aff. *parma*, *Metacarnites footei*, *Dittmarites lilliformis*, *Atractites*, cf. *alveolaris*, *Paranautilus arcestiformis* :

Bivalves .. *Lima* cf. *serraticosta*, *Pecten* aff. *monilifero*, *Halobia* aff. *fascigeræ*.

Coral limestone.—The base of the overlying stage, the Coral limestone, is a calcerous sandstone with plant remains. The Coral limestone, which is 100 ft. thick, abounds in crinoidal and coral remains and contains two brachiopods *Spiriferina griesbachi* and *Rhynchonella bambanagensis*.

Monotis shales.—Above the Coral limestone are shaly limestones, black limestones, flaggy sandstones and sandy shales, which attain a thickness of 300 ft. The sandy shales and sandstones especially contain abundant fossils, which include—

Helictites cf. *geniculato* (2/3) 44 *Jellinekites barnardi* (1/3) (confined to Tropites limestone beds). 45. *Thisbites meleagri* (1/3). 46. *Didymites tectus* (1/3). 47. *Proarcestes gaytani* (1/3). 48 *Carnites floridus* (1/4). 49. *Placites polydactylus* (1/4) (numerically the most abundant fossil in the Tropites limestone bed). 50. *Jovites daciformis* (1/4). 51. *Atractites ellipticus* (1/5).

Bivalves ..	*Monotis salinaria, Lima* cf. *serraticosta, Pecten* aff. *monilifero, P. margariticostatus, Pleuromya himaica.*
Brachiopods .	*Spiriferina griesbachi, Spirigera dieneri, Aulacothyris Joharensis, Rhynchonella bambanagensis.*

Quartzite series.—Immediately above the Monotis shales are white and brown quartzites, 300 ft. thick, which form a conspicuous horizon visible from a distance. Most of its fossils are also found in the Monotis shales, but *Spirigera maniensis* is restricted to it.

Megalodon limestone (=Kioto limestone).—The topmost beds of the Triassic sequence are thick massive limestones and dolomites which Griesbach originally included in his Rhætic system. Their total thickness is of the order of 2,500 ft. and they bear a striking resemblance to the Dachsteinkalk of the Alpine region both in lithology and stratigraphical position. They have a uniform appearance throughout their thickness and are for the most part unfossiliferous. Fossils have been found between 200 and 300 ft. from the base, amongst which are—

Megalodon ladakhensis, Entolium cf. *subdemissum, Pecten chabrangensis, Lima cumaunica; Spirigera noetlingi, Spiriferina* cf. *haueri.*

Near Hansi, large numbers of *Megalodon ladakhensis* and *Diceracardium himalayense* are seen in the limestone about 50 ft. above the Quartzite series. This was called the *Para Limestone* by F. Stoliczka and referred to the Rhætic. The fossil assemblage however shows the limestone to be Noric.

The Megalodon Limestone, to which Hayden has advocated the use of the name Kioto Limestone, is overlain by the *Spiti Shales* of Callovian age. Near Giumal, the Megalodon limestone yielded the typical Middle Jurassic fossil *Stephanoceras coronatum* about 370 feet below the base of the Spiti Shales. About 1,000 feet further below (*i.e.*, below the *Stephanoceras coronatum* zone) *Spiriferina* cf. *obtusa* was found which is probably Liassic in age. Diener has therefore come to the conclusion that, out of a total thickness of 2,550 ft. for the Megalodon Limestone, the lower

800 ft. may be assumed to be Upper Triassic and the rest Jurassic.

PAINKHANDA (KUMAON).

Excellent sections of the Trias are exposed in the Bambanag and Shalshal cliffs in the north-western part of Kumaon. Table 23 shows the general succession observed. The Painkhanda section, though resembling that of Spiti, has some peculiarities. In particular, the Ladinic stage dwindles down to insignificance and the Upper Trias is much less thick.

The lowest three beds of the Trias contain the *Otoceras-Ophiceras* fauna in which, besides species of these, there are *Episageceras dalailamae*, *Hungarites* sp., *Meekoceras hodgsoni*, *Xenodiscus himalayanus*, etc. The top of the lowest zone contains also abundant *Pseudomonotis griesbachi.* Dark shales having a thickness of 18 ft. intervene between the Ophiceras beds and the Meekoceras beds, which are succeeded by 5 ft. of unfossiliferous grey limestones and these again by the Hedenstroemia beds which contain *Flemingites rohilla*, *Xenodiscus nivalis* and *Pseudomonotis himaica.*

The *Muschelkalk* begins with a 3-foot limestone zone containing *Rhynchonella griesbachi* and *Sibirites prahlada.* The nodular limestone of Spiti is represented here by the Niti limestone having a thickness of 60 ft. The *Spiriferina stracheyi* beds with *Keyserlingites dieneri*, *Monophyllites hara* and *Dalmatites ropini* overlie the Niti limestone. They are followed by the Upper Muschelkalk limestone (Ptychites beds) enclosing a very rich Cephalopod fauna the important species in it being : *Hollandites voiti*, *H. ravana*, *Ceratites thuilleri*, *C. trinodosus*, *Beyrichites khanikoffi*, *Buddhaites rama*, *Gymnites jollyanus*, *G. vasantasena*, *Ptychites rugifer*, *P. gerardi.*

The Ladinic stage is all but absent, being represented by 20 ft. of thin bedded limestones containing a few fossils, most of which are the same as those occurring in the overlying beds. It is only the presence of *Joannites* cf.

TABLE 23.—TRIASSIC SECTION IN PAINKHANDA.

LIAS		Megalodon limestone (in part) ..	1500'
Noric.	Upper	Megalodon limestone (in part) ..	500'?
	Middle	Quartzite series with *Spirigera maniensis* ..	250'
		Sagenite or Anodontophora beds : Brown limestones with *Anodontophora griesbachi* ..	160'
	Lower	Earthy limestones with *Spiriferina griesbachi* passing down into calcareous shales ..	320'
		Halorites beds · Massive grey limestones with numerous cephalopods, especially *Halorites procyon* and other species.	200'
		Nodular and slaty limestone with *Proclydonautilus griesbachi*	100'
Carnic		Halobia beds : Black flaggy limestones, shales, massive earthy grey limestones and dolomites passing up into micaceous shales, with *Halobia* cf *comata* ..	800'
		Traumatocrinus beds Black flaggy limestones with shale partings, with *Traumatocrinus* and *Daonella indica* ..	10'
Ladinic		Passage beds (shalshal) Thin bedded concretionary limestone with *Daonella indica*, *Spirigera hunica*	20'
Muschelkalk		Upper Muschelkalk limestone with *Ptychites rugifer* ..	20'
		Spiriferina stracheyi beds with *Keyserlingites dieneri* ..	3'
		Niti limestone—Hard nodular limestone ..	60'
		Shaly limestone with *Rhynchonella griesbachi* and *Sibirites prahlada* ..	3'
Lower Trias		Hedenstroemia beds : Thin bedded grey limestone with shale partings, with *Flemingites rohilla* and *Pseudomonotis himaica* near the top ..	25'
		Grey limestone—no determinable fossils ..	5'
		Meekoceras bed—Dark concretionary limestone with *Meekoceras varaha* and *M markhami* ..	1'
		Dark blue shales—Unfossiliferous ..	18'
		Dark limestone with *Otoceras woodwardi* and *Ophiceras tibeticum*	$\frac{1}{2}$'
		Dark hard clay with concretions containing *Episageceras dalailamae* and *Ptychites scheibleri* ..	$1\frac{1}{2}$'
		Dark blue limestone with *Otoceras woodwardi* and *Ophiceras sakuntala*	1'
Premian		Productus shales	

proavus that indicates the presence of the Ladinic. The characteristic fossil of this stage, *Daonella* cf. *lommeli*, is not found in Painkhanda.

The beds above them are the *Traumatocrinus beds*—well-bedded limestones containing abundant crinoid stems, cephalopods, etc., which indicate the Julic horizon of the Carnic stage. The fossil fauna includes:

Bivalves	..	*Daonella indica*
Brachiopods	..	*Spirigera hunica, Retzia* aff. *ladina, Aulacothyris nilangensis, Rhynchonella rimkinensis.*
Cephalopods	..	*Proclydonautilus* cf. *buddhaicus, Joannites cymbiformis, J. kossmati, Grypoceras rimkinensis, Lobites delphinocephalus, Anatomites* sp., *Carnites* cf. *floridus, Rimkinites nitiensis, Arpadites rimkinensis, Dittmarites* cf. *circumscissus, Trachyceras austriacum, Sirenites cookei.*

Overlying the crinoidal beds are a thick series of dark carbonaceous shales and shaly limestones which constitute the *Halobia beds.* They are 650 ft. to 800 ft. thick and contain fossils throughout and especially in the lower part:

Brachiopods	..	*Spiriferina shalshalensis, Retzia schwageri, Rhynchonella laucana.*
Lamellibranchs	..	*Halobia* cf. *comata, Avicula girthiana.*
Cephalopods	..	*Jovites* aff. *daci, Anatomites bambanagensis, Juvavites* cf. *tonkinensis, Placites polydactylus, Mojsvarites eugyrus, Discophyllites ebneri*; also *Sagenites, Tibetites, Monophyllites, Proarcestes,* etc., which could not be determined specifically because of the poor state of preservation.

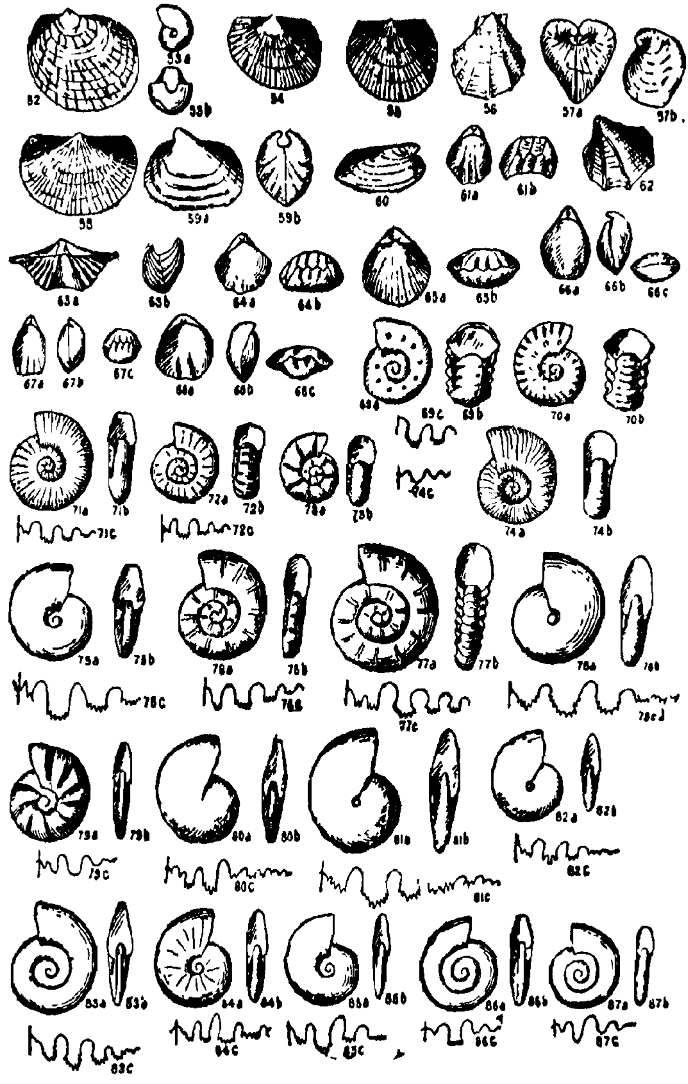
The lowest beds of the Noric stage are nodular and shaly limestones, 100 ft. thick, containing *Proclydonautilus griesbachi, Pinacoceras* aff. *imperator, Metacarnites* sp., *Arcestes, Sagenites, Juvavites,* etc.

The Halobia beds are succeeded by the *Halorites beds,* consisting of dark shales with limestone bands. The fossiliferous Halorites zone, about 20 to 30 ft. above the base, is a rich cephalopod horizon containing numerous fossils of which mention may be made of—

Halorites procyon, H. Sapphonis, Parajuvavites blanfordi, Tibetites ryalli, Paratibetites bertrandi, Helictites atalanta, Steinmannites desiderii, Clionites woodwardi, Sirenites richteri, Sandlingites nicolai, Pinacoceras metternichi, P. parma, Bambanagites dieneri, Placites sakuntala; also a few brachiopods

PLATE XVI.

TRIASSIC FOSSILS III.



EXPLANATION OF PLATE XVI.

52 *Pseudomonotis griesbachi* (1/3) 53 *Bellerophon vaceki* (2/3). 54 *Daonella lommeli* (1/3). 55 *Daonella indica* (1/4). 56. *Lima serraticosta* (1/3). 57. *Megalodon ladakhensis* (1/8) 58 *Halobia comata* (1/3). 59. *Anodontophora griesbachi* (1/3). 60. *Myophoria* cf *ovatae* (1/4) 61 *Rhynchonella trinodosi* (2/3) 62 *Myophoria middlemissi* (1/3). 63 *Spiriferina stracheyi* (1/2). 64 *Rhynchonella griesbachi* (2/3). 65 *Retzia himaica* (2/3). 66 *Spirigera hunica* (2/3). 67. *Rhynchonella imkinensis* (2/3). 68 *Dielasma julicum* (1/2).

and lamellibranchs including *Rhynchonella bambanagensis*, *Anodontaphora griesbachi*, *Lima serraticosta* and *Halobia* cf. *comata*.

The Halorites beds pass upwards into earthy compact limestones, often dolomitic or micaceous, having a thickness of over 300 ft. They contain abundant *Spiriferina griesbachi*, and also *Spirigera dieneri*, *Aulacothyris joharensis* and *Retzia schwageri*, and the bivalves *Lima cumaunica* and *Pecten interruptus*. Above them are the beds containing *Anodontophora griesbachi* in which a specimen of *Sagenites* was discovered. They are liver-coloured or brown limestones having a thickness of about 150 ft. They are overlain by the *Quartzite series* similar in constitution to that of Spiti and containing *Spirigera maniensis* and *S. dieneri*. The topmost beds are, as in Spiti, the Megalodon limestones which here have a thickness of 1,800 to 2,000 ft. of which perhaps 500 to 600 ft. may be of Upper Triassic (Upper Noric) age and the rest Lower Jurassic.

BYANS.

The Triassic succession in Byans in north-eastern Kumaon, close to the Nepal border, is less well developed than in the western areas and the facies is also generally different, limestones predominating to a very large extent.

The Lower Trias of Byans is composed of chocolate coloured limestone with shales in the lower part. The basal portion contains *Otoceras* and *Meekoceras* fauna, while the *Hedenstroemia* bed of Spiti is here represented by the *Sibirites spiniger* zone. The Muschelkalk is a light grey limestone without any shales, contrasting strongly with the shaly facies elsewhere. It contains a brachiopod bed

---

The following fossils are from the Salt Range.

69. *Stephanites superbus* (1/12). 70. *Achrochordiceras coronatum* (1/4) 71. *Ceratites normalis* (1/4). 72. *Celtites armatus* (1/4). 73. *Dinarites coronatus* (1/2). 74. *Sibirites chidruensis* (1/3). 75. *Gonіodiscus typus* (1/2). 76. *Flemingites radiatus* (1/6) 77. *Flemingites flemingianus* (1/12). 78. *Proptychites lawrencianus* (1/6). 79. *Ambites discus* (1/4). 80. *Clypites kingianus* (1/4). 81 *Aspidites superbus* (1/12). 82. *Kingites lens* (1/4). 83. *Koninckites volutus* (1/3). 84. *Meekoceras varians* (1/6). 85 *Prionolobus rotundatus* (1/4). 86. *Gyronites frequens* (1/3) 87. *Lecanites gangeticus* (1/3).

TABLE 24.—TRIAS OF BYANS.

Noric	Megalodon Limestone (in part)	? 400'
	Grey limestones with shales at the top, containing undeterminable ammonites	1000'
	Black shales with *Arcestes*	
Carnic	Tropites limestone very rich in fossils	3'
? Ladinic	Light grey Limestones unfossiliferous	170'
	,, ,, Cephalopod bed with *Ceratites thuilleri*, *Buddhaites rama*, etc.	10'
Muschelkalk	,, ,, Brachiopod bed with *Spiriferina stracheyi* and *Rhynchonella griesbachi*	10'
	,, ,, mainly unfossiliferous	70'
Lower Trias	Chocolate limestone with some shales — *Sibirites spiniger* zone near top; *Meekoceras* and *Otoceras* fauna near bottom	150'
Permian	Productus shales.	

70 ft. above the base and a cephalopod bed a little above it. The latter contains, besides some familiar cephalopods such as *Ceratites thuilleri*, *Buddhaites rama*, *Gymnites jollyanus* and *Ptychites sahadeva*, also species not known elsewhere, *e.g.*, *Smithoceras drummondi*, *Bukowskites colvini*, *Pinacoceras loomisii* and *Philippites jolinkanus*. The Ladinic is apparently absent. At the top of the limestone, a 3-foot zone constitutes the Tropites zone which is extraordinarily rich in fossils representing a mingling of Carnic and Noric typess This mixture is apparently due to the faunal remain. accumulating more rapidly than the sediments at the sea bottom. The Noric is, however, well represented by a series of thick shales and limestones overlaid by limestones of the Dachsteinkalk type (*i.e.*, Megalodon limestone). The shaly beds and associated limestones are about 1,000 ft. thick and fossils found in them are all crushed and undeterminable, even generically. The Megalodon limestone is 1,500 ft. thick, and as usual includes the Lower Jurassic.

Some 150 species of cephalopods have been identified from the Tropites limestone besides which there are several which are not specifically determinable. Two-thirds of the species are peculiar to this region while the rest are identical with species of the Hallstatt marble of the Alps. The fauna of the Tropites limestone includes the following :—

Lamellibranchs . *Halobia* cf. *comata*, *H.* cf. *fascigera*, *Avicula* aff. *caudata*.

Cephalopods .. *Atractites* cf. *ellipticus*, *Orthoceras* cf. *triadicum*, *Proclydonautilus griesbachiformis*, *Pinacoceras parma*, *P. metternichi*, *Placites polydactylus*, var. *oldhami* (Placites being numerically the most abundant fossil), *Bambanagites kraffti*, *Carnites* cf. *floridus*, *Megaphyllites jarbas*, *Discophyllites ebneri*, *Arcestes diceras*, *Proarcestes* cf. *gaytani*, *Lobites* cf. *ellipticus*,

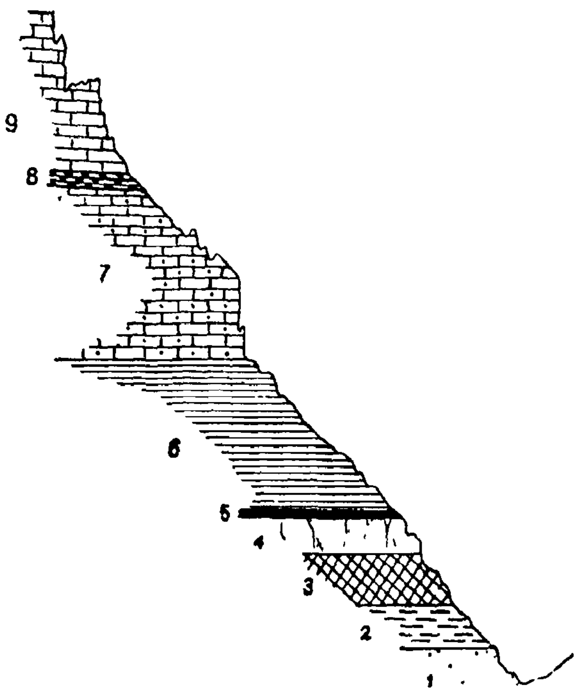


FIG 9.—SECTION N. W OF KALAPANI, BYANS
(AFTER A. VON KRAFFT AS IN DIENER, *Mem* 36, Pt. 3.)

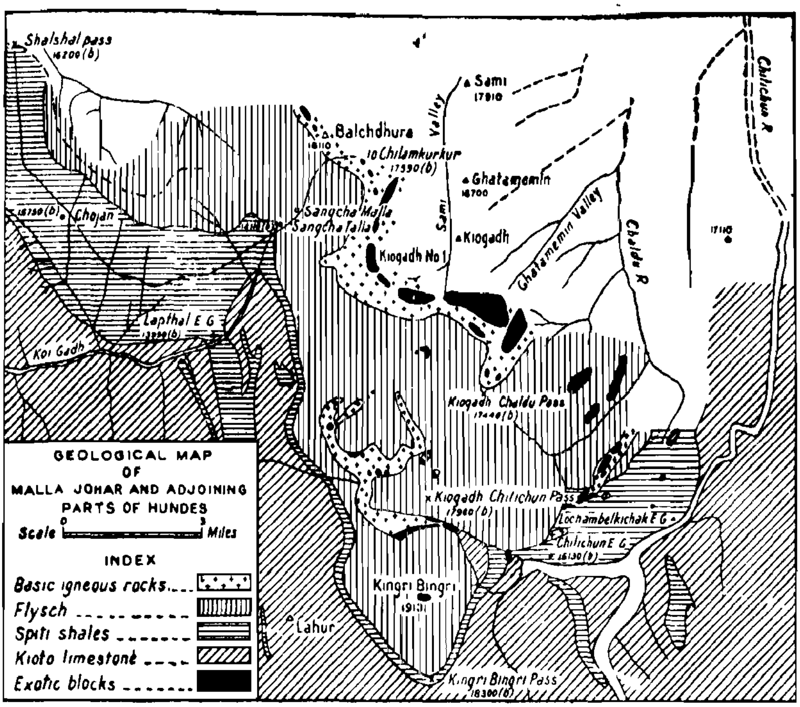
1. White quartzite 2 Productus shales 3 Chocolate limestone (L. Trias). 4. Grey limestone (Muschelkalk, Ladinic and Carnic stages). 5 Tropites limestone. 6. Black shales with *Arcestes*. 7. Grey limestone. 8. Shales with ammonites. 9. Megalodon limestone.

Helictites cf. *geniculatus*, *Thisbites meleagri*, *Jellinekites barnardi*, *Arpadites tassilo*, *Dittmarites rawlinsoni*, *Drepanites schucherti*, *Tibetites* cf. *ryalli*, *Paratibetites adolphi*, *Himavatites watsoni*, *Clionites gracilis*, *Sandlingites* cf. *oribasus*, *Sirenites* cf. *argonautae*, *S. vredenburgi*, *Distichites sollasii*, *D. ectolcitiformis*, *Ectolcites hollandi*, *Isculites smithii*, *Halorites* aff *procyon*, *Jovites spectabilis*, *Anatomites speciosus*, *Didymites tectus*, *Discotropites krafftii*, *Margarites acutus*, *Tropites subbullatus*, *T.* cf. *fusobullatus*, *Anatropites nihalensis*, etc.

JOHAR.

North of the main Mesozoic belt of the northern Himalaya there is a region of the Tibetan frontier of Kumaon—Malla Johar, Balchdhura and Chitichun—containing a large number of blocks and masses of limestone lying pellmell over the Mesozoic rocks, and closely asso-

MAP IX.



ciated with lavas of late Cretaceous or Eocene age and of andesitic to basaltic composition. The masses vary in size from small boulders to those as big as hillocks, and even sheet-like masses covering a few square miles. The limestone is entirely different from any known in the Himalayan region and the fossil contents have also a different facies, being allied more to the Eastern Alps than to Spiti or Kumaon, and must belong to some area in Tibet where it was originally deposited.

These are the 'exotic blocks' described by A. von Krafft and C. Diener. Their presence close to the Spiti zone is explained as due to shattering by volcanic explosions and transport by lava flows to their present position. An alternative hypothesis is that they represent the remnants of overthrust sheets ('nappes') which carried the rocks from their original site.

The exotic blocks include limestones of Permian to Cretaceous age. Some of them contain the equivalents of the Triassic horizons observed in the Shalshal cliff, but the horizons are of smaller thickness and the facies quite different, the Upper Triassic especially being extraordinarily like the red and white Hallstatt marble of the Alps both in lithology and fossil content.

The Lower Trias is represented by earthy limestones containing *Meekoceras joharense*, *Xenodiscus nivalis* and *Hedenstræmia* cf. *byansica*, which facies is closely related to that of Spiti. The Middle Trias was noticed near Chitichun I, containing *Ceratites (Danubites) kansa*, *Sibirites pandya*, *Monophyllites confucii*, *Xenaspis middlemissi*, etc., which can be correlated faunistically with the *Spiriferina stracheyi* beds of the Muschelkalk. The Carnic stage is represented by the red marble blocks in Balchdhura and Malla Johar containing *Cladiscites crassestriatus*, *Arcestes* cf. *richthofeni*, *Proarcestes gaytani*, *Pinacoceras* aff. *rex*, *Tropites* cf. *subbullatus*, *Juvavites kraffti*, *Tibetites bhotensis*, etc., which show greater affinites to the Julic and Tuvalic stages of the Alpine Hallstatt marble than to the corresponding stages of Spiti.

Arcestes and *Cladiscites* which occur in great numbers in these blocks are characteristic of the Hallstatt marble and rare in Spiti. The Upper Noric is represented by white or grey dolomitic limestone different in appearance from the Megalodon limestone, and containing no fossils. The Liassic has also a striking resemblance to the Alpine facies as in the case of the Carnic stage of the Triassic.

KASHMIR.

The Himalayan Triassic belt extends into Kashmir and occurs in the Sind and Lidar valleys, Wardwan, Gurais and Central Ladakh and also in north-west Kashmir and Pir Panjal. In the Pir Panjal the Trias occurs as a long thin band extending from Kishtwar on the east to Tosh Maidan beyond the Jhelum valley on the west. In north-western Kashmir only the Upper Trias is seen. Good sections are observed in the Vihi district near Khunmu, Khrew and in the Guryal ravine. The Kashmir Triassic beds are easily accessible from the Kashmir valley, in contrast with the other Himalayan occurrences.

TABLE 25.—TRIAS OF KASHMIR.

Upper (several thousand ft)	Grey to dark, massive limestone with occasional fossils. mostly fragmentary. Zone of *Spiriferina stracheyi* and *S* cf *haueri* Lamellibranch beds
Middle (over 900 ft)	Ptychites horizon sandy shales with calcareous layers. Ceratite beds " " " *Rhynchonella trinodosi* beds " " " Gymnites and Ceratite beds—Red and grey slabby limestone. Lower nodular limestones and shales. Interbedded thin limestones, shales and sandy limestones.
Lower (over 300 ft.)	Hungarites shales (position uncertain). Meekoceras beds—limestones and shales. Ophiceras limestone.

LOWER TRIAS.

The Lower Trias is well represented in the Sind and Lidar valleys. Good sections have been studied near

Pastanna and other places but the lowest beds are much concealed by scree and vegetation. The horizons known in Spiti have been found here, except the basal Otoceras zone. The Ophiceras zone contains :

Ophiceras sakuntala, O. ptychodes, Xenodiscus himalayanas, X cf. *ophioneu., Vishnuites pralambha ; Pseudomonotis griesbachi, P. painkhandana*, etc.

A slightly younger fauna, of the Hedenstroemia zone, is found in the Guryal ravine. It shows :

Flemingites sp , *Meekoceras* aff. *jolinkense, Prionites guryulensis, Sibirites kashmiricus, Kashmirites blaschkei, Stephanites superbo, Hungarites* sp.

The Lower Trias has a thickness of over 300 ft., and systematic excavations may reveal more fossiliferous zones.

MIDDLE TRIAS.

Above the Hungarites zone there occurs a succession of thin bedded limestones with intercalated shale and sandstone layers. The lower 200 ft. consist of dark grey limestones with only occasional lamellibranchs. They are overlain by alternating beds of thin limestones and shales and these again by 100 ft. of grey, thin bedded sandy limestone containing a lamellibranch bed near its base. Above this is a bed 200 ft. thick, of pale nodular sandy limestone with hard shale partings, containing cephalopod horizons 20 ft. and 80 ft. respectively below the top. At the top of the last mentioned beds is a conspicuous horizon of red and grey slabby limestones rich in *Gymnites* and other fossils (Gymnites and Ceratites beds). These have yielded :

Ceratites thuilleri, Hollandites voiti, H. ravana, Beyrichites khanikofi, Sibirites cf. *prahlada, Gymnites jollyanus, G. sankara, Acrochordiceras balarama, Buddhaites rama, Grypoceras vihianum*, and some lamellibranchs.

Twenty feet above the main *Gymnites horizon* is another fossiliferous bed of the same character, the intervening beds being black shales. They are followed by 400 to 600 ft. of alternating limestones and shales. In the Khrew section, the *Ptychites horizon* occurs about

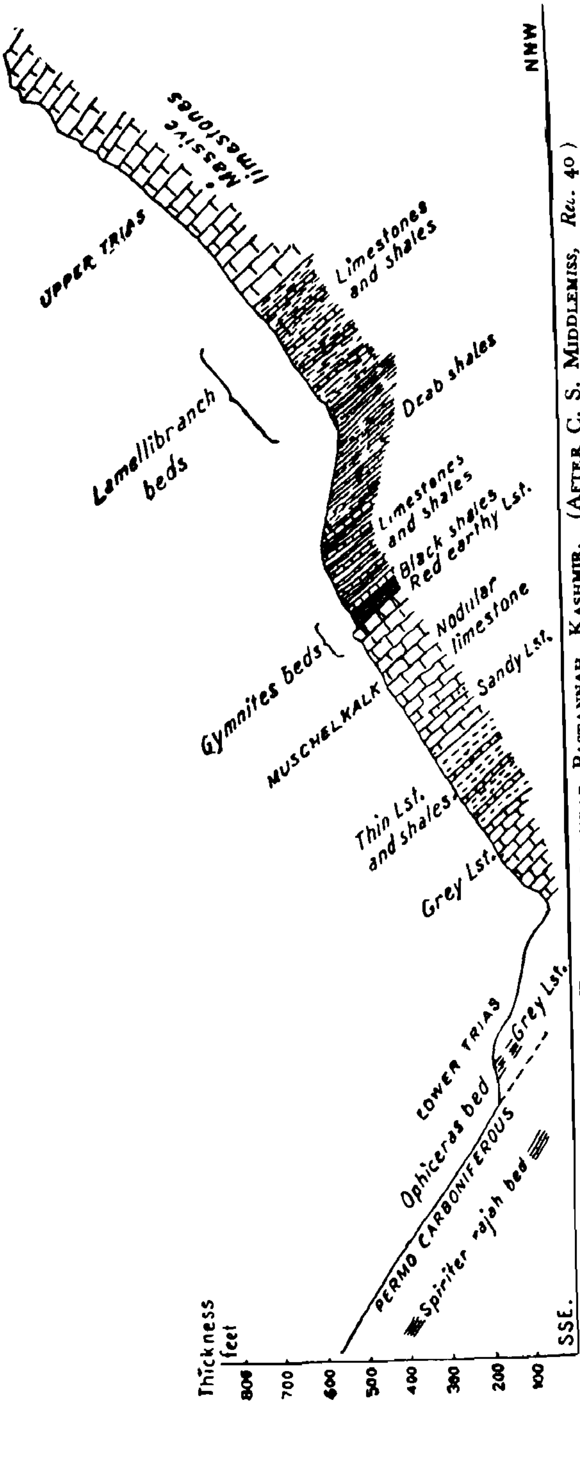


FIG. 10.—SECTION OF THE TRIASSIC ROCKS NEAR PASTANNAH, KASHMIR. (AFTER C. S. MIDDLEMISS, *Rec.* 40)

530 ft. above the Gymnites beds and contains the following:

Ceratites trinodosus, Buddhaites rama, Ptychites sahadeva, Ptychites sp., *Mojsvaroceras kagae, Grypoceras vihianum* ; *Myophoria, Lima, Pecten,* etc.

These belong to the Upper Muschelkalk.

UPPER TRIAS.

The *Ptychites*-bearing beds pass gradually upwards into massive limestones. The Lamellibranch bed and the zone of *Spiriferina griesbachi* occur in the lowest parts of the Upper Trias and belong to the Carnic stage. The lamellibranch bed contains only one brachiopod, *Dielasma julicum*, but is rich in lamellibranchs, including :—

Myophoria middlemissi, M. cf. *kefersteini, Hoernesia bhavani, Chlamys middlemissii, Pseudomonotis* sp., *Lima* cf. *subpunctata.*

The *Spiriferina stracheyi* bed contains, besides that fossil, *Spiriferina* aff. *lilangensis, Mentzelia mentzelii, Rhynchonella trinodosi*, etc.

The Upper Trias is well developed in the mountains of Vihi and Anantnag districts and in other places and forms conspicuous scarps. It lacks the Daonella and Halobia beds which are developed in Spiti. But further search may reveal the equivalents of these. The upper portion resembles the Megalodon (or Kioto) limestone but has not yielded any *Megalodon* in the Vihi district. Elsewhere in Kashmir it is known to contain some corals, crinoidal stems and bivalves.

SIKKIM.

Above the Lachi series of Permian age there occur Triassic beds. In the Lachi ridge the calcareous sandstone with Upper Permian fossils is overlaid by thick quartzites and shales having a thickness of several hundred feet. These may be of Triassic age. In the same region, some dark limestones and shales have been obtained, containing Triassic ammonoids, lamellibranchs and gastropods. They also apparently overlie the fossiliferous Upper Permian beds.

REVIEW OF THE WESTERN HIMALAYAN TRIAS.

The Triassic rocks of the different areas in the western Himalayas may conveniently be reviewed at this stage.

The Lower Triassic is well represented in Kashmir, Spiti, Painkhanda and Byans. It is only 40 ft. thick in Spiti and slightly more in Painkhanda. Though it attains a thickness of over 300 ft. in Kashmir, it does not seem to be richer in fossils, but this is partly because it has not been investigated in detail. It is also quite thick in Byans (150 ft.) and contains a new element in the fauna, *viz.*, *Sibirites.*

The Muschelkalk of Spiti falls into three divisions. The lower portion is a nodular limestone with a brachiopod horizon (*Rhynchonella griesbachi*) at the base; the middle one contains a fauna with *Spiriferina stracheyi* and *Keyserlingites* (*Durgaites*) *dieneri.* The Upper Muschelkalk is extraordinarily rich in fossils and characterised by *Ptychites rugifer.* The same characters are more or less recognised in Kashmir where the strata thicken to 900 ft. In Painkhanda the Muschelkalk is only a little over 100 ft. thick, though the different zones are recognizable. In Byans it is a pure limestone facies but faunistically closely related to Spiti.

There is a great variation in the Ladinic stage of the different areas. It is 300 ft. thick in Spiti, dwindles down to about 20 ft. in Painkhanda and is apparently absent or represented by unfossiliferous limestone in Byans. Its equivalents in Kashmir should be looked for in the strata above the Ptychites beds. This marked difference continues also into the Carnic stage. The Carnic is 1,600 ft. thick in Spiti, consisting of a lower *Joannites* horizon and an upper *Tropites* horizon. It attains only half that thickness in Painkhanda and much less in Byans where the Tropites horizon is extremely rich in fossils, but contains also some Noric elements. The Lamellibranch beds and

TABLE 26.—CORRELATION OF THE TRIASSIC ROCKS OF THE HIMALAYA.

		Divisions	Spiti	Ft.	Painkhanda.	Ft	Byans.	Ft.	Kashmir.	Ft.
Upper Trias	Noric.	Upper	Megalodon limestone in part (total 2600′).	800	Megalodon limestone in part (2000′).	500	Megalodon Limestone (1200′).	300	Megalodon limestone.	—
		Middle	Quartzite series (*Spirigera maniensis*). Monotis beds (*Monotis salinaria*). Coral limestone (*Spiriferina griesbachi*).	300 300 100	Quartzite series (*Spirigera maniensis*). Sagenite beds (*Anodontophora griesbachi*) Limestone with *Spiriferina griesbachi*	250 160 320	Greenish black shales with sandy bands.	1000	Intercalated shales and limestones.	Several thousand Ft.
		Lower	Juvavites beds (*Juvavites angulatus*)	500	Halorites beds (*Halorites procyon*). Nodular limestones (*Proclydonautilus griesbachi*).	200 100				
	Carnic.	Tuvalic	Dolomitic limestone (*Lima* cf *austriaca*) Tropites shales (*Trapites subbullatus*)	300 600			Tropites limestone		*Spiriferina stracheyi* zone.	
		Julic	Grey beds { Upper with brachiopods and bivalves. Lower with *Joannites cymbiformis*. Halobia limestone (*Halobia* cf *comata*)	500	Beds with *Halobia* cf. *comata*. Traumatocrinus limestone.	800 25			Lamellibranch beds	

Middle Trias.	Ladinic	Daonella limestone upper with *D. indica* lower with *D. lommeli*	150	Passage beds of Shalshal cliff.	20		250	Ptychites beds Ceratites beds Rhynchonella trinodosi beds Gymnites beds. Nodular limestone Limestones and shales.	Over 900 feet.
		Daonella shales (*D. lommeli*).	160						
	Muschelkalk.	Concretionary limestone (*Ptychites rugifer*) Beds with *Spiriferina stracheyi* and *Keyserlingites dieneri*. Nodular limestone. Shaly limestone (*Rhynchonella griesbachi*)	100	Beds with *Ptychites rugifer*. Beds with *Spiriferina stracheyi* and *Keyserlingites dieneri*. Niti limestone. Shales with *Rhynchonella griesbachi*.	100	Cephalopod bed (*Ceratites thuilleri*) Brachiopod bed *Spiriferina stracheyi* Limestone (*Rh griesbachi*)			
Lower Trias.	Campil beds.	Hedenstroemia beds (*Flemingites rohilla*).	30	Hedenstroemia beds (*Flemingites rohilla*)		Sibirites spiniger zone.	150	Hungarites shales.	Over 300 feet.
	Scis beds	Meekoceras bed (*Meekoceras varaha*) Ophiceras bed (*Ophiceras sakuntala*). Otoceras bed (*Otoceras woodwardi*)	7	Meekoceras bed (*Meekoceras markhami*) Otoceras beds *Ophiceras sakuntala* and *Otoceras woodwardi*).	51	Chocolate limestone.		Meekoceras beds Ophiceras beds.	
Permian		Kuling or Productus shales.		Kuling or Productus shales.		Productus shales.		Zewan beds.	

Spiriferina stracheyi beds of Kashmír represent the Carnic stage.

The Noric stage is dominantly calcareous in all the areas except Byans where it is shaly and generally contains crushed fossils. In Kashmir the Noric seems to be practically unfossiliferous. The Upper Noric division is the Megalodon limestone (Kioto Limestone) which attains large thicknesses in all areas and whose upper portion is Liassic in age. It is thickest in Kashmir (several thousand) feet), and gradually becomes thinner southeastwards, being 2,500 ft. in Spiti, 2,000 ft. in Painkhanda and 1,500 ft. in Byans.

The correlation of the Triassic formations of these areas is given in Table 26.

SALT RANGE.

Triassic rocks, known as *Ceratite beds*, are well developed in the Salt Range on either side of the Indus. In the Cis-Indus portion, only the Lower Trias and the lower part of the Middle Trias are observed westward from Kathwai near Kundghat, their total thickness being 150 to 200 ft. In the Trans-Indus region the Upper Trias is also seen, the thickness of the whole system being around 400 to 500 ft.

It has already been mentioned that the Chidru stage of the Upper Productus beds becomes arenaceous at the top. A slight but distinct unconformity intervenes between the Permian and Trias; a conglomerate marking the break in deposition is found near Siran-ki-dhok, and a marked change occurs in the fauna with the earliest Triasic rocks. Table 27 shows the Triassic succession found in the Salt Range.

The basal bed of the Trias is the *Lower Ceratite Limestone* which is a hard thin-bedded light grey limestone containing numerous *Gyronites frequens*, and which is the equivalent of the *Ophiceras* beds of Spiti. The *Otoceras* horizon is probably represented by the unfossiliferous sands and clays which lie between this limestone and the Chidru beds of Upper Productus Limestone. The Lower Ceratite Limestone is overlaid by thick greyish green marly beds with limestone bands, called the *Ceratite Marls*, containing abundant fossils. The marls constitute a very conspicuous and easily visible horizon because of their colour, and weather into rounded outcrops. The *Ceratite sandstones* which succeed them are divided into an upper and a lower sandstone separated by a calcareous horizon rich in *Stachella*, a genus closely allied to *Bellerophon.* The Upper Ceratite sandstone is characterised by the presence of *Flemingites flemingianus*, which can be correlated with the *Flemingites rohilla* zone of Painkhanda. Above the Ceratite sandstone is the *Upper Ceratite Limestone* composed of hard limestones and intercalated grey marls with highly ornamented *Ceratites* of the genera *Sibirites, Stephanites*, etc. This corresponds to the *Sibirites spiniger* zone of Byans.

TABLE 27.—TRIAS OF THE SALT RANGE.

Division.		Salt Range.	Thickness Ft	Himalaya.
Carnic		Crinoidal dolomite	250	? Halobia beds.
Middle Trias		Sandy limestones with bivalves	100	? Daonella beds and Muschelkalk.
Lower Trias.	Ceratite Beds.	Upper Ceratite limestone with *Stephanites superbus* and *Sibirites chidruensis*.	20	*Sibirites spiniger* zone (Byans)
		Ceratite sandstone: Upper Ceratite Sandstone with *Flemingites flemingianus*; Stachella beds with *Stachella* sp and *Flemingites radiatus*. Lower Ceratite Sandstone with *Celtites fallax*.	30	*Flemingites rohilla* zone. Hedenstroemia beds.
		Ceratite Marls with *Prionolobus rotundatus* and *Proptychites lawrencianus*.	20 to 60	Meekoceras beds.
		Lower Cerotite Limestone with *Gyronites frequens* Unfossiliferous sands and clays.	10	Ophiceras zone. ? Otoceras zone.
Permian.		Chidru stage Upper Productus Limestone.		Productus shales.

The Ceratite beds are succeeded by the *Bivalve beds* which range in composition from limestone to calcareous sandstone and contain abundant bivalves but very few ammonoids. The uppermost member consists of yellowish, somewhat brecciated or cavernous dolomites containing some obscure fossils. The top of these is sometimes marked by a thin limestone with bivalves.

The succession varies in different places as to details ; limestones vary to dolomite and sometimes there are pisolitic limestones with glauconitic matter. Sandstones and limestones may vary to marls.

FAUNA.—As mentioned already, fossils belonging to the Ceratite group of Ammonoids characterise the Ceratite beds. Some of the beds, and especially the Bivalve bed, contain lamellibranchs. The chief fossils of the different sub-divisions are shown below :

Lower Ceratite Limestone. .	*Gyronites frequens, Prionolobus atavus, P. ophioneus, Lecanites psilogyrus, Meekoceras varians, Dinarites cuccensis.*
Cleratite Marls ..	*Proptychites lawrencianus, Prionolobus rotundatus, Dinarites minutus, Koninckites ovalis, Clypites typicus, Kongites lens.*
Lower Ceratite sandstone. ..	*Celtites fallax, Ceratites normalis, Gyronites rotula G. radians.*
Stachella beds ..	*Stachella* sp., *Flemingites radiatus, F. rotula, Celtites acuteplicatus, Aspidites kingianus.*
Upper Ceratite sandstone.	*Flemingites flemingianus, F. compressus, Aspidites superbus, Celtites armatus, Ceratites wynnei.*
Upper Ceratite Limestone.	*Stephanites suerbus, S. corona, Sibirites chidruensis, S. kingianus, Dinarites dimorphus, Celtites patella, Prionites tuberculatus, celtites dimophtus, Acrochordiceras coronatum.*

HAZARA.

The southeastern parts of Hazara contain Mesozoic rocks. Excellent sections of a sequence extending from Upper Trias to Eocene are observed in Mount Sirban south of Abbottabad.

The Infra-Trias rocks are overlain by a thickness of 100 ft. of lavas of rhyolitic and felsitic character, succeeded by thick-bedded grey limestones, which vary in thickness from 500 to 1,200 ft. They contain Upper Triassic fossils similar to those of Spiti. The Hazara area belonged to the geosynclinal basin of deposition in contrast with the Salt Range whose deposits were of a comparatively shallow to coastal facies.

ATTOCK DISTRICT, PUNJAB.

Between Hazara and the Punjab Salt Range, and along the northern border of the Potwar plateau, lie the folded rocks of the Kala Chitta hills, the denuded anticlines of which expose a series of strata ranging in age from Upper Trias to Siwaliks, as shown below :

Siwalik System	..	Pliocene.
Murree Series	..	Miocene.
Nummulitic rocks	..	Eocene.
Giumal sandstones, etc.	..	Albian.
Spiti shales	..	Argovian - Tithonian.
Kioto limestone	..	Upper Trias to Lias.
Attock slates	..	Pre-Cambrian to Cambrian.

The Kioto limestones of Spiti are represented by similar limestones which are grey or cream-coloured and include a few shaly bands. They are sparsely fossiliferous and range in age from Upper Triassic to Liassic as in Spiti. The Upper Triassic fossils found in them between Jhalar and Campbellpore include *Rhynchonella* cf. *bambanagensis*, *Terebratula* sp., *Velata velata*, *Lima serraticosta*, *Pecten* sp. etc.

BALUCHISTAN.

The Upper Trias is represented in the Zhob and Pishin districts of Baluchistan by a vast thickness, amounting to several thousand feet, of greenish slaty shales with intercalations of thin black limestone. They occupy an area 70 miles long (east to west) and some 12 miles broad. They are fairly rich in fossils which include abundant *Monotis* *salinaria* and a few species of ammonoids of the genera *Halorites*, *Didymites* and *Rhacophyllites*.

BURMA.

Triassic rocks are found in the Shan States, Amherst district, the Arakan Yomas and possibly also in the Manipur hills.

NORTHERN SHAN STATES.

Napeng beds.—We find a hiatus in sedimentation between the Plateau Limestone and the Napeng beds of Rhætic age, there being a well marked unconformity between the two. The Napeng beds occur in a series of patches and consist of a variety of sediments—yellow shales, clays, sandy marls, sandstones and limestones—deposited in very shallow and irregular basins. They contain a fauna including the following :

Corals	..	*Isastraea confracta.*
Lamellibranchs	..	*Palaeoneilo fibularis, P. nanimensis, Pinna* cf. *blanfordi, Conocardium superstes, Grammatodon lycetti, Gervillea shaniorum, G. rugosa, Avicula contorta, Myophoria napengensis, Plicatula carinata, Modiola frugi, Cardita singularis.*
Gastropods	..	*Turritella* sp., *Promathilda exilis.*

The fauna is of Rhætic age and of peculiar character, being composed mainly of lamellibranchs and recalling the fauna of the Wetwin Shales. It is quite distinct from the fauna of the Himalayas or of the Salt Range.

AMHERST DISTRICT.

Kamawkala Limestone.—In the eastern part of the Amheret district near the Siamese frontier, the Permo-Carboniferous beds are succeeded by the Kamawkala limestones which are referred to the Triassic, probably the Noric age. The fauna includes *Rhynchonella bambanagensis*, *Chlamys* aff. *valoniensis*, *Trachyceras* sp., and *Centrastraea cotteri*.

ARAKAN YOMA AND NAGA HILLS.

The oldest rocks exposed in the Arakan Yomas belong to the *Axial System* the lower part of which is referable to the Triassic. The rocks of this system are found in Prome and Thayetmyo districts, usually much folded and disturbed. They consist of dark shales and sandstones with some limestones. The only fossils found in them are *Daonella lommeli* and specimens of *Monotis* and *Avicula*. These seem to indicate a Triassic age.

Further south in Minbu and Pakokku districts, the equivalents of the Lower Axials are the *Chin Shales*. Black slates, sandstones and quartzites found in the Manipur State on the Assam-Burma border have also been referred to the Axials and may probably be partly of Triassic age.

THE FAUNA OF THE TRIASSIC PERIOD.

During the Triassic period all the major groups of animals existed except birds and mammals. The important class of Arthropoda, *viz.*, Trilobites, had disappeared during the Permian or at any rate in the upheaval before the dawn of the Mesozoic era.

The ammonoids, including the *Ceratites*, *Goniatites* and *Orthoceras*, constitute the most nemerous and useful fossils of this system. The oldest *Belemnites* are also to be found here represented by the genus *Atractites*. *Rhynchonellidæ* and *Spiriferinæ* have also an extensive distribution, and in addition some genera and species of mollusca. In the case of the ammonoids individual species are highly useful because of the very short range of their vertical distribution. The species of brachiopods and molluscs have also proved useful because some of them occur in enormous numbers in certain beds, e.g., *Rhynchonella griesbachi*, *Spiriferina strachyei*, *Spiriferina griesbachi*, *Daonella Indica*, *Daonella* cf. *lommeli*, *Halobia* cf. *comata* and *Monotis salinaria*.

The ammonoids, however, are eminently suited for use as zone fossils because of the richness of forms, their easily recognizable differences in external characters, extensive and world-wide distribution in marine beds and very limited distribution of species in range of time. The Trias of the Himalayas and of the Salt Range carry exceptionally rich ammonoid faunas. The Ceratites are characteristics of the Trias—the Lower Trias with primitive Ceratites, the Middle Trias with typical members and the Upper Trias with specialised and ornamented members.

The Lower Triassic ammonoids appear simple and monotonous in appearance in comparison with the variety seen in the Upper Permian. The simple-sutured but robust Lower Triassic types vere able to withstand and survive the changes that took place at the end of the Permian, whereas the specialised Permian types died out. The primitive Ceratites seem to have first appeared in Middle to Upper Permian times represented by such forms as *Xenodiscus carbonarius*. *Otoceras* which characterises the earliest Trias in India has a raised ear-like rim around the umbilicus and a ceratitic suture of the type rendered familiar by the common European Muschelkalk fossil *Ceratites nodosus* ; the saddles have a smooth rounded outline while the lobes are slightly denticulated. *Hendenstroemia* and *Pseudosageceras* still retain the ceratitic outline of the suture, but the lobes and saddles become numerous, thus foreshadowing the complex sutures of the *Pinacoceratidae* of Middle and Upper Trias. Another genus, *Episageceras*, which occurs in the Otoceras beds of the Himalaya and the Stachella beds of Salt Range, is a relic of the *Goniatite* group, very closely allied to and derived from the Permian *Medlicottia*. Further up in the Lower Trias the beds are characterised by the large and spirally grooved Ceratite of the genus *Flemingies*.

The Muschelkalk is the age of the typical *Ceratites*, which begin to develop here along two lines ; in one the shell gains strength by corrguations while the sutures remain simple; in the other the shell remains smooth but gains strength by the ramifications of the sutural lines. The first group constitutes the typical *Ceratites*, of which large numbers are present both in the Himalaya and Kashmir, being somewhat evolute forms with thick ribs and blunt knobs. In *Sibirites* the sutures remain simple but the shells are highly sculptured. The smooth-shelled forms with sutures tending to complexity are represented by *Gymnites* and *Ptychites*, the former a compressed form and the latter rather globose. The genus *Sturia* resembles *Gymnites* but has a spirally grooved shell.

In the Upper Triassic beds, the *Ceratites* reach their zenith of development, and are represented by a number of beautiful forms in the Himalayan strata. The two lines of development continue here, the contrast becoming stronger than in the Muschelkalk. The genus *Arpadites*, some species of which are of fairly large dimensions, resembles the typical *Ceratites* but has a deep smooth furrow on the outer margin; in *Ceratites* proper the periphery is either rounded or raised into a keel. The genus *Distichites* is similar to *Arpadites* but has somewhat simpler suture line. In the genera *Tibetites* and *Sirenites*, the shell is sculptured and involute and shows a tendency to become clypeiform in shape. In *Tropites* the shell tends to become globose but the whorls do not completely overlap the umbilical channel. The involution is much more pronounced in *Halorites* and *Juvavites* in which the umbilicus is nearly or almost completely obliterated. Smooth-shelled forms are less prominent than the highly sculptured ones in the Upper Trias, often tending to become globose. The genera *Lobites* and *Didymites* combine a subdued sculpturing with only slightly serrated sutures which however have a large number of inflections. Amongst the smooth clypeiform ammonoids is *Placites* (abundantly represented in the Tropites limestone of Byans) which is distinguished by the multiplicity of auxiliary inflections. In *Carnites* and *Fina-*

coceras the inflections are greatly multiplied by the splitting up of the external saddle. The well-known forms *Pinacoceras parma* and *P. metternichi* are amongst the ammonoids which exhibit the most complicated sutural lines. They are accompanied by *Bambanagites* which has a sculptured shell but has the same plan of suture though less complicated. A true member of the Ammonite group is represented by *Discophyllites* which is a precursor of the *Phylloceratidae* which attains prominence in the Jurassic.

The vast majority of the specialised Ceratites died out at the end of the Trias as was the case with the earlier ammonoids at the end of the Permian. Only a few ammonoids like the Phylloceratids survived the changes at the end of the Trias.

SELECTED BIBLIOGRAPHY

Bittner, A. Triassic brachiopoda and lamellibranchiata. *Pal. Ind. Ser. XV*, Vol. III, 2, 1899.

Diener, C. Trias of the Himalayas. *Mem.* 36, Pt. 3, 1912.

Diener, C. Upper Triassic and Liassic faunæ of the exotic blocks of Malla Johar. *Pal Ind. Ser. XV*, Vol. I, (1), 1908.

Diener, C. The Cephalopoda of the Lower Trias. *Op. cit* Vol. II, (1), 1897.

Diener, C. The Cephalopoda of the Muschelkalk. *Op. cit.* Vol. II, (2), 1895.

Diener, C. Fauna of the Tropites limestone of Byans. *Op. cit.* Vol. V, (1), 1906.

Diener, C. Fauna of the Himalayan Muschelkalk, *Op. cit.* Vol. V, (2), 1907.

Diener, C. Ladinic, Carnic and Noric faunæ of Spiti. *Op. cit.* Vol. V, (3), 1908.

Diener, C. and von Krafft. Lower Triassic Cephalopoda from Spiti, Malla Johar and Byans. *Op. cit.* Vol. VI, (1), 1909.

Diener, C. Fauna of the Traumatocrinus limestone (Painkhanda). *Op. cit.* Vol. VI, (2), 1909.

Diener, C. Triassic faunæ of Kashmir. *Pal. Ind. N. S. V*, (1), 1913.

Gregory, J.W. *et al.* Upper Triassic fossils from Burma-Siam frontier. *Rec.* *63*, 155-181, 1930.

Hayden, H H. Geology of Spiti. *Mem.* *36*, Pt. 1, 1904.

Healy, M. Fauna, of the Napeng beds (Rhaetic) of Upper Burma. *Pal. Ind. N. S. II*, (4), 1908.

Krafft, A. von. Exotic blocks of Malla Johar. *Mem* *32*, Pt. 3, 1902.

Mojsisovics, E. von. Upper Triassic Cephalopod faunae of the Himalayas. *Pal. Ind. Ser. XV*, Vol. III, (1), 1899.

Waagen, W. Salt Range Fossils—Ceratite formation. *Pal. Ind. Ser. XIII*, Vol. II, 1895.

CHAPTER XIII.

THE JURASSIC SYSTEM.

GENERAL.

Distribution and Facies.—Rocks belonging to the Jurassic System are developed in the Indian region in the Himalayas of Spiti, Kumaon, Nepal, Kashmir, Hazara; in Baluchistan and Salt Range; in Cutch and Rajputana; in the Rajmahal hills; in the Puri district of Orissa; in the Ellore, Ongole, Madras and Trichinopoly regions on the eastern coast. The Himalayan areas belong to the geosynclinal facies and the others to the coastal facies. In Baluchistan and the outer border of the Iranian arc, the rocks are mainly calcareous in this as well as in the succeeding Cretaceous system, for which reason the region of their development is called the Calcareous zone. To the interior (north-west) of this zone as well as in the Himalayan area the rocks are dominantly shaly. The Tibetan facies of the Lias, which is seen in the exotic blocks of the Kiogarh region, consists of reddish earthy limestones which resemble rocks of the corresponding age in the Eastern Alps.

Unconformity and Marine Transgression.—The geosynclinal region shows a marked interruption of sedimentation commencing from the Callovian and lasting until the Oxfordian or later. This Callovian unconformity is widespread and recognised in many parts of the world. In Spiti and northern Himalayan this interruption ranges up to the Oxfordian while in Baluchistan it extends to the Neocomian. In both cases the unconformity is marked by a bed of ferruginous laterite. In the coastal facies, on the other hand, the Lower Jurassic rocks are absent and the deposition begins later, assuming a marine character in the Callovian and continuing on beyond the Jurassic times. It is interesting to note that the Callovian is marked by a regression in the geosynclinal area but by a transgression along parts of the coasts of the Peninsula.

SPITI.

The geosynclinal deposits are typically developed in Spiti. Here, the Upper Triassic (Upper Noric stage) and the Liassic form one lithologic unit called the Megalodon (or Kioto) limestone, consisting of massive limestones and dolomites, mostly unfossiliferous, and forming steep and imposing cliffs. The lower 700 to 800 feet of this formation constitute the *Para stage* and are of Upper Noric age as they contain *Megalodon ladakhensis*, *Diceracardium himalayense*, *Lima cumaunica*, *Spirigera noetlingi*, etc. The portion above that, having a thickness of 1,500-1,600 feet, belongs to the Jurassic, and an important zone fossil, *Stephanoceras* cf. *coronatum*, occurs 350 feet below the top of the limestone. The Jurassic part of the Megalodon limestone is called the *Tagling stage.* At its top occur the *Sulcacutus beds*, so called from the abundance of *Belemnites sulcacutus* in them. They are overlain by the Spiti shales, ranging in age from the Oxfordian to the Tithonian. The *Spiti shales* form a persistent and well-marked horizon which has been traced from Sikkim and Nepal to Kashmir and thence to Hazara. The Jurassic succession of Spiti is as follows :

TABLE 28.—JURASSIC SUCCESSION IN SPITI.

Strata.		Age.
Spiti Shales	Lochambal beds	Portlandian to Tithonian.
	Chidamu beds	Kimmeridgian
	Belemnites gerardi beds	Oxfordian - Sequanian.
unconformity		
Megalodon or Kioto limestone.	Sulcacutus beds	Callovian
	Tagling stage	Lias to Bathonian.
	Para stage	Upper Trias

The Sulcacutus beds contain, besides *Belemnites*, bivalves and brachiopods of Callovian age.

Spiti shales.—The overlying Spiti shales from rolling downs at an altitude of about 15,000 feet in contrast with the precipitous cliffs formed by the Kioto limestone. They are about 500 feet or more in thickness, but the thickness varies in different regions. They consist of grey to black, soft, friable shales with a few thin intercalations of limestone in the upper part, and contain calcareous nodules enclosing ammonites and other fossils. The Spiti shales are divided into three units, the lower one being grey shales characterised by the occurrence of *Belemnites gerardi*, the nodules found in the beds being unfossiliferous. The Middle division, of Kimmeridgian age, is called the *Chidamu beds* and contains large numbers of ammonites amongst which the genera *Perisphinctes* and *Oppelia* are the most important. The Upper division, constituting the *Lochambal beds*, are characterised by the genera *Hoplites* and *Holcostephanus* (*Spiticeras*) the latter being abundant in species as well as individuals.

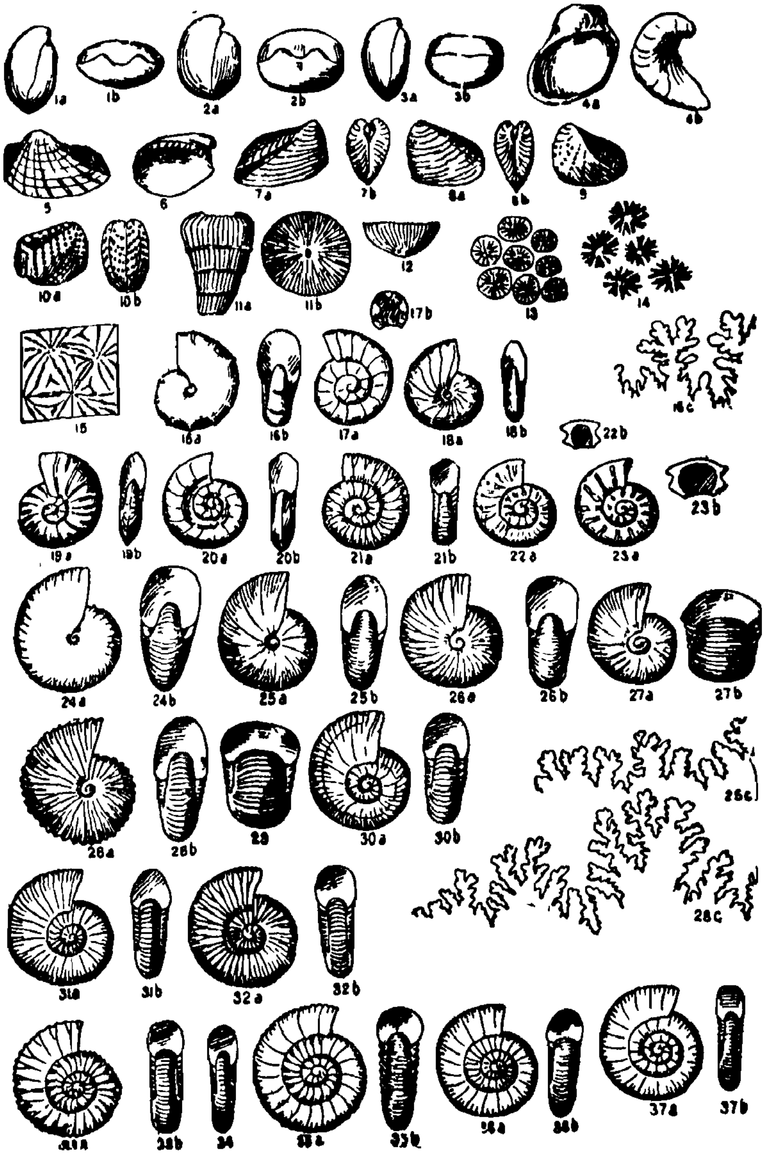
The Spiti shales have yielded a rich fauna which has been described in *Palaeontologia Indica* (Series XV, Vol. IV, 1910-1914). The more important species are enumerated below :

Cephalopods .. *Phylloceras plicatius*, *Lytoceras exoticum*, *Hecticoceras kobelli*, *Oppelia* (*Streblites*) *kraffti*, *Aspidoceras avellanoides*, *Spiticeras spitiensis*, *S. grotei*, *Himalayites seideli*, *Acanthodiscus octagonus*, *Hoplites* (*Thurmannia*) *boissieri*, *Macrocephalites* cf. *maya*, *Perisphinctes* (*Paraboliceras*) *sabineanus*, *P.* (*Virgatosphinctes*) *denseplicatus*, *P.* (*V.*) *raja*, *P.* (*Aulacosphinctes*) *spitiensis*, *P.* (*A*), *torquatus*.

Lamellibranchs .. *Avicula spitiensis*, *Aucella spitiensis*, *Lima melancholica* *Nucula spitiensis*, *Astarte hermanni*, *Cosmomya egregia*, *Homomya tibetica*, *Goniomya uhligi*, *Ostrea*, *Pecten*, *Leda*, etc.

The spiti shales pass upwards into the Giumal sandstones of neocomian age.

PLATE XVII.
JURASSIC FOSSILS I.



EXPLANATION OF PLATE XVII

1. *Terebratula punjabiensis* (1/3). 2 *Sphaeroidithyris attockensis* (1/3). 3. *Holcothyris subovalis* (1/3) *Gryphæa balli* (1/3) 5 *Grammatodon iddurghurensis* (1/3) 6. *Nuculoma blakei* (1/3) 7. *Trigonia smeei* (1/8) 8 *T crassa* (1/8). 9. *T. cutchensis* (1/4) 10 *T. ventricosa* (1/3) 11 *Montlivaltia cornutiformis* (1/2) 12 *M kachhensis* (6) 13 *Stylina kachhensis* (6). 14 *Isastræa parva* (4). 15. *Centrastraea kobyi* (2). 16. *Phylloceras* (*Ptychophylloceras*) *ptychoicum* (1/6).

NITI PASS.

In the region of the Niti Pass, about 150 miles east of Lilang, the general sequence is the same as in Spiti. The Kioto limestone is about 2,000 feet thick ; it consists of 1,300 feet of dolomitic limestone with flaggy limestone layers, overlaid successively by 500 feet of thin-bedded limestone, 120 feet of light grey flaggy limestone, 30 feet of dark oolitic limestone and finally 150 feet of grey calcareous sandstone constituting the Sulcacutus beds. Overlying this is a conglomerate denoting an unconformity, followed by the Spiti shales.

SHALSHAL CLIFFS.

In the Shalshal cliffs of north-western Kumaon, the Kioto limestone is 2,000 ft. thick and consists, at the base, of 500 feet of grey dolomite weathering to a brownish tinge and forming inaccessible cliffs ; it is followed by 1,000 feet of dark dolomites with thin layers of bluish black crinoidal limestone and occasional shales ; then by 150 feet of massive dolomite and 350 feet of crinoidal limestones and shales. The Sulcacutus beds at the top are only 20 feet thick and contain *Belemnites sulcacutus*, *B. tibeticus*, and species of *Gervillea*, *Cardium*, etc. At the top of this is a zone of laterite indicating disconformity and a period of subaerial weathering. The laterite is overlain by Spiti shales of Upper Oxfordian (Argovian) age.

---

17 *Lytoceras* (*Hemilytoceras*) *rex* (1/15) 18 *Oppelia* (*Taramelliceras*) *kachhensis* (1/4) 19 *Harpoceras* (*Sublunuloceras*) *lairense* (1/10). 20 *Harpoceras* (*Hildoglochiceras*) *kobelli* (1/3). 21 *Peltoceras* (*Peltoceratoides*) *semirugosum* (1/7). 22 *Peltoceras athleta*(=*P. kachhense*) (1/6). 23 *P ponderosum* (*Aspidoceras ponderosum Waag*) (1/8). 24. *Stephanoceras* (*Macrocephalites*) *macrocephalus* (1/8) 25 *Stephanoceras* (*Mayaites*) *maya* (1/12). 26. *Stephanoceras* (*Epimayaites*) *polyphemus* (1/112). 27. *Stephanoceras*. (*Indocephalites*) *diadematum* (1/6). 28 *Stephanoceras* (*Kamptokephalites*) *dimerum* (1/5) 29 *Stephanoceras grantanum* (=*Pleurocephalites habyensis*) (1/3) 30 *Perisphinctes orion* (=*Oriononoides indicus*) (1/3) 31 *Perisphinctes* (*Virgatosphinctes*) *frequens* (1/4). 32 *Perisphinctes* (*Virgatosphinctes*) *denseplicatus* (1/4) 33. *Perisphinctes* (*Pachysphinctes*) *bathyplocus* (1/6). 34 *Perisphinctes* (*Ataxioceras*) *leiocymon* (1/6). 35. *Perisphinctes* (*Katroliceras*) *katrolensis* (1/8) 36 *Perisphinctes* (*Torquatisphinctes*) *torquatus* (1/8). 37. *Perisphinctes* (*Indosphinctes*) *calvus* (1/8).

BYANS.

Further south-east, in Byans, near the Nepal border, the Kioto limestone is less massive and only about 1,200 feet thick, composed of 250 feet of flaggy limestone with shaly bands, succeeded by 700 feet of shaly limestone and shales, then by 200 feet of massive grey limestone and 30 feet of dark shales and finally by the Sulcacutus beds with a laterite bed at the top. This is followed by the Spiti shales. In Ngari Khorsum on the border of the Tibetan plateau, north of the main Himalayan Mesozoic belt, there are large blocks of thin-bedded nodular earthy limestone of Liassic age occurring amidst volcanic breccia. These differ in lithology and fauna from the Spiti facies just as the Upper Triassics of the two areas differ. The fauna of this Tibetan facies resembles closely the Alpine fauna. It is rich in species of the genus *Phylloceras*, *Rhacophyllites*, *Schlotheimia*, *Arietites*, etc., showing that the beds are of Lower Liassic age.

MOUNT EVEREST REGION AND TIBET.

The Jurassic rocks apparently continue eastwards through Nepal to Sikkim and Lhasa in Tibet. North of Mount Everest there are large thicknesses of shales and limestones containing *Belemnites*, crinoids and ammonites. They are overlain by Cretaceous and Eocene strata.

SUB-HIMALAYA OF GARHWAL.

As already mentioned, the Jaunsars are overlain by the *Krol beds* which are probably of Permian (? Permo-Trias) age. East of the Ganges in Garhwal, the Krols are overlain by the *Tal series* consisting of shales in the lower portion and quartzites and limestones in the upper portion. The Tal series contains fragmentary molluscs and corals and may represent partly the Jurassic System or even the Cretaceous. It is overlain by Eocene rocks.

KASHMIR.

We have already seen that the Megalodon limestone is present in the Vihi district and in Ladakh. The upper portion of this is referable, as in Spiti, to the Lias. This limestone is known to be overlain, in parts of Ladakh and the Zanskar range, by the Spiti shales. Fossils are found in concretions in the shales but have not been studied in detail. They include ammonites (*Macrocephalites* among them), *Belemnites*, lamellibranchs and brachiopods.

Jurassic rocks are also found in a small area north of the Banihal Pass in the Pir Panjal mountains. It is likely that Jurassic rocks are associated with bands of Trias in other parts of this range.

In the area of the syntaxial bend of north-western Kashmir, there is a band of orange coloured strata, some 150 feet thick, which it is thought may be Jurassic to Cretaceous in age.

HAZARA.

Hazara is a region of transition from the Himalayan to the Baluchistan type of development. Here there are two neighbouring zones running N.E.-S.W. and parallel to each other, the north-western one containing massive limestones overlain by the Spiti shales as in the Himalaya, and the south-eastern showing limestones overlain by Neocomian strata as in Baluchistan.

The massive limestone (of the north-western belt) is dark grey in colour and varies in thickness from 500 to 1,200 feet. It contains *Megalodon* and *Diceracardium* in the lower part and is therefore similar to the Megalodon limestone of Spiti. The upper portion is presumed to be Lower Jurassic in age. It is succeeded by shales of the Spiti shale type containing *Gymnodiscoceras acucinctum*, *Virgatosphinctes frequens*, *Belemnites gerardi*, *Inoceramus* sp., and *Trigonia ventricosa*.

ATTOCK DISTRICT.

Jurassic rocks are present in the folded strata of the Kala Chitta hills of this district. The lower portion is included in the *Kioto limestone* and the upper in *Spiti shales*. The latter are however not easily separable from the overlying Giumal series because the lithology is continuous and shows very gradual change. The Spiti shales consist of sandy and carbonaceous shales, Belemnite-bearing beds and olive clays. The fossils found in the lower limestones are :

Sphaeroidothyris attockensis, *Burmirhynchia* cf. *namyauensis*, *Lophrothyris euryptycha*.

The fossils of the Spiti shales are :

Epimayaites polyphemus, *Peltoceratoides*, sp., *Perisphinctes orientalis*, *P.* cf. *indogermanus*, *Prososphinctes virguloides*, *Blanfordiceras wallichi*, *Spiticeras*, *Belemnopsis tanganensis*, *Hibolites budhaicus*, *H. tibeticus*, etc.

These indicate an age similar to that of the Chari beds of Cutch and younger, and approximately Bathonian to Oxfordian. The horizons above these do not show any fossils except one which has yielded *Oxytropidoceras*, indicating an Albian (Gault) age.

It may be mentioned here that there is a fairly close resemblance between the Gault horizons of Attock, Hazara and Kohat.

SALT RANGE.

The Middle and Upper divisions of the Jurassic System are developed in the western portion of the Salt Range in the Trans-Indus region as a series of sandstones and limestones, the latter increasing in proportion westwards. The strata are 100 to 200 feet thick near Amb, 500 feet near Kalabagh on the Indus and over 2,000 feet in the Sheik Budin hills and Surghar range. The facies is dominantly coastal and generally resembles that of Cutch in Western India.

In the Salt Range proper, the lower beds are called the *Variegated series*. The lower part of this consists of thick bedded soft sandstones of red, yellow and variegated colours alternating with grey and brown bands which are often ripple-marked. They are succeeded by argillaceous

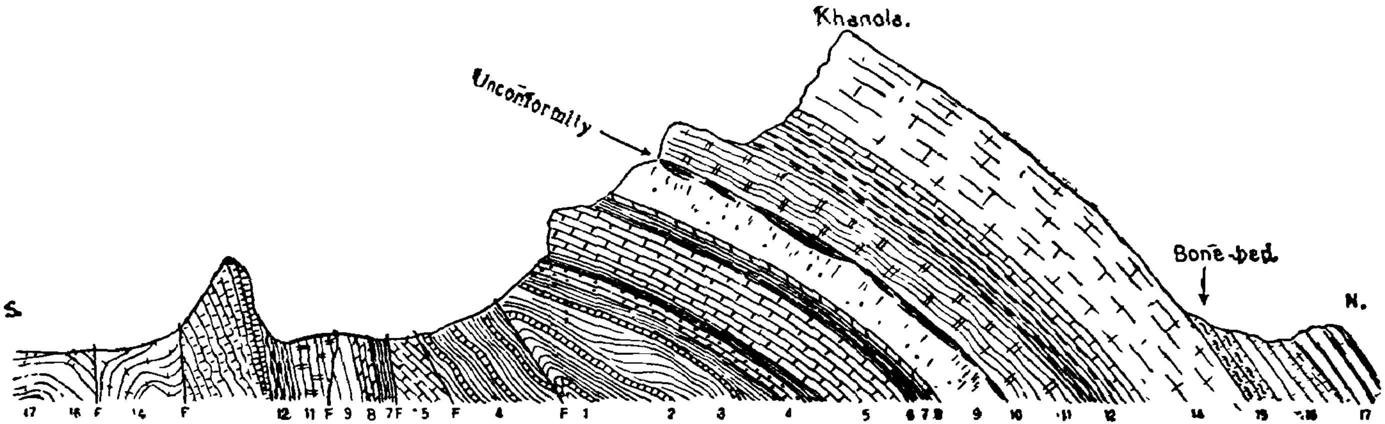


FIG. 11.—SECTION IN THE CHICHALI PASS, TRANS-INDUS REGION. (AFTER A. B WYANNE. *Mem* 14.)

1. Limestones and shales. 2. Golden oolite. 3 Shales and sandstones 4. Limestones and shaly sands. 5. White limestone. 6. Olive sandstone and clay. 7-9. Sandy beds. 10. *Alum shales.* 11 *Lower limestone.* 12 *Dark shales.* 13. Nummulitic marls. 14 Compact grey limestone. 15. Bed with bone fragments 16 Sandstones. 17. Red clays.

yellow limestone, grey gypseous and pyritous clays (alum shales) and soft white incoherent sandstones. Amidst these beds are bands of hæmatite and thin layers of 'golden oolite', composed of iron-coated oolite grains resembling the golden oolite of Cutch (*see* p. 383). The upper beds of the Variegated Series are coarse brown sandstones, yellow marls, white cavernous sandstones and bands of hard grey limestone. The sandstones become locally conglomeratic.

The upper Jurassic beds seen in the Trans-Indus region are not developed in the Cis-Indus Salt Range.

Near Kalabagh, just beyond the Indus, the Variegated Series contains thin coal seems amidst sandstones. The coal is of poor and variable quality, high in ash.

In the Trans-Indus region the Variegated Series consists mainly of shales in the lower portion, overlain by thick-bedded dun-coloured limestone intercalated with shales and clays. The limestones are succeeded by black shales containing *Belemnites* with Neocomian affinities, these beds corresponding to the Belemnite beds of Baluchistan. The Jurassic succession is underlain by white crinoidal limestone which may be Lower Jurassic or Upper Triassic.

TABLE 29.—JURASSIC SUCCESSION IN SHEIK BUDIN HILLS.

Neocomian.	Black shale with Belemnites.	60′
Upper Jurassic .	Limestones and intercalated shales	800′
Middle to lower Jurassic	Variegated series. Variegated sandstones and shales with carbonaceous matter gypseous and pyritous shales.	1000′ to 1400′
?Lower Jurassic .	Crinoidal Limestone	200′

Fossils.—The carbonaceous layers of the Variegated Series have yielded some plant fossils including *Ptilophyllum acutifolium* and *Podozamites* sp. which indicate Upper Gondwana affinities. The associated limestones contain marine fossils including lamellibranchs, gastropods, terebratulids and echinoids. The ammonites include *Indocephalites* aff. *transitorius*, *Pleurocephalites habyensis*, *Kamptokephalites* cf. *magnumbilicatus*, etc., which are fossils of the Macrocephalites beds of Cutch. The Neocomian strata above contain *Olcostephanites* and *Thurmannites*.

The similarity of stratigraphy of the Cutch and Salt Range regions would seem to show that a sea connected the two, probably through Jaisalmer. Both are associated with Upper Gondwana fossil plants.

BANNU DISTRICT (N.-W. F. P.).

In the Bannu district, sandy limestones of Callovian age have been found containing *Burmirhynchia* and *Daghanirhynchia*. These are separated by a thickness of 500 feet of strata from rocks which have yielded *Ornithella coulsoni*, *O. indica*, *O. ovalis*, *Kingena punjabica*, *Daghanirhynchia coulsoni* and *D. pezuensis*. These indicate, according to M. R. Sahni, an Oxfordian-Kimmeridgian age. Associated with these are beds containing cephalopods which Spath regarded as Neocomian. Though the thickness separating the two beds is only 4 feet, there is no stratigraphic break. There is thus an anomaly here of the Kimmeridgian affinity of brachiopods and the Neocomian affinity of Cephalopods.

SAMANA RANGE.

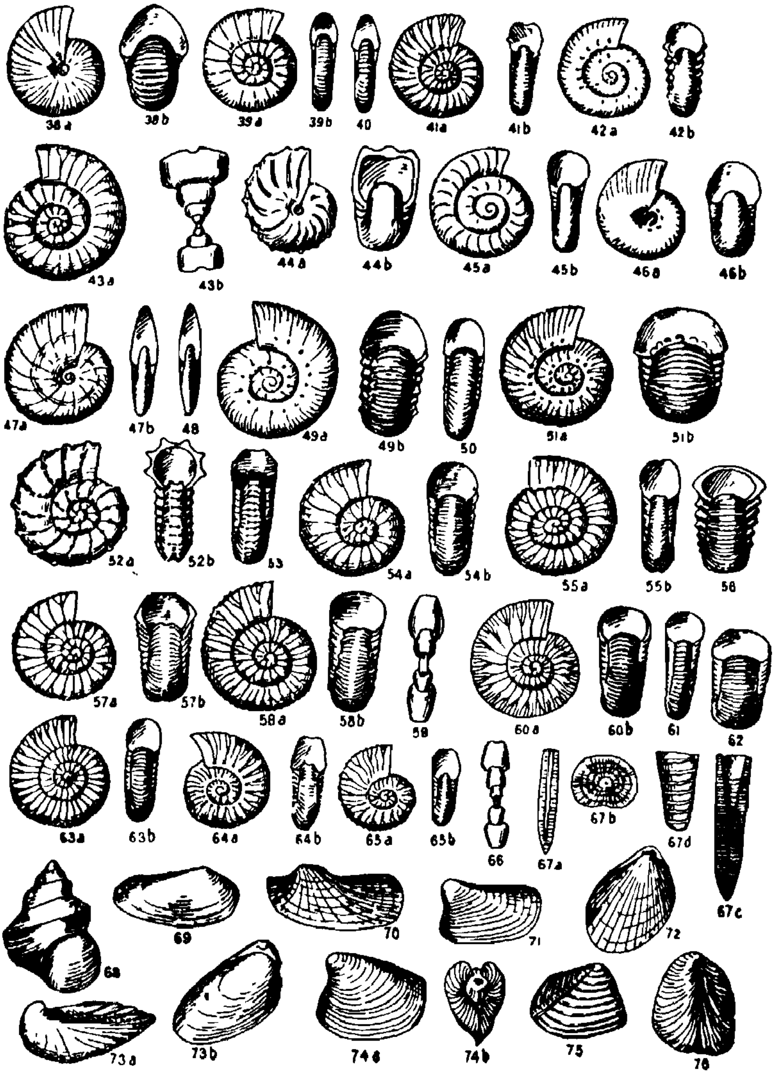
A Jurassic-Eocene succession has been discovered in the Samana Range near Fort Lockhart. The lowest beds noted are sandstones and shaly limestones with shale bands. From the fact that *Rhynchonella arcuata* is found in the upper part of these beds, they are thought to be of Callovian to Bathonian age. They are succeeded by dark grey limestones called *Samana Suk Limestones* which are regarded as Upper Jurassic.

BALUCHISTAN.

A calcareous geosynclinal facies is developed in Eastern Baluchistan comprising strata ranging in age from

PLATE XVIII.

JURASSIC FOSSILS II



EXPLANATION OF PLATE XVIII.

38 *Stephanoceras* (*Macrocephalites*) *chariensis* (1/3). 39. *Perisphinctes* (*Sivajiceras*) *congener* (1/8) 40. *Perisphinctes* (*Procerites*) *hians* (1/12). 41 *Perisphinctes* (*Reineckeia*) *anceps* (=*R reissi*) (1/6). 42. *Perisphinctes rehmanni* (=*Reineckeites waageni*) (1/12). 43. *Micracanthoceras micracanthum* (1/3). 44 *Phylloceras strigile* (1/2) 45. *Lytoceras exoticum* (1/3). 46 *Aspidoceras avellanoides* (1/4). 47 *Oppelia* (*Streblites*) *krafft* (1/4) 48. *Oppelia acucincta* (1/3) 49 *Holcostephanus* (*Spiticeras*) *spitiensis* (1/4) 50 *Holcostephanus* (*Spiticeras*) *cautleyi* (1/6). 51. *Holcostephanus* (*Astrieria*) *schenki* (1/3) 52. *Hoplites* (*Acanthodiscus*) *octagonus* (1/6). 53 *Hoplites* (*Acanthodiscus*) *himalayanus* (1/6). 54. *Hoplites* (*Blanfordia*) *wallichi*

Permo-Carboniferous to Jurassic, followed by Neocomian beds. The Liassic beds are 3,000 to 4,000 feet thick and include crinoidal and oolitic limestones and calcareous shales containing a few fossiliferous horizons which are easily correlated with Liassic horizons of the Mediterranean region. The Liassic beds are succeeded by massive limestones, also of about the same thickness, well exposed near Quetta and in the mountains of the Calcareous Zone. The uppermost beds of the massive limestone constitute the *Polyphemus beds* so named because of their containing the giant ammonite *Macrocephalites polyphemus*. Other fossils of these beds are *Macrocephalites macrocephalus*, *M. grantanum*, *M. madagascariensis*, *M. lamellosus*, *Perisphinctes (Choffatia) baluchistanensis*, *Choffatia balinensis*, *Nautilus giganteus*, *N. intumescens*, *Terebratula ventricosa*, and *Rhynchonella plicatella*. These indicate a Callovian age.

The Liassic and Middle Jurassic limestones form prominent hill masses in the Calcareous Zone of Jhalawan and Sarawan. Amongst the conspicuous hills may be mentioned Zaradak, Anjiro and Sumbaji in Jhalawan (Liassic), and Chehiltan and Koh-i-Maran in Sarawan (Middle Jurassic).

COASTAL FACIES.

General.—Peninsular India, which was practically devoid of marine sediments since the Vindhyan times, witnessed marine transgressions in the coastal regions in the Jurassic, Upper Cretaceous and Miocene times. The

(1/6). 55. *Perisphinctes (Aulacosphinctes) spitiensis* (1/3) 56. *Hoplites (Blanfordia) middlemissi* (1/4). 57. *Himalayites hyphasis* (1/3). 58 *Himalayites seideli* (1/4). 59 *Perisphinctes (Paraboliceras) sabineanus* (1/3) 60 *Perisphinctes (Virgatosphinctes) raja* (1/4). 61. *Perisphinctes (Aulacosphinctes) infundibulum* (1/3) 62. *Perisphinctes (Virgatosphinctes) kraffti* (1/4). 63. *Perisphinctes (Virgatosphinctes) biplicatus* (1/3). 64. *Hoplites (Sarasinella) varians* (1/4) 65 *Hoplites (Neocomites) walkeri* (1/4). 66 *Hoplites (Neocomites) indicus* (1/3). 67 *Belemnites (Belemnopsis) gerardi*—*a*, external appearance; *b*, transverse section; *c*, longtitudinal section, *d*, phragmocone (1/4). 68 *Pleurotomaria spitiensis* (1/3). 69 *Homomya tibetica* (1/4). 70. *Arca egertoniana* (1/3). 71. *Nucula spitiensis* (1/2) 72. *Lima roberti* (1/4). 73. *Aucella spitiensis superba*. 74. *Astarte sowerbyana* (1/3). 75. *Trigonia spitiensis* (1/3). 76. *Inoceramus everesti* (1/2).

TABLE 30.—JURASSIC SUCCESSION IN CUTCH.

	Age	Sub-divisions	Leading Fossils
UMIA 3,000 ft	Aptian	Marine Sandstones.	*Columbiceras waageni, Cheloniceras* aff *martini, Tropaeum australis.*
	Neocomian or ? Up. Tithonian.	Umia plant beds (sandstones and shales)	*Pagiophyllum, Brachyphyllum, Ginkgoites, Williamsonia, Cladophlebis denticulata.*
		Ukra beds (unfossiliferous sandstones)	No fossils.
	L Tithonian	Trigonia beds	*Trigonia ventricosa, T smeei*
		Ammonite beds (Green oolites and sandstones)	*Virgatosphinctes denseplicatus, V. oppeli, Ptychophylloceras tithonicum, Microcanthoceras* aff. *microcanthum, Umiaites,*
	Portlandian	Zamia shales.	*Hildoglochiceras Kobelli, H propinquum, Dorsoplanites mirabilis.*
KATROL 1,000 ft.	Portlandian	Gajansar beds.	*Belemnopsis gerardi, Streblites gajansarensis, Phylloceras* cf *plicatius, Hildoglochiceras* spp.
	Bononian	Upper Katrol (barren)	No fossils
	”	Upper Katrol	*Aulacosphinctoides meridionalis, Virgatosphinctes indosphinctoides*
	Havrian	Middle Katrol (red sandstones).	*Waagenia kachhensis, Katroliceras katrolense, Katroliceras pottingeri, Pachysphinctes* spp *Aspidoceras lerense*
	Sequanian	Lower Katrol (Sandstones, shales, marls).	*Torquatisphinctes similis, Aspidoceras asymmetricum, Ptychophylloceras ptychoicum, Taramelliceras kachhense, Streblites plicodiscus, Waagenia,* spp
	Up. Argovian	Kantkote sandstone.	*Epimayaites* spp. *Prograyiceras, grayi, Ataxioceras leiocymon, Biplices wagurensis, Prososphinctes virguloides, Torquatisphinctes torquatus*
CHARI 1,200 ft.	L. Argovian to Up. Divesian.	Dhosa oolite (green and brown oolites).	*Taramelliceras jumarense, Discosphinctes* aff *kreutzi, Perisphinctes indogermanus, Mayaites maya, Epimayaites polyphemus, Paracenoceras kumagunense, Peltoceratoides semirugosus*
	Mid to L Divesian-	Athleta beds (marls and gypseous shales).	*Peltoceras athleta, P ponderosum, P. metamorphum Orionoides indicus, O purpurus*
	Up Callovian	Anceps beds (limestones and shales)	*Perisphinctes anceps, Indosphinctes calvus, Reineckeia ravana Kinkeliniceras,* sp. *Hubertoceras mutans.*
	L. Callovian	Rehmanni beds (yellow limestone).	*Reineckeia rehmanni, R tyranniformis, Sivajiceras kleidos, Idiocycloceras singulare, Kellawaysites greppini.*

Age.		Sub-divisions.	Leading fossils.
CHARI 1,200 ft.	Up. Bathonian	Macrocephalus beds (shales with calcareous bands, with golden oolite—diadematus zone—in the upper part).	*Macrocephalites macrocephalus M chariensis, Dolichocephalites subcompressus, Indocephalites diadematus, Kamptokephalites dimerus, Pleurocephalites habyensis, Belemnites*.
PATCHAM 1,000 ft.	L. Bathonian.	Patcham coral bed.	*Macrocephalites triangularis, Sivajiceras congeuer, Procerites hyans, Thamnastrea, Stylina, Montlivaltia*
	L. Bathonian.	Patcham shell limestone.	*Macrocephalites triangularis Trigonia pullus, Corbula lyrata*
		Patcham basal limestone.	*Megateuthis*.

eastern coast seems to have taken roughly the present outline in the Jurassic, when probably the Gondwana Continent began gradually to separate into different units which drifted apart. A sea also invaded the area north of Kathiawar during this period.

The strata formed during these temporary incursions of the sea are of clastic nature and of moderate thickness, generally dipping gently seaward. Sometimes however they attain a large thickness as in the case of the Jurassic rocks of Cutch (about 6,000 feet) which is to be attributed to gradual sinking of the basin of sedimentation as the deposition proceeded.

The Jurassic rocks of Western India occupy large areas in Kathiawar, Cutch and Rajputana all of which seemed to have formed parts of a large sedimentary basin, a shallow sea which extended northwards from Cutch as far as the Salt Range in the Punjab. The outcrops are now isolated by intervening large stretches of desert sands and alluvia. The Salt Range deposits, though folded, compressed and much disturbed, are similar to those of Cutch and show much less affinity with those of the Himalayan and Baluchistan geosynclinal facies of the same age. Compared to the geosynclinal facies, these rocks are

TABLE. 31.—SECTION IN THE JUMARA DOME, CUTCH.

(*Pal. Ind. N. S.* IX, II, Part 6.)

Age.	Stage and zone.	Characteristic ammonites.
Up. Argovian	Upper Dhosa oolite (green oolite).	*Taramelliceras jumarense.*
L. Argovian	Lower Dhosa oolite (brown oolite).	*Mayaites maya, Peltoceratoides semi rugosus.*
Up. Divesian	Lower Dhosa oolite (brown oolite.	*Euaspidoceras* sp
Mid. Divesian	Upper Athleta beds (shales and yellow marls)	*Metapeltoceras* spp , *Peltoceras ponderosum, Orionoides indicus.*
Mid. Divesian	Middle Athleta beds (shales and yellow marls).	*Peltoceras metamorphum, Orionoides purpurus*
L Divesian	Lower Athleta beds Gypseous shales).	*Peltoceras* sp., *Reineckeites* sp
Up. Gallovian	Upper Anceps beds (yellow limestone).	*Kinkeliniceras* sp. *Hubertoceras mutans*
	Lower Anceps beds (yellow limestone).	*Indosphinctes calvus, Sivajiceras fissum*
L. Calloviun	Upper Rehmanni beds (yellow limestone).	*Reineckeia tyranniformis, Sivajiceras kleidos, Idiocycloceras singulare*
	Lower Rehmanni beds (yellow limestone).	*Reineckeia rehmanni, Kellawaysites greppini*
Up Bathonian	Upper Macrocephalus beds (limestone).	*Dolicephalites subcompressus, Macrocephalites* spp *Kamptokephalites* aff *magnumbilicatus.*
” ”	Middle Macrocephalus beds (Shales with ferrugenous nodules).	*Dolicephalites subcompressus, Nothocephalites semilaevis.*
” ”	” ”	*Macrocephalites chariensis, Kamptokephalites dimerus, Indosphinctes* sp.
” ”	” ”	*Macrocephalites chariensis, Alcidia* sp , *Parapetoceras* sp.
” ”	” ”	*Macrocephalites chariensis, Kamptokephalites dimerus, Pleurocephalites habyensis*
” ”	Lower Macrocephalus beds (White limestones and shales)	*Macrocephalites triangularis, M. madagascariensis, Sivajiceras* aff. *congener*
L. Bathonian	Upper Patcham (coral limestone).	*Macrocephalites triangularis, Sivajiceras congener, Procerites hians.*
” ”	Lower Patcham (Shelly limestone).	*Macrocephalites triangularis* and other species.

of shallower origin and laid down not far from the land, as evidenced by the presence of intercalated plant remains.

RAJPUTANA.

The Jurassic sea of Western India which covered Cutch seems also to have spread over a large part of Rajputana. Outcrops are seen in Bikaner and Jaisalmer States but their full extent is hidden from the view by desert sands and alluvia. The rocks consist of alternations of compact, buff, light brown or yellow limestones and grey or brown sandstones and grits. Some of the bands are rich in fossils of marine character and can be correlated with similar beds of Cutch. Some of the limestones are grey to bluish grey at depth but on weathering assume a yellow or brown colour. Two types of these are quarried in Jaisalmer ; one is a compact, fine grained orange or yellow brown limestone and the other a brown and yellow shell-limestone full of shells. Both of these take good polish and are handsome stones for decorative building.

The succession of these rocks in Jaisalmer is as follows :

Abur beds ..	Limestones and shales	Uppermost Jurassic
Parihar sandstones ..	Felspathic sandstones (unfossiliferous).	?
Badasar beds ..	Ferruginous sandstones ..	Katrol.
Jaisalmer limestones.	Fossiliferous sandstones and limestones.	Middle and upper Chari.

The lowest beds appear to be the Jaisalmer limestones with rich fossils including *Stephanoceras fissum* (=*Idiocycloceras singulare*), *Sindeites sindensis*, *Reineckeia* aff. *reissi*, *Grossouvria steinmanni*, etc., which indicate the same age as that of the upper portion of the Chari beds of Cutch. The Badasar beds contain *Pachysphinctes* aff. *bathyplocus* and other fossils and may be correlated with part of the Katrol series. The Parihar sandstones are unfossiliferous, while the Abur beds indicate an age high up in the Jurassic as they have yielded *Pseudohaploceras aburense* and *P. indicum*.

CUTCH.

Jurassic rocks occupy a large area in Cutch and are the oldest rocks except for some patches of Pre-Cambrians.

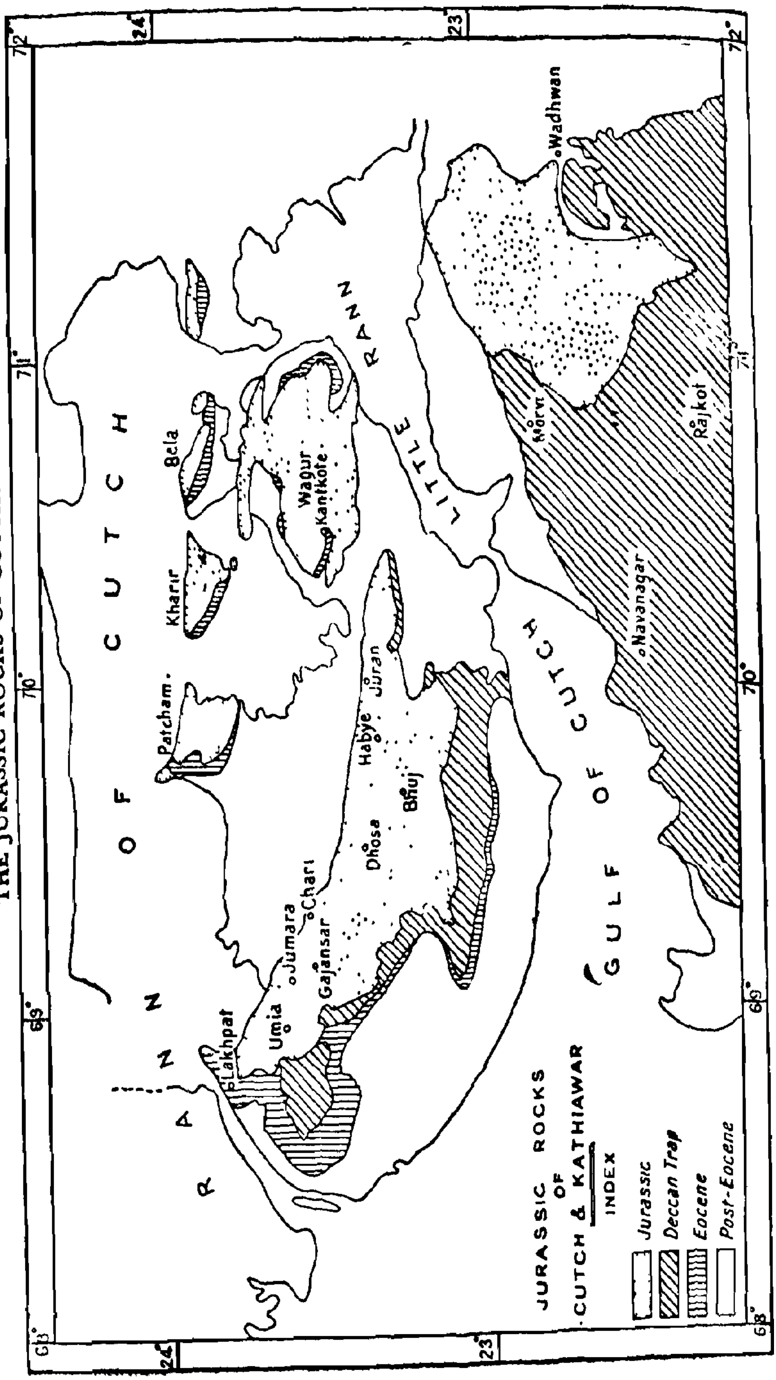
They are bordered to the south by the Deccan traps while on the north lies the saline marsh of the Rann of Cutch.

The Jurassic rocks have an estimated thickness of some 6,300 feet and crop out in three anticlinal ridges trending E.-W. Owing to an E.-W. fault the whole sequence is repeated. The northern range is about 100 miles long and is broken up into four islands (Patcham, Karrir, Bela and Chorar) in the Rann of Cutch. The middle ridge is 120 miles long, trending E. S. E. from Lakhpat on the west. A large outcrop occurs around Wagur in the east, separated by a plain. The southern ridge, south of Bhuj, is 40 miles long and forms the Charwar and Katrol hills. These anticlines show transverse undulations so that the dome-like parts have been separated from each other by denudation. Some distance to the east, in Dhrangadhra in Kathiawar, there is a large outcrop of Jurassic rocks which forms part of the same sedimentary basin.

The Jurassic sequence has been divided into four main divisions which are named PATCHAM, CHARI, KATROL and UMIA SERIES from below upwards, and range in age from Bathonian (Inferior Oolite) to Neocomian (Lowest Cretaceous). The topmost beds appear to contain representatives of the Aptain. They are covered over in places by the Eocene or by the lavas of the Deccan trap.

Patcham series.—The lowest rock group exposed in the Jurassic sequence is the Patcham series named after the island of Patcham in the Rann of Cutch as this is exposed in the ridge of this island as well as further eastwards. The lower strata are yellow limestones and sandstones containing lamellibranches (e.g., *Corbula*, *Trigonia*) in the earlier beds and corals and some ammonites in the later beds. The upper strata seen near Jarra consist of white limestones and shales with *Macrocephalites* and brachiopods. The Patcham series is estimated to be about 1,000 feet thick on the whole. Though ammo-

MAP X.
THE JURASSIC ROCKS OF CUTCH.



nites are present in this, they are not very numerous or as important as the brachiopod and molluscan fauna.

Chari series.—This takes its name from a village 30 miles north-west of Bhuj and contains five main stages. The lowest is the MACROCEPHALUS BEDS (so called from the common fossil—*Macrocephalites macrocephalus*) which can be sub-divided into several zones by means of the ammonite fauna. The upper part of the middle division of this stage contains a few layers of 'golden oolite' constituting the DIADEMATUS ZONE (*Indocephalites diadematus*) which is a calcareous oolite, the grains of which are coated with thin films of ferric oxide giving them a golden colour. Species of *Nucula* and *Astarte* are also very common in the Macrocephalus stage. Above this occur dark shales and sandy shales with calcareous and ferruginous nodules. The lower portion of these beds is the REHMANNI ZONE (*Reineckeia rehmanni*) in which *Macrocephalites* persists and *Phylloceras* and *Lytoceras* begin to appear; *Idiocycloceras* and *Subkossmatia* are characteristic, as also some terebratulids and Trigonias. The ANCEPS BEDS (*Perisphinctes anceps*) succeeding the Rehmanni zone contain ammonites, brachiopods and lamellibranchs. The ATHLETA BEDS (*Peltoceras athleta*) above them are composed of white limestones with a similar fauna. The topmost beds of the Chari series are the DHOSA OOLITES, composed of green and brown oolitic limestones and very rich in fossils, among which may be mentioned *Mayaites maya*, *Epimayaites polyphemus*, *Perisphinctes indogermanus*, *Peltoceratoides semirugosus*, *Paracenoceras kumagunense*, *Euaspidoceras waageni* and some terebratulids.

Katrol series.—This series, composed of different types of sandstones and shales, includes the KANTKOTE SANDSTONES, KATROL BEDS proper and GAJANSAR BEDS in the ascending order, and range in age from upper Argovian to Portlandian. The Kantkote sandstone is found in the neighbourhood of Wagad and indicates a horizon below the Katrol beds proper, the chief fossils being *Epimayaites* *transiense*, *Prososphinctes virguloides* and *Torquatisphinctes torquatus*. The lower and middle Katrol beds proper contain *Oppelids*, *Katroliceras*, *Aspidoceras*, *Streblites* and *Waagenia*, but the upper Katrol beds are barren. Interstratified with these strata are horizons containing plant remains. The Gajansar beds contain a fauna in which appear species of *Glochiceras*, *Phylloceras*, etc.

Umia series.—The Katrol series is overlain by the Umia series whose aggregate thickness is over 3,000 feet, consisting of sandstones, conglomerates and shales, the sandstones often showing bands of hard brown or black ferruginous grit. The shaly beds which are assigned to the basal Umias (ZAMIA BEDS) have yielded *Belemnopsis* cf. *gerardi*, *Hildoglochiceras kobelli*, *H. propinquum*, etc. The Zamia shales are assigned a higher horizon, *i.e.*, just below the Umia plant beds, by Dr. Raj Nath. The lower portion of the Umia beds, which comprises calcareous sandstones and oolites, has a Tithonian fauna including *Hibolites claviger*, *Ptychophylloceras tithonicum*, *Virgatosphinctes denseplicatus*, etc., some of which attain a large size. *Acanthorhynchia multistriata*, *Lobothyris* sp. and other branchiopods are also abundant. Succeeding the lower ammonite beds and separated from them by 200 feet of sandstones and conglomerates, are the TRIGONIA BEDS with *Trigonia ventricosa*, *T. Smeei* and other species. The Trigonia beds are overlain by 1,000 feet of unfossiliferous shaly strata which have been called the UKRA BEDS by Raj Nath. At the top of the Umia series are the Umia plant beds (BHUJ STAGE of Raj Nath), containing a flora of Lower Cretaceous age, which has been dealt with under the Gondwana System. Their upper portion contains an ammonite bed with *Crioceras* and *Acanthoceras* which are referable to the Aptian.

This sequence is overlapped by the Deccan trap lava flows or by Nummulitic rocks, with a distinct unconformity.

MADRAS COAST.

Marine fossils are associated with the Upper Gondwana beds of the East coast of the Peninsula in the Godavari-Kistna-Guntur tract. Ammonites and other marine fossils were found in some of the beds. The Ammonites, which are however in a bad stage of preservation, have been examined by L. F. Spath who assigns an Upper Neocomian age for them. The plant fossils in these beds are thought to be of Upper Jurassic age. Further details about them will be found in the chapter on the Gondwana System.

BURMA.

Namyau Series.—The Napeng beds of Northern Shan States are overlain by red sandstones, conglomerates and shales with occasional limestone bands. They are well developed in the Namyau valley and show evidences of shallow water origin. Fossils are found in the limestones and calcareous shales, comprising only brachiopods and lamellibranchs but no cephalopods, differing in this respect from other areas. The fossils include species of *Burmirhynchia*, *Holcothyris*, *Terebratula*, *Modiola*, *Pecten*, etc. which are considered to indicate a Bathonian age. The Namyau beds extend into Yunnan and Szechuan in China.

The LOI-AN SERIES of Southern Shan States is considered to be of Jurassic age. It is composed of shales and sandstones, with coal seams in the upper portion. The plant remains found in them include *Ginkgoites digitata*, *Cladophlebis denticulata*, *Pagiophyllum divaricatum*, *Brachyphyllum expansum* and *Podozamites distans*.

There are certain red sandstones in Amherst and Mergui districts which continue into Thailand and Tonkin. Though fossils are rare in them and of little value for determining the age, they are assigned to the Jurassic from their lithological similarity to beds in Northern Shan States and Siam (Thailand).

SELECTED BIBLIOGRAPHY.

Buckman, S. S. The brachiopods of Namyau beds, Burma, *Rec.* 45, 75-81, 1915.

Buckman, S. S. The brachiopods of Namyau beds. *Pal. Ind. N. S. III*, (2), 1917.

Cox, L. R. The triassic, Jurassic and Cretaceous gastropoda and lamellibranchiata of the Attock district. *Pal. Ind. N. S. XX*, (5), 1935

Holdhaus, K. Fauna of the Spiti shales—Lamellibranchiata and gastropoda. *Pal. Ind. Ser. XV*, Vol. IV, Fasc. 4, 1913.

Middlemiss, C.S. Geology of Hazara. *Mem. 26*, 1886.

Muir-Wood, H. M. Mesozoic brachiopoda of the Attock district. *Pal. Ind. N. S. XX*, (6), 1937.

Raj Nath. A contribution to the stratigraphy of Cutch. *Q.J G.M. M. S India*, 4, 161-174, 1933.

Spath, L F. Revision of the Jurassic cephalopod fauna of Cutch. *Pal Ind. N. S. IX*, 1924-33.

Spath, L.F. Jurassic and Cretaceous ammonites and Belemnites of the Attock district. *Pal. Ind. N. S. XX*, (4), 1934.

Uhlig, V. and Steiger, P. Fauna of the Spiti shales—Cephalopoda. *Pal. Ind. Ser. XV*, Vol. VI, (1, 2, 3, 5), 1903-14.

Waagen, W. Gergory, J.W. and Kitchin, F.L. Jurassic fauna of Cutch. *Pal. Ind. Ser. IX*, Vol. I, II, III, 1873-1903.

Wynne, A.B. Geology of Kutch, *Mem.* 9, Pt. I, 1872.

CHAPTER XIV.

THE CRETACEOUS SYSTEM.

General.

The Cretaceous is one of the most widely distributed sedimentary systems in India and is, moreover, represented by a variety of facies. The Himalayan area, as in the earlier systems, shows the geosynclinal facies. A large area of Tibet and northern Himalaya is covered by these rocks. In Baluchistan there is an eastern calcareous fossiliferous facies and a western arenaceous unfossiliferous facies consisting of sandy strata of the European *Flysch* type. Similar rocks are developed also in the Arakan region at the other border of India. Marine incursions of this period have left their deposits in the Narbada valley, in the Trichinopoly—South Arcot area of southern Madras and in Assam. The latter two have a faunal assemblage different from that of the geosynclinal deposits. Estuarine and lacustrine deposits are developed in various parts of the centre of the Peninsula underlying the great group of lava flows called the Deccan Traps.

Towards its end, the Cretaceous was a period of extensive igneous activity. Granites and basic rocks belonging to this period are found in the Himalayan area. Baluchistan and the Arakan region of Burma likewise witnessed igneous phenomena. The Peninsula was the scene of stupendous volcanic outbursts which were responsible for a large thickness of lava flows and fragmental products which at one time probably covered close upon half a million square miles of the land surface.

The eastern coast of India seems already to have taken shape at the beginning of the Cretaceous, but on the west there was still land from the southern end to as far north as Gujarat and Kathiawar. The Tethys extended into Baluchistan and further west on the one hand and into the Arakan region on the other. A sea connected with it transgressed into the Narbada valley in Upper Cretaceous times and about the same time a southern sea invaded the eastern shores of the Peninsula in Southern Madras and Assam.

It is an interesting fact that there is a more or less pronounced stratigraphical gap between the Lower and Upper Cretaceous in the geosynclinal area. Strata belonging to the age of the great transgression in the coastal areas —*i.e.*, the Cenomanian—are absent in Baluchistan and Hazara, and possibly also in the Arakan. This would suggest that the Cenomanian transgression may be compensated for by the marine regression on the borders of some parts of the geosynclinal area of the Extra-Peninsula.

SPITI.

Giumal series.—At Giumal, Kibber and Chikkim, the Lochambal beds gradually merge into yellow and brown sandstones and slaty quartzites. These constitute the Giumal sandstones and have a thickness of about 300 feet. The uppermost Lochambal beds contain the cephalopods *Hoplites* (*Neocomites*) *neocomensis* and *Acanthodiscus subradiatus* which clearly point to a Neocomian age.* The Giumal sandstones enclose a fauna which indicates that they cannot be older than Upper Velanginian or Lower Hauterivian nor younger than the Albian :

Cephalopods *Holcostephanus* (*Astieria*) aff. *atherstoni*, *Stephanoceras* sp., *Perisphinctes*, sp.

---

* A. Spitz (*Rec.* 44, p. 197-217, 1914) remarks, in connection with the ammonites of the Lochambal beds, that the European forms indicate even a somewhat later age than that assigned by him. This is significant in view of the assignment by Spath of an Upper Neocomian age for the imperfect ammonites found in the East coast Upper Gondwana strata, and of a Neocomian age for beds in Bannu which contain brachiopods of Kimmeridgian affinities Perhaps the 'Neocomian' ammonites of the Indian region are older than their European relatives would lead us to believe. This is a problem for experienced palaeontologists to elucidate.

Lamellibranchs.. *Cardium gieumalense* (abundant), *Pseudomonotis superstes* (abundant), *Ostrea*, sp., *Gryphaea* aff. *baylei*, *Pecten*, sp. etc.

Chikkim series.—The Giumal sandstones are overlain by grey or whitish limestones having a thickness of 100 feet or more. These are the Chikkim limestones which contain *Belemnites*, *Hippurites*, and some foraminifera including *Cristellaria*, *Textularia*, *Nodosaria*, *Dentalina*, etc. These are probably of the same age as the Hemipneustes beds of Baluchistan. The Chikkim shales are 150 feet thick, highly folded and unfossiliferous.

The Chikkim series is overlaid by a group of sandstones and arenaceous shales of the Alpine *flysch* facies, which are entirely unfossiliferous. In some places even the Neocomian is represented by the *flysch* formation. It is clear therefore that after the deposition of the Spiti shales the sea gradually became shallow and became unsuitable for supporting a rich fauna. There is also a distinct difference between the Spiti shale fauna and the Cretaceous fauna since the two have very few common elements.

MALLA JOHAR.

In Malla Johar, the Giumal sandstones are 500 feet thick, and are followed by 100 feet of red and greenish shales with intercalations of limestone and chert. These are followed by 300 feet of black, friable, *Belemnite shales* which are probably to be correlated with the Belemnite shales of Baluchistan, of Hauterivian age. Then follow 600 feet of *flysch* sediments resembling the Pab sandstones of Baluchistan. These are overlain by 150 feet of green tuffs, 50 feet of red tuffs and finally by a great mass of volcanic breccia 1,000 feet or more thick. This breccia is associated with blocks of all sizes of sedimentary rocks ranging in age from Permian to Cretaceous and including the underlying *flysch*. These blocks have already been referred to as 'exotic blocks.' (*See* p. 345).

KUMAON AND TIBET.

Near the Niti Pass the Chikkim limestones are well developed. Beyond it in Tibet, there are volcanic rocks (of Cretaceous age) overlain by sandstones and shales of Lower Eocene age and these again by sediments of Middle and late Tertiary age containing mammalian remains.

Cretaceous rocks, consisting of Giumal sandstones and Cenomanian limestones, occupy a large area in Western and Central Tibet. They are overlain by Eocene and later Cretaceous rocks towards the south-east. In the Phari plain are exposed a thick series of limestones, shales, slates and quartzites which include Triassic and possibly older beds. The upper limestones of this group contain Liassic brachiopods. Jurassic rocks occupy a large area in the Provinces of Tsang and U, and fossiliferous Middle Jurassic limestones are known. Typical Spiti shales have been found near Kampa Dzong and in the hills east and south-east of Gyantse.

A full Cretaceous sequence, though the whole of it is not fossiliferous, is noted near Kampa Dzong in a series of faulted folds. Together with the associated early Tertiary rocks it constitutes the Kampa system. The succession near Kampa Dzong is shown in Table 32.

The lower Cretaceous is represented by the *Giri limestone* which is unfossiliferous. The overlying *Kampa shale* and *Hemiaster beds* are Cenomanian as shown by their fossil content. The *Scarp limestones* and the *Tuna limestones* range in age from Turonian to Mæstrichtian and are apparently the equivalents of the Hemipneustes beds and *Cardita subcomplanata* beds of Baluchistan. The ferruginous sandstones at the top are thought to be partly Cretaceous and partly Eocene.

In this region there are altered basic intrusives and serpentines which appear to be late Cretaceous or Eocene in age. There is also an unfoliated hornblende granite intrusive into the Mesozoic rocks.

KASHMIR.

The presence of white Cretaceous limestone containing *Gryphaea vesiculosa* is known in Rupshu and in Ladakh on the Leh-Yarkand road. Some *Hippurite*-bearing rocks are known in the Lokzhung range in northernmost Kashmir.

TABLE 32.—THE KAMPA SYSTEM OF TIBET.

Age.		Sub-divisions.		Thick Ft
EOCENE		Dzongbuk Shales		.
		Alveolina limestones		100
		Shales and limestones, unfossiliferous		400
		Sandy micaceous shales and flaggy sandstones		150
		Orbitolites limestone with *Orbitolites* and *Miliolina*		50
		Spondylus shales—Varicoloured and needle shales		150
		Operculina limestone — Shaly nodular foraminiferal limestone with *Nummulites*		
		Gastropod limestone—Limestones, thin-bedded below but hard, massive and dark above with gastropods, especially *Velates schmideliana*		?
		Ferruginous sandstones—no determinable fossils		200
CRETACEOUS	Maestrichtian	Tuna limestone	Flaggy shaly limestone with sandy layers and with Lithothamnion limestone in the middle (*Cyclolites regularis*, *Hemipneustes tibeticus*, *Holectypus*, *Orbitolites macropora*, *Vola quadricostata*	150
			Third scarp limestone with shaly bands—with *Radiolites* and *Actaeonella*	100
	Senonian	Thin, flaggy and shaly limestone with Radiolites and Echinoids		?
		Second Scarp limestone with *Rudistae*, *Orbitolites media*, Echinoids and Lamellibranchs		150
	Turonian	Dark shales and limestones with a few *Gryphaea*		?
		First scarp limestone, hard and splintery—no determinable fossils		150
	Cenomanian	Hemiaster beds—Pale grey shales with *Hemiaster grossouvrei*, *H. cenomanense*, *Gryphaea*, *Inoceramus*		250
		Kampa shale—Brown shaly limestone and black needle shales with *Acanthoceras rhotomagense* and other species and *Turrilites costatus*		?
	Lower Cretaceous.	Giri limestone—hard thin-bedded limestone, unfossiliferous		..
JURASSIC		Spiti shales.		

In the Astor-Burzil region, Cretaceous limestones and shales bearing foraminifera (*Orbitolina* cf. *bulgarica*), gastropods and corals are found intercalated with volcanic rocks, while granites, pyroxenites and other igneous rocks are also known to be intrusive into the Cretaceous.

HAZARA.

Mention has already been made of the fact that there are two parallel zones in Hazara in which different facies of rocks are developed side by side. This applies not only to the Jurassic but also to the Cretaceous.

In the northwestern zone, the Spiti shales of Jurassic age pass conformably upwards into the Giumal sandstones, succeeded by 10 to 20 feet of yellow sandstone containing Albian ammonites. Amongst the fossils are *Lyelliceras lyelli* (abundant), *L. cotteri*, *Eutrephoceras*, sp., *Douvilleiceras mammillatum* *D.* aff. *monile*, *Brancoceras*, *Diploceras* aff. *bouchardianum*, *Hamites* cf. *attenuatus*, *Metahamites* aff. *elegans*, *Oxytropidoceras multifidum*, *O. roissyanum*, *Mojsisovicsia* aff. *delaruei*. This bed is followed by 400 feet of well-bedded grey limestone with a laterite layer on top, the latter indicating subaerial weathering before the Eocene was laid down.

In the south-eastern zone, the massive limestone of Upper Jurassic age is succeeded by Giumal sandstones which are 100 feet thick, and dark green to nearly black in colour. Calcareous intercalations in these sandstones contain abundant *Trigonia*. They are succeeded by 100 feet of sandstone and shell limestone, overlain by 100 feet of buff, thin-bedded shaly limestone. All these form a conformable series and appear to be of Neocomian to Albian age. Their junction with the overlying Eocene is marked by a bed of laterite. In this south-eastern zone, therefore, the beds between the Albian and Eocene are missing whereas in the north-western zone the unconformity is much smaller, *i.e.*, between the Middle Albian and some part of the Upper Cretaceous.

ATTOCK DISTRICT.

The Spiti shales of this region pass imperceptibly upwards into the Giumal horizon containing *Oxytropidoceras* aff. *roissyanum* in the uppermost beds which are of Albian age. There are no strata belonging to an age between these and the Eocene.

SAMANA RANGE.

Above the Samana Suk limestone of Jurassic age there occur dark grey glauconitic sandstones with limestone bands containing the ammonite *Astieria* and *Belemnites* of Neocomian age. The glauconitic sandstones are unconformably succeeded by the MAIN SANDSTONE SERIES of Albian age consisting of white quartzitic sandstones with hæmatitic bands and having a thickness of about 700 feet. Fossils occur in the topmost grits including :—

Cephalopods	. *Douvilleiceras mammillatum* (very abundant), *Pictetia* cf. *astieriana*, *Cleoniceras daviesi*, *Desmoceras latidorsatum*, *Brancoceras indicum*, *Hamites* cf. *attenuatus*.
Brachiopods	.. *Rhynchonella samanensis*, *R. reticulata*, *Terabratula samanensis*, *T. daviesi*, *Kingena spinulosa*.
Gastropods	.. *Metacerithium* cf. *ornatissimum*, *Semisolarium moniliferum*
Lamellibranchs	. *Pecten*, *Neithea*, *Venus*, *Cyprina* cf. *quadrata*.
Echinoderms	*Discoidea* aff. *decorata*, *Conulus* sp , *Holaster* sp.

The Main Sandstone series is succeeded, after a slight unconformity, by 150 feet of flaggy limestone called the LOWER LITHOGRAPHIC LIMESTONE, of probably Chikkim age. Above this there are variegated quartzitic sandstones and the UPPER LITHOGRAPHIC LIMESTONE, which also appear to be of Upper Cretaceous age.

CHITRAL.

Middle to Upper Cretaceous strata, consisting of limestones containing *Orbitolina* and *Hippurites*, are found in a series of outcrops in Chitral, often faulted against older strata. They are succeeded by the RESHUN CONGLOMERATE BEDS whose age may be Upper Cretaceous or Eocene.

BALUCHISTAN—SIND.

In the eastern or Calcareous zone of Baluchistan, the Cretaceous System is well developed as a series of shales and limestones, whereas in the western or Flysch zone it consists mostly of dark greenish grey sandstones and sandy shales.

THE CALCAREOUS ZONE.

Belemnite shales.—In the Calcareous zone the Neocomian succeeds the Callovian strata unconformably. It consists of two divisions, the lower BELEMNITE BEDS and the upper PARH LIMESTONES. The Belemnite beds are dark shales containing abundant belemnites of the genus *Duvalia* (a flatted form) and other fossils including *Duvalia dilatatus*, *Belemnites latus*, *B. subfusiformis*, *Gryphaea oldhami*, etc. At times the Belemnite beds swell into a thick formation of green shales with thin limestone intercalations ; by the accession of arenaceous materials these pass into the flysch facies developed on a large scale in Lower Zhob. The Belemnite shales are younger than the upper parts of the Spiti shales which, as we have seen, are of Lower Neocomian age.

Parh Limestones.—Conformably overlying the Belemnite shales are the Parh Limestones of white, red and purple colours and often of porcellanoid texture. They occasionally reach a thickness of 1,500 feet. They are unfossiliferous in the main, but occasionally contain *Inoceramus* and the aberrant genus *Hippurites* characteristic of the Mediterranean province.

The Parh Limestones and the Belemnite beds are seen forming the peripheral portions of the domes and anticlines whose cores are of dark-coloured Jurassic limestone. These two divisions, which form one stratigraphic unit of Upper Neocomian age, unconformably overlie the Callovian Polyphemus beds and are in turn unconformably overlain by rocks of Senonian (Campanian) age.

Hemipneustes beds.—The Upper Cretaceous is developed in the Laki range of Sind and in a large area in the Calcareous zone of Baluchistan. The lowest strata, called the HEMIPNEUSTES BEDS, are limestones of Campanian to Maestrichtian age, which have yielded a rich fauna :—

Cephalopods . *Nautilus sublaevigatus, Parapachydiscus dulmensis, Bostrychoceras polyplocum.*

Echinoids . *Hemipneustes pyrenaicus, H leymeriei, H compressus, Echinoconus gigas, E. helios, Holectypus baluchistanensis, Pyrina ataxensis, Hemiaster blanfordi.*

Lamellibranchs .. *Alectryonia pectinata, Gryphaea vesicularis, Vola quadricostata, Spondylus santoniensis, Pecten (Chlamys) dujardini, Corbula harpa.*

Gastropods .. *Ovula expansa.*

TABLE 33.—MESOZOIC SUCCESSION IN BALUCHISTAN.

(*After* Vredenburg—*Rec.* 38, p 199-200.)

Age.	Sub-divisions
Eocene	Ghazij beds—Gypseous clays etc , with *Assilina granulosa*
Danian to Maestrichtian	Cardita beaumonti beds with volcanic agglomerates, basalts dolerites and serpentines
	Pab sandstones—Massive, rather coarse, sandstones, sometimes of large thickness, accompanied by volcanic materials
Senonian	Olive shales with numerous ammonites, occasionally interbedded with volcanic ash.
	Hemipneustes beds—Limestones and calcareous shales with *Parapachydiscus, Bostrychoceras*, and several echinoids.
~~	~~~~~~ unconformity ~~~~~~
	Lituola beds—Flaggy porcellanic limestones and shales of buff and pale green colours, containing numerous small foraminifera principally of the genus *Lituola*
	Parh limestone—white, porcellanic, well stratified limestones with ferruginous basal beds
Neocomian	Belemnite beds—Black splintery shales with abundant belemnites (*Duvalia*) and *Hoplites*
~~	~~~~~~ unconformity ~~~~~~
Callovian	Polyphemus beds—thin bedded limestones and shales containing the large ammonite *Macrocephalites polyphemus*
Bathonian and Bajocian	Massive grey limestone, several thousand feet thick.
Lias	Dark, well-bedded limestones, several thousand feet thick, sometimes with fossiliferous horizons
Trias	Thick, greenish grey slaty shales with thin black limestone layers *Monotis salinaria, Didymites, Halorites*, etc
Permo-Carboniferous.	Limestones with *Productus* and other Permo-carboniferous fossils.

Cardita subcomplanata beds.—The Hemipneustes beds are overlain by shales containing occasional fossiliferous bands, one of these containing a rich ammonite fauna, though only 6 inches thick. The fossils from this zone include *Cardita (Venericardia) subcomplanata* (by which name the beds are sometimes called), and the ammonites *Indoceras baluchistanensis*, *Sphenodiscus acutodorsatus*, *Parapachydiscus dulmensis* and *Gaudryceras* sp.

Pab Sandstones.—The above-mentioned shales are followed by a thick series of flysch-like sandstones, called the Pab sandstones. Though mainly unfossiliferous, they contain rare fossiliferous horizons of shaly constitution, especially in the upper part, in which *Cardita (Venericardia) beaumonti* has been found. Other fossils of these beds include :

Lamellibranchs .	*Venericardia vredenburgi, Ostrea acutirostris, O. flemingi, Liostrea orientalis, Corbula sulcifera, C. harpa, Crassatella austriaca, Cardium inaequiconvexum, Glycimeris vredenburgi.*
Gastropods ..	*Bellardia indica, Nerita haliotis, Morgania fusiformis, Turritella praelonga, Potamides chaprensis, Procerithium triplex, Campanile breve.*
Cephalopods .	*Nautilus forbesi, N. lebechi.*

The Pab sandstones are intercalated with, and sometimes overlain by, volcanic materials of a basic character, mainly dolerites and basalts. They are largely developed in Jhalawan around Nal, Jebri, and Wad and in a broad zone west of the Porali river, continuing west of the Las Bela plain down to the sea-coast at Gadani.

The Jurassic and Cretaceous succession of Baluchistan is shown in Table 33, based on the work of E. Vredenburg.

SALT RANGE.

Belemnite beds.—Only the lower portion of the Cretaceous is represented here, consisting of a 10 feet thick grey sandstone supposed to be glauconitic, overlain by white sandstones. At Kalabagh, just beyond the Indus, they contain *Belemnites* of Neocomian age. They continue on to Chichali, Makarwal and Sheik Budin hills where the lower belemnite-bearing beds are shaly and associated with grey marls overlain by white and yellow sandstones.

The Belemnite beds contain a fairly rich fauna belonging to the Valanginian age, amongst which are the following:

Olcostephanus salinarius (abundant), *O. sublaevis*, *O. fascigerus*, *O.* (*Rogersites*) *schenki*, *Blanfordiceras* aff. *wallichi*, *B.* cf. *boehmi*, *Subthurmannia media*, *S. fermori*, *S patella*, *Himalayaites* cf. *seideli*, *Neocomites similis*, *Parandiceras* sp., *Kilianella asiatica*, *K. besairiei*, *Neocosmoceras hoplophorum*, *Sarasinella uhligi*, *Neohoploceras submartini*, *Neolissoceras grasianum*, *Hibolites subfusiformis* (abundant);

Pleurotomeria blancheti, *Astarte herzogi*, *Exogyra imbricata*.

Also fish and reptilian remains.

There are apparently no Mesozoic beds in this region younger than the Albian (Gault). They are succeeded by ferruginous marls having a thickness of about 6 feet, and these by Eocene limestones. The marls are also thought to be of Eocene age.

PENINSULAR AREAS.

BOMBAY.

Ahmednagar (Himmatnagar) sandstone.—The Ahmednagar sandstones, discovered by C.S. Middlemiss in the Idar State, consist of thick, horizontally bedded sandstones, shales and conglomerates, having pink, red and brown colours. Amongst the plant fossils found in these, *Matonidium indicum* and *Weichselia reticulata* have been identified, which point to a Lower Cretaceous (Wealden) age. These sandstones are therefore older than the Bagh beds and may be contemporaneous with the Nimar sandstones underlying the Bagh beds.

The Ahmednagar sandstone is similar to the Dhrangadhra sandstone (*see* Upper Gondwanas, p. 265), the Songir sandstone of Baroda and the Barmer sandstone of Western Rajputana, all of which appear to be of about the same age.

CUTCH.

The Jurassic rocks of Cutch pass upwards into the Umia plant beds which are overlaid by sandstones containing marine fossils like *Colombiceras* and *Cheloniceras*. The age of these beds is Aptian.

NARBADA VALLEY.

Bagh beds.—Strata of Cretaceous age are observed in a series of outcrops between Barwah east of Bagh in Gwalior State and Wadhwan in Kathiawar, the best exposures being found around Chirakhan and in the Alirajpur—Jhabua area in Gujarat. They rest on the ancient metamorphic rocks and attain a thickness of 60 feet or more in Gwalior State but are believed to be much thicker in Rajpipla State. The lower part of the beds is arenaceous while the upper is mainly calcareous.

Near Bagh, the lower beds consist of a basal conglomerate with sandstone and shale layers above. These are called the Nimar sandstones. The upper portion consists of three divisions, a lower nodular limestone, a middle marly bed (Deola marls) and an upper coralline limestone.

	Deccan Traps.	
Bagh beds .. Upper	..	Coralline limestone Deola Marls Nodular argillaceous limestone.
Bagh beds .. Lower	..	Nimar Sandstones
	Metamorphics.	

The Nimar Sandstones thicken when followed westwards. They yield good and durable building stones, quarries for the extraction of which exist near Songir in Baroda. The Nodular Limestone is compact, argillaceous and light coloured. The Deola (or Chirakhan) Marl is only 10 feet thick but richly fossiliferous. The Coralline Limestone is red to yellow in colour and contains abundant fragments of Bryozoa. The Deola Marls are the chief fossiliferous beds, but closely related fossils occur also in the limestones above and below them :

Cephalopods ..	*Knemiceras mintoi, Namadoceras scindiae, N. bosei.*
Lamellibranchs .	*Crassinella trigonoides, C planissima, Neithea morrisi, Ostrea arcotensis, O. leymeriei, Plicatula multicostata, Protocardium pondicherriense, Cardium (Trachycardium) incomptum, Macrocallista,* cf. *sculpturata, Grotriana* cf. *jugosa, Inoceramus concentricus, I. multiplicatus.*
Gastropods ..	*Lyria granulosa, Fulguraria elongata, Fasciolaria rigida, Turritella multistriata.*
Echinoids ..	*Cidaris namadica, Salenia keatingei, Cyphosoma cenomanense, Orthopsis indicus, Echinobrissus goybeti, Nucleolites similis, Hemiaster cenomanensis, H. similis*

This fauna is referable mainly to the Turonian, perhaps extending from uppermost Cenomanian to Senonian.

In his examination of the Bagh beds of the Dhar Forest area, Vredenburg came to the conclusion that they were contemporaneous with, and represented the marine facies of, the Lametas. The fossil evidence points to the age of these beds as Cenomanian to Upper Senonian.

The fauna of the Bagh beds has a close resemblance to that of the Cretaceous of Arabia and Southern Europe so that it is thought that the area was occupied by an arm of Tethys. There are however some elements which show affinities with the South Indian Cretaceous—*Protocardium pondicherriense, Trachycardium incomptum, Macrocallista* cf. *sculpturata, Turritella (Zaria) multistriata,* and the Uttattur forms *Grotriana* cf. *Jugosa,* and *Crassinella* cf. *planissima.* The available data are not sufficient to infer an intermingling of the fauna of the Tethyan and Indo-Pacific (Southern) regions.

SOUTHERN MADRAS.

The great Cenomanian transgression covered a large area of the Coromandel coast from near Pondicherry to the Cauvery valley. The Cretaceous rocks are found in three areas separated by the Pennar and Vellar rivers.

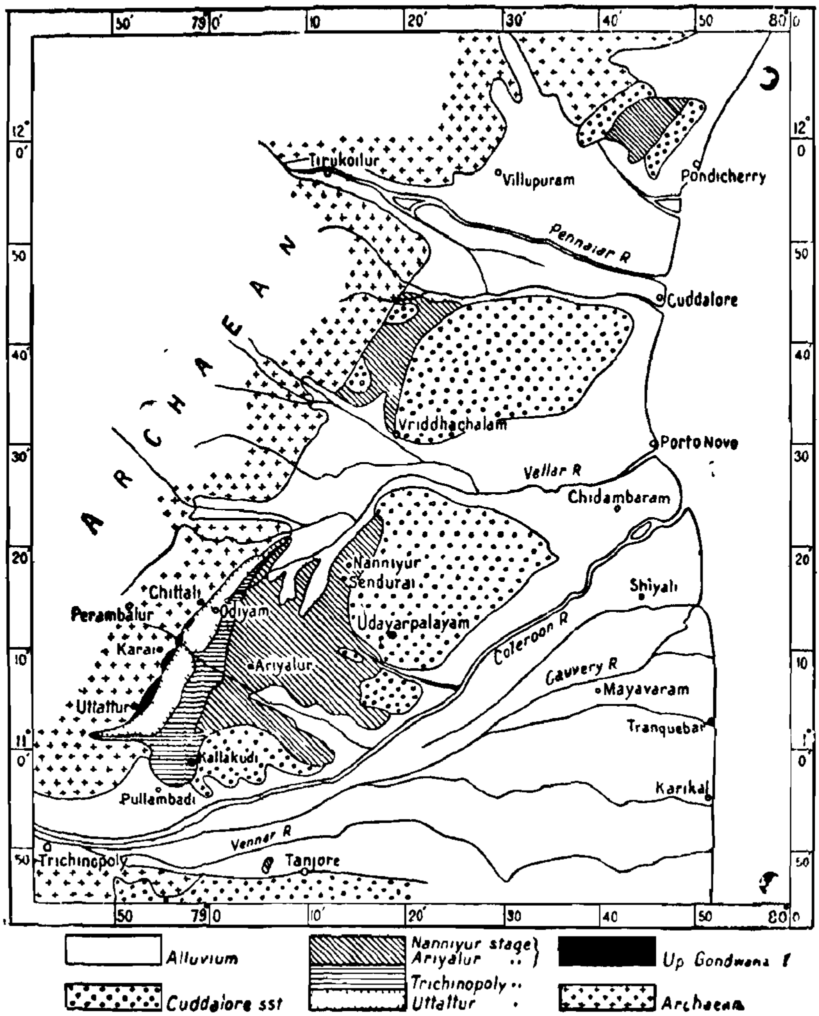
There is, besides, a tiny patch to the south of the Cauvery, a few miles west of Tanjore. The largest of these is in the north-east of the Trichinopoly district and occupies about 250 square miles.

TRICHINOPOLY DISTRICT.

Here the rocks lie on a platform of granitic gneisses and charnockites, a thin fringe of Upper Gondwanas

MAP XI.

THE CRETACEOUS ROCKS OF TRICHINOPOLY.



intervening between the sediments and the Archaeans in a few places along the western margin. On the north they are covered by alluvium and on the east by the Cuddalore sandstones of Miocene age. The Cretaceous rocks are divided into four stages as shown in Table 34. The oldest stage is found on the west and is successively overlain, and in places overlapped, by the younger ones which occur to the east. The general dip of the formations is to the east or E.S.E. at low angles. Slight unconformities exist between the three lower stages, though these are not prominent.

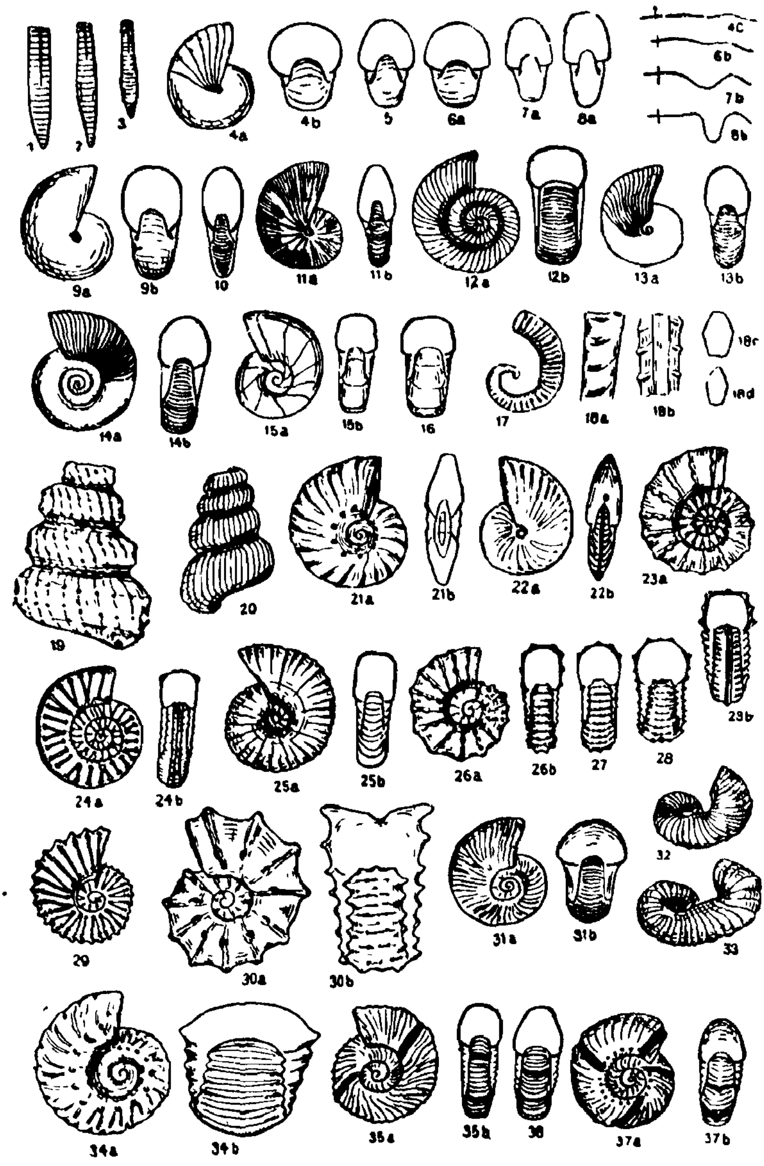
Uttattur stage.—The lowest beds are named after the village of Uttattur (about 20 miles N.E. of Trichinopoly) which lies on the western margin of the Cretaceous strata. This stage lies on charnockites for the greater part, and on gneiss and granite at its northern and southern ends.

TABLE 34.—CRETACEOUS SUCCESSION IN TRICHINOPOLY.

Age.	Stage.	Description and fossils.
Danian	Niniyur	White sandy limestones and sandstones with *Nautilus danicus*, *Lyria formosa*, *Codakia percrassa*, *Stylina parvula*
Maestrichtian	Ariyalur	*Upper*. Sandy strata without fossils
Senonian		*Lower*: Pale sands and clays with *Pachydiscus egertoni*, *P. otacodensis*, *Brahmaites brahma*, *Baculites vagina*, *Rostellaria palliata*, *Macrodon japeticum*, *Gryphaea vesicularis*, *Alectryonia ungulata*, *Stigmatopygus elatus*.
	Trichinopoly	*Upper* Sandstones, clays with *Placenticeras tamulicum*, *Schloenbachia dravidicum*, *Heteroceras indicum*, *Fasciolaria rigida*
Turonian		*Lower*: Sandstones, clays and shell limestones with *Pachydiscus peramplus*, *Schloenbachia* (*Prinocyclus*) *serraticarinatus*, *Trigonia trichinopolitensis*, *Protocardium hillanum*
	Uttattur	*Upper* Sandy beds with *Mammites conciliatus*, *Acanthoceras newboldi*, *Nautilus huxleyanus*
Cenomanian to uppermost Albian.		*Middle* Clays with *Acanthoceras* cf *rhotomagense*, *A mantelli*, *A coleroonense*, *Turrilites costatus*, *Alectryonia carinata*
		Lower. Basal limestone and coral rag with clays above, with *Schloenbachia inflata*, *Stoliczkaia dispar*, *Turrilites bergeri*, *Hamites armatus*, *Belemnites*.

PLATE XIX.

CRETACEOUS FOSSILS I.



EXPLANATION OF PLATE XIX

1. *Belemnites fibula* (1/3) 2. *B stilus* (1/3). 3 *B seclusus* (1/3). 4. *Nautilus bouchardianus* (1/8) 5. *N clementinus* (1/6) 6. *N huxleyanus* (1/4). 7. *N. danicus* (1/6). 8 *N. forbesianus* (1/4). 9. *Phylloceras forbesianum* (2/3). 10. *Phylloceras velledoe* (1/3). 11. *Phylloceras surya* (1/6). 12. *Lytoceras* (*Gaudry-ceras*) *kayei* (2/3). 13. *Lytoceras* (*Pseudophyllites*) *indra* (1/4). 14. *Lytoceras* (*Gaudryceras*) *varagurense* (1/4.)

Near its junction with the Cretaceous rocks, the charnockite is heavily weathered and replaced or veined with tufaceous limestone (kankary matter). Upper Gondwana shales and sandstones intervene between this stage and the charnockites in a few places, forming four or five separate patches. The junction between the Gondwanas and basal Cretaceous rocks does not show any disconformity but a thin ferruginous bed may be seen intervening between the two. The outcrop of this stage is 4 to 5 miles wide near the southern end but narrows down to less than a mile in the north, being overlapped at both ends by the next higher stage.

The Uttattur beds consist of fine silts, calcareous shales, and sandy clays containing ferruginous, phosphatic and calcareous nodules. The clays are often streaked with yellow and brown ferruginous stains. At the base, in a few places, there is a dark grey, somewhat arenaceous, limestone which is usually weathered (to a depth of 10 to 15 feet) to a yellow colour. It is locally of the nature of a coral rag containing corals and other fossils. It is locally used as a building stone and, within the last five years, for the manufacture of portland cement at Kallakkudi (Dalmiapuram) near Pullambadi. The lower beds are argillaceous and generally gypseous and traversed by veins of gypsum which are up to 5 inches thick. In certain areas similar but sparsely distributed veins of fibrous celestite and calcite also occur as also phosphatic nodules up to four or five inches long. The upper beds are more arenaceous and show current-bedding. There must have

---

15 *Lytoceras* (*Tetragonites*) *epigonum* (1/3) 16 *Lytoceras* (*Tetragonites*) *timotheanum* (1/3). 17 *Hamites* (*Anisoceras*) *indicus* (1/3) 18. *Baculites vagina* (a, side view, *b*, back view, *c*, *d*, cross sections) (1/4) 19. *Turrilites circumtæniatus* (1/2) 20. *Turrilites* (*Heteroceras*) *indicus* (1/3). 21. *Placenticeras tamulicum* (1/3) 22 *Sonneratia obesa* (1/4). 23. *Schloenbachia inflata* (1/6) 24 *Schloenbachia* (*Peroniceras*) *dravidica* (1/4). 25 *Stoliczkaia dispar* (1/6). 26. *Acanthoceras laticlavum* (1/6). 27 *Acanthoceras gothicum* (1/4). 28. *Acanthoceras newboldi* (1/3) 29 *Acanthoceras mantelli* (1/4). 30. *Acanthoceras cunningtoni* (1/6). 31, 32. *Scaphites obliquus* (2/3). 33. *Scaphites kingianus* (2/3). 34. *Olcostephanus superstes* (1/3). 35. *Holcodiscus theobaldianus* (1/3). 36. *Holcodiscus bhavani* (1/2) 7. *Holcodiscus karapadensis* (1/2).

been an interval before the close of the Uttattur times when the sea became desiccated, impregnating the sediments with gypsum and salt.

The dips are low and irregular, from a few degrees to as much as 25 degrees towards the east or southeast, the average being about 10 degrees. The thickness of the Uttattur stage should however be more than the 1,000 feet allowed for by Blanford, and probably about 2,000 feet.

Fauna.—This stage contains a fauna rich in ammonites and other invertebrates. Three divisions can be recognised from the faunal content, the lower with *Schloenbachia (Pervinquieria) inflata*, the middle with *Acanthoceras* cf. *rhotomagense* and other species and the upper with *Mammites conciliatus*. According to F. Kossmat, the lower two divisions are of uppermost Albian and Cenomanian age and the upper one of Lower Turonian age.

Gastropods ..	*Nerinea incavata, Turritella nodosa, Scala clementina, Littorina attenuata.*
Lamellibranchs ..	*Lucina fallax, Grotriana jugosa, Trigonarca gamana, Inoceramus labiatus, Neithea quinquecostata, Alectryonia diluviana, Gryphaea columba.*
Cephalopods ..	*Belemnites fibula, B. stilus: Nautilus huxleyanus, N. splendens, N. ootatoorensis, N. negama; Schloenbachia inflata, Stoliczkaia dispar, Acanthoceras,* cf. *rhotomagense, A. coleroonensis, A. mantelli, Lytoceras timotheanus, L. sacya, Phylloceras forbesianum, Mammites conciliatus, Anisoceras armatum, Turrilitus bergeri, T. costatus, Ptychoceras forbesianum, Baculites vagina.*
Corals ..	*Astrocoenia retifera, Caryophyllia granulifera, Platycyathus indicus, Stylina multistella, S. grandis. Thecosmilia geminata, Isastraea expansa, Thamnastraea crassa, Heliopora edwardsana.*

Trichinopoly stage.—This stage is unfortunately named, since the city of Trichinopoly is at least 15 miles from the nearest outcrop. The best known villages on this stage are Garudamangalam and Kunnam. It has a maximum width of 4 miles in the southwest where it overlaps the Uttattur stage and rests on the metamorphics. It gradually narrows down northwards where it is overlapped by the succeeding Ariyalur stage.

The Trichinopoly stage seems to have been laid down after the Uttattur stage was slightly uplifted and denuded. A slight unconformity, somestimes marked by a bed of conglomerate or coarse pebbles, is seen at the base of the Trichinopoly stage, but this is not always noticeable since the upper Uttattur beds are arenaceous and similar in constitution to the succeeding beds and angular unconformity is not easy to detect in the irregularly dipping strata. Some gypsum is associated with the lower part of this stage. Some of the conglomerate is full of granite, quartz and felspar pebbles derived from the granitic area to the south and southwest.

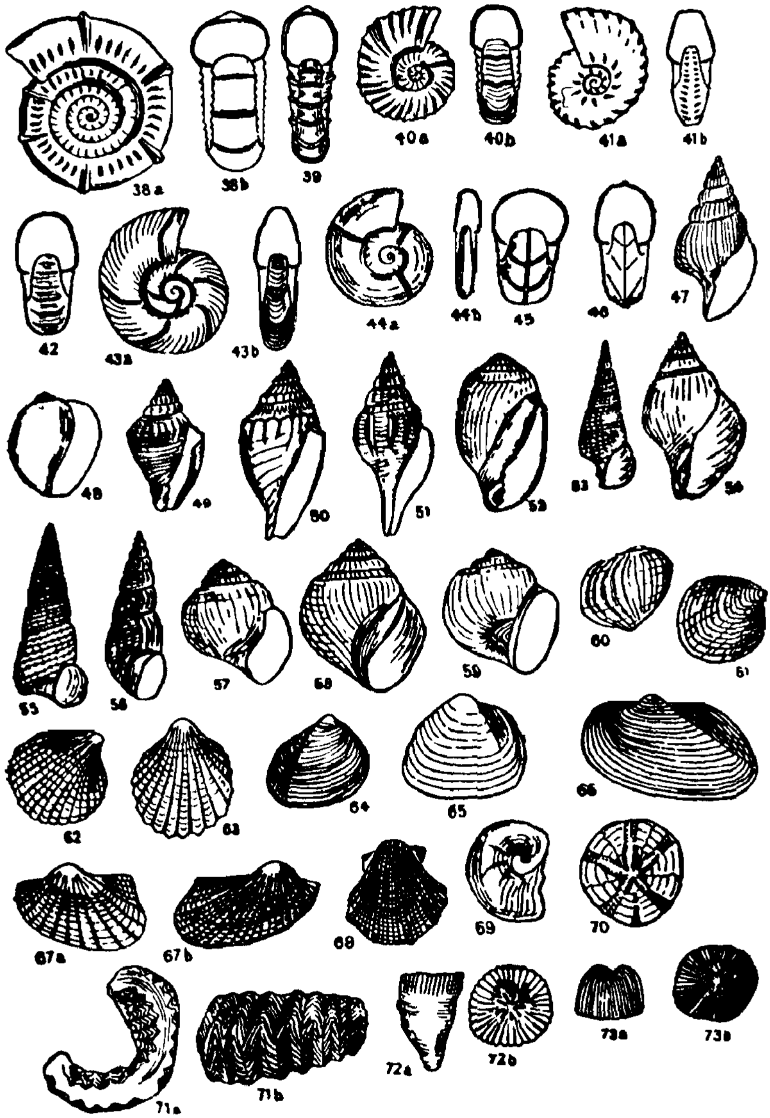
The Trichinopoly stage is a littoral, shallow marine formation consisting of sandstones, grits, calcareous grits, occasional shales and bands of shell limestone full of gastropod and lamellibranch shells. This shell limestone (found near Pullambadi, Garudamangalam, Anaipadi, Kunnam and other places), is a beautiful ornamental stone capable of taking a good polish, the white or opalescent molluscan shells being embedded in a very fine-grained dark grey matrix.

Though there is an unconformity at the base, the stage has a general dip conformable to that of the underlying and overlying beds. It shows large trunks as well as broken pieces of fossil wood in several places. One of these, discovered in 1940 near Sattanur by the author, measured 86 feet long and 54 inches in diameter at the base. Several smaller opalised and silicified trunks were found east and southeast of Garudamangalam.

The Trichinopoly stage has yielded a large number of fossils, the majority being lamellibranchs and gastropods, a change of fauna being indicated after the Uttattur times. The uncoiled ammonites characteristic of the Uttatturs—

PLATE XX.

CRETACEOUS FOSSILS II.



EXPLANATION OF PLATE XX.

38. *Brahmaites brahma* (1/3) 39 *Brahmaites vishnu* (1/4) 40 *Pachydiscus jimboi* (1/4). 41 *Pachydiscus gollevillensis* (1/4) 42. *Pachydiscus otacodensis* (1/4). 43. *Puzosia gaudama* (1/4) 44 *Desmoceras gardeni* (1/2). 45 *Desmoceras latidorsatum* (1/2). 46. *Desmoceras sugata* (1/3). 37. *Rostellaria palliata* (2/3). 48 *Cypraea kayei* (1/2). 49 *Gosavia indica* (2/3). 50. *Fulguraria elongata* (1/3). 51. *Fasciolaria rigida* (1/2). 52. *Actæonella cylindrica* (2/3). 53. *Cerithium arcotense* (2/3). 54 *Athleta purpuriformis* (1/3). 55 *Turritella (Zaria) multistriata* (2/3). 56. *Cheitziamn-*

Scaphites, *Turrilites*, *Anisoceras*—are apparently rare in this stage. The Chief fossils of this stage are:

Cephalopods .. *Peroniceras dravidicum*, *Gaudryceras varagurensis*, *Tetragonites epigonum*, *Pachydiscus peramplus*, *Parapachydiscus koluturensis*, *Prionocyclus serraticarinatus*, *Placenticeras tamulicum*, *Puzosia gaudama*, *Desmoceras sugata*, *Holcodiscus* (*Kossmaticeras*) *theobaldianus*, *H.* (*K.*) *bhavani*.

Gasropods .. *Alaria tegulata*, *Rostellaria palliata*, *Cypraea newboldi*, *Gosavia indica*, *Fulguraria elongata*, *Fasciolaria rigida*, *Hemifusus cinclus*, *Cerithium trimonile*, *Turritella affinis*, *Chemnitzia undosa*, *Velates decipiens*, *Eutrochus geinitzianus*. *Actaeon turriculatus*, *Avellana ampla*, *Dentalium crassulum*.

Lamellibranchs .. *Alectryonia diluviana*, *Spondylus calcaratus*, *Vola* (?*Neithea*) *multicostata*, *Modiola typica*, *Trigonarca trichinopolitensis*, *Trigonia scabra*, *Protocrdium pondicheriense*, *P. hillanum*, *Trachycardium incomptum*, *Cytherea vagrans*, *Panopea orientalis*, *Corimya oldhamiana*, *Corbula parsura*.

Corals .. *Trochosmilia inflexa*, *Isastraea morchella*.

Ariyalur stage.—Taking its name from Ariyalur town which is situated on it, this stage is more extensively developed than the lower ones and consists of grey to light brown argillaceous sandstone and white sandstone. Fossils occur in the calcareous, somewhat nodular, shaly rock which forms the lower part of the stage. The upper part consists of white unfossiliferous sandstones. The strata are regularly bedded and appear conformable to the Trichinopoly stage, though here and there conglomerates occur at the base. Moreover, they overlap on to the Uttattur beds in the north. They are found as detached

undosa (1/3). 57. *Euspira pagoda* (2/3) 58. *Ampullina bulbiformis* (1/2). 59. *Gyrodes pansus* (2/3). 60. *Nerita divaricata* (1/2). 61. *Grotriana jugosa* (1/2). 62. *Cardita jaquenoti* (1/2). 63 *Cardium* (*Trachycardium*) *incomptum* (1/2). 64. *Protocardium pondicherriense* (1/3). 65 *Lucina* (*codakia*) *percrassa* (1/4). 66. *Trigonarca galdrina* (1/2). 67. *Macrodon* (*Grammatodon*) *Japeticum* (2/3). 68. *Vola quinquescostata* (1/3). 69. *Exogyra ostracina* (1/2). 70. *Stygmatopygus elatus* (1/3). 71. *Alectroyonia ungulata* (1/4). 72. *Caryophyllia arcotensis* (1/3). 73. *Cyclolites filamentosa* (1/2).

outcrops in the Vridhachalam and Pondicherry areas and in a small patch amidst alluvium a few miles west of Tanjore. To the east they are covered by the Cuddalore sandstones. They have a gentle easterly or north-easterly dip (averaging 3 to 5 degrees) and attain a thickness of around 1,000 feet. Though shallow water deposits, they are not coastal deposits like the Trichinopoly stage.

The fauna of the Ariyalur stage resembles that of the underlying Trichinopoly stage though many new fossils appear. There is therefore no faunal break between these two as is evident between the Uttattur and Trichinopoly stages. The fauna includes reptiles, fishes, mollusca, echinoderms, brachiopods, corals and bryozoa, amongst which gastropods and lamellibranchs are the most numerous. The more important fossils are :

Reptiles (Dinosaurs) ..	Megalosaurian and Titanosaurian bones.
Fishes ..	*Otodus* cf. *semiplicatus*, *Oxyrhina* sp., *Ptychodus latissimus*.
Cephalopods ..	*Nautilus bouchardianus*, *N. clementinus*, *N. valudayurensis*, *N. trichinopolitensis* ; *Schloenbachia blanfordiana*, *Kossmaticeras bhavani*, *K. pacificum*, *K. aemilianum*, *Baculites vagina*, *Sphenodiscus siva*, *Desmoceras sugata*, *Brahmaites brahma*, *Parapachydiscus otacodensis*, *P. egertonianus*, *P. grossouvrei*, *Pachydiscus crishna*, *Hauericeras gardeni*, *H. rembda*, *Puzosia varuna*.
Lamellibranchs ..	*Alectryonia ungulata*, *Pholadomya caudita*, *Cyprina cristata*, *Trigonia orientalis*, *Trigonarca galdrina*, *Macrodon japeticum*, *Yoldia striatula*, *Radiolites mutabilis*, *Inoceramus balticus*.
Gastropods ..	*Pugnellus uncatus*, *Rostellaria palliata*, *Alaria tegulata cypraea kayei*, *Fulguraria elongata*, *Volutolithes, septemcostata*, *Neptunea rhomboidalis*, *Cancellaria breviplicata*, *Cerithium arcotense*, *C. karasurense*, *Turritella pondicherriensis*, *T. dispassa*, *T. (Zaria) multistriata*, *Euspira pagoda*, *Gyrodes pansus*, *Helcion corrugatum*, *Actaeon pugilis*.
Echinoderms ..	*Stygmatopygus elatus*, *Hemiaster cristatus*, *Epiaster nobilis*, *Cidaris sceptrifera*.
Corals ..	*Cyclolites filamentosa*, *C. conoidea*, *Stylina parvula*.

Niniyur stage.—The fossil-bearing beds overlying the Ariyalur stage are regarded as a separate stage. They are well exposed around Niniyur (Nanniyur) and Sendurai, northeast of Ariyalur. The rocks are grey, brown, ochreous and calcareous sands and shales, in which there are fragments of flint and chert containing algae. There are no ammonites in this stage, but the presence of *Nautilus* (*Hercoglossa*) *danicus*, and *Orbitoides minor* fixes its age as Danian. The fossils found in the Niniyur stage include :

Cephalopods ..	*Nautilus* (*Hercoglossa*) *danicus*, *N* (*H.*) *tamulicus*
Lamellibranchs ..	*Tellina arcotensis*, *Lucina* (*Codakia*) *percrassa*, *Cardita-jaquinoti.*
Gastropods ..	*Pseudoliva percrassa*, *Euspira lirata*, *Solarium arcotense*, *Lyria formosa*, *Turritella elicita.*
Corals ..	*Caryophyllia arcotensis*, *Stylina parvula*, *Thamnastraea brevipes*
Protozoa ..	*Orbitoides minor*, *O. faujasi.*
Algae ..	*Dissocladella savitriae*, *Indopolia satyavanti*, *Acicularia dyumatsenae*, *Parachaetetes asvapatii*, *Archaeolithothamnium* sp., *Orioporella malaviae.*

VRIDDHACHALAM AREA (SOUTH ARCOT).

Beyond the Vellar river, near Vriddhachalam, the Ariyalur beds emerge out of the alluvium and are overlapped on the east by the Cuddalore sandstone. They are exposed in a strip 15 miles long (N.N.E.—S.S.W.) and 3 to 5 miles wide between the two rivers Manimukta and Gadilam. The strata are of the same nature as around Ariyalur and have yielded *Trigonia semiculta*, *Neithea quinquescostata*, *Pecten verdachellensis*, etc.

VALUDAVUR-PONDICHERRY AREA.

Further north, around Valudavur (10 miles W. by N. of Pondicherry) and in the French territory of Pondicherry, the upper stages of the Cretaceous are exposed in a strip 8 miles long (N.N.E.—S.S.W.) and 4 miles broad. A large part of the area is under cultivation or under water (ponds or tanks). Dr. H. Warth, who investigated this area in 1895, distinguished six lithological horizons designated by letters A to F, but the investigation of the fossils by Dr. F. Kossmat proved that only three faunal horizons could be distinguished (*see* Table 35).

The total thickness of the strata is about 900 feet. It was originally thought that the Uttattur and Ariyalur stages were present here, but later work by H. Warth proved that only the Ariyalur and Niniyur stages were present.

RAJAMAHENDRI (GODAVARI DISTRICT).

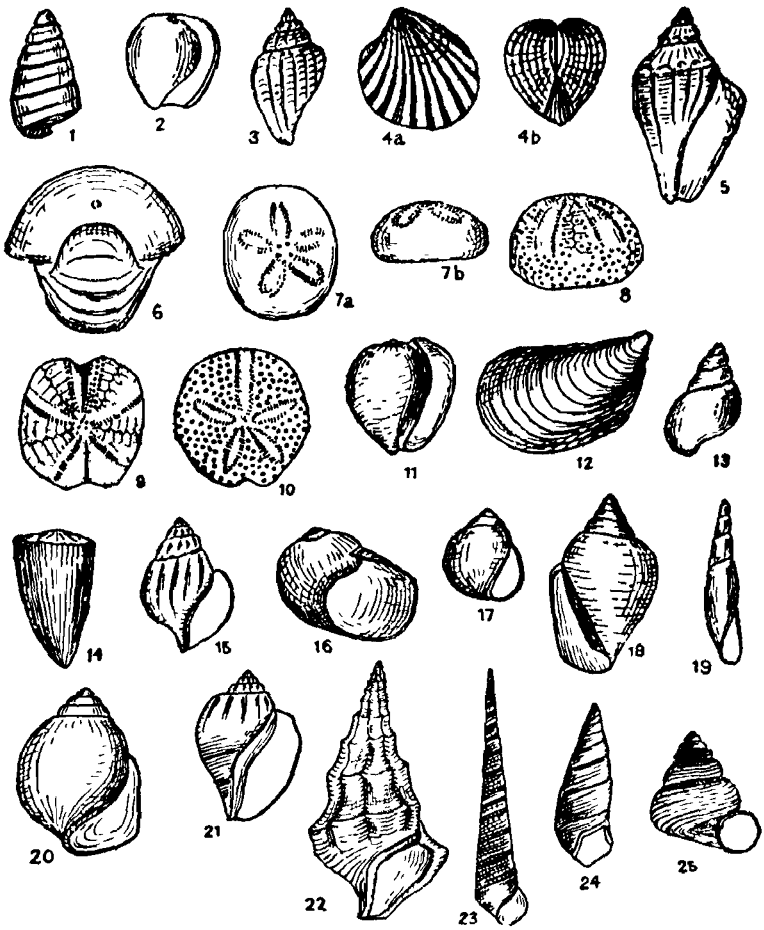
In the vicinity of Rajamahendri (Rajahmundry) at the head of the Godavari delta, the Upper Gondwana rocks

TABLE 35.—CRETACEOUS OF THE PONDICHERRY AREA.

Stage.	Beds.	Zone.	Description and fossils.
Niniyur.	Nerinea beds	F	Yellow, somewhat sandy limestones and sands with calcareous nodules. The limestones contain fucoid casts, while the overlying sands contain *Caryophyllia*, large gastropods and *Nautilus*. Fossils *Nautilus danicus*, *N. tamulicus*, *N. serpentinus*, *Nerinea* sp., *Cerithium karasurensis*, *Caryophyllia arcotensis*, *Cyclolites conoidea*, abundant *Orbitolites*.
Ariyalur	Trigonarca beds.	E.	Shell limestone occurring as nodules and blocks in marly and sandy strata. *Cyclolites filamentosa* abundant. Many fossils common to zones D and E. *Cyclolites filamentosa*, *Nautilus sublaevigatus*, *Pseudophyllites indra*, *Brahmaites brahma*, *Baculites vagina*; *Exogyra ostracina*, *Alectryonia ungulata*, *Pholadomya lucerna*, *Cypraea kayei*, *Turritella breantiana*
		D.	Sandy shales with phosphatic nodules which often replace fossils. *Trigonarca galdrina* characteristic, *Alectryonia ungulata*, *Exogyra ostracina*, *Turritella breantina*, *Nerita divaricata*, *Rostellaria palliata*, *Macrodon japeticum*
	Valudavur or Anisoceras beds.	C.	Loose blocks of fine grained calcareous rock in soft marl. *Anisoceras* common. *Baculites vagina*, *Gaudryceras kayei*, *Pseudophyllites indra*, *Sphenodiscus siva*, *Parapachydiscus menu*, *P. egertoni*, *Brahmaites brahma*, *Anisoceras indicum*, *A. rugatum*, *Pholadomya lucerna*, *Pharella delicatula*; *Rostellaria palliata*, *Athleta purpuriformis*, *Turritella pondicherriensis*, *T. Warthi*, *Trochus arcotensis*, *Bullina cretacea*, *Dentalium arcotinum*.
		B.	Concretions in sandy matrix containing many of the fossils occurring in Zone C.
		A.	Whitish sands with large nodules containing only annelid tracks and dendritic markings. No other fossils.

PLATE XXI.

CRETACEOUS AND EARLY TERTIARY FOSSILS.



EXPLANATION OF PLATE XXI.

1. *Morgania fusiformis* (2/3). 2 *Bernaya globus* (2/3) 3 *Volutocorbis indica* (2/3). 4. *Cardita* (*Venericardia*) *beaumonti* (2/3). 5 *Diploconus elegans* (2/3) 6 *Nautilus blanfordi* (1/3) 7. *Echinolampas griesbachi* (1/3). 8. *Clypeolampas helios* (1/3). 9. *Hemipneustes compressus* (1/3). 10 *Hemiaster oldhami* (1/2). 11. *Ovula expansa* (1/4). 12 *Inoceramus simplex* (1/2). 13. *Paludina normalis* (2/3). 14. *Radiolites muschketoffi* (1/3). 15 *Pugnellus crassicostatus* (1/2) 16 *Nerita d' archiaci* (2/3). 17. *Avellana ampla* (2/3). 18. *Physa* (*Bullinus*) *prinsepii* (1/3) 19. *Lymnoea subulata* (2/3). 20. *Natica stoddardi* (2/3) 21. *Pseudoliva elegans* (2/3). 22. *Cerithium stoddardi* (1/2). 23. *Turritella proelonga* (1/3). 24. *Vicarya fusiformis* (2/3). 25. *Valvata multicarinata* (3/2).

are seen to be superposed by sandstones and limestones of a total thickness of 50 feet. The limestones, which form the upper portion, contain bivalves and gastropods among which *Turritella* is very common. The fauna, though not examined in detail, is thought to be related to that of the Ariyalur stage. These strata are overlain by the Deccan Traps.

ASSAM.

Marine Cretaceous rocks occur in the Garo, Khasi and Jaintia Hills, the beds being dominantly arenaceous, with occasional shales and carbonaceous material. In the Garo Hills they rest on a gneissic platform and are composed of sandstones with some coaly layers. In the Khasi and Jaintia Hills the basal beds are conglomeratic, reaching a thickness of up to 100 feet. The conglomerates are succeeded by the MAHADEO BED (glauconitic sandstone), LANGPAR BED (light coloured sandstones containing plant remains) and the CHERRA SANDSTONE (massive sandstones).

The Cretaceous beds are 600 to 1,000 feet thick near the edge of the Assam plateau, having gentle dips on the plateau but plunging steeply down the southern flanks under the alluvial valley to the south. There are several isolated but small outcrops on the plateau ; they are interesting as indicating the large original spread of the Cretaceous rocks on the plateau region.

Fossils have been obtained from the glauconitic sandstones near Mahadeo and from a locality two miles distant from Therria Ghat on the Cherrapunji road. They include the following :

Echinoderms ..	*Echinoconus douvillei, Stigmatopygus elatus. Hemiaster.*
Brachiopods ..	*Rhynchonella depressa, Terebratula carnea.*
Lamellibranchs ..	*Neithea faujasi, Vola propinqua Chlamys* cf. *dujardini, Ostrea* (*Alectryonia*) *arcotensis, O.* (*Alectryonia*) *angulata, Gryphaea visicularis.*
Gastropods ..	*Helcion corrugatum, Nerita divaricata, Natica* (*Lunatia*) *larteti, Turritella pondicherriensis, T. multistriata,*

Gyrodes pansus, Campanile turritelloides, Aporrhais tegulata, Rostellaria palliata, Cypraea, cf. *globulina, Lyria crassicostata.*

Cephalopods .. *Nautilus baluchistanensis, Baculites vagina, Puzosia planulatus, Stoliczkaia dispar, Anisoceras indicum.*

The Assam fauna is very closely related to that of the Trichinopoly Cretaceous, especially the Ariyalur stage. According to E. Spengler, it is of Senonian age. Very similar fauna is found in Natal in South Africa and all the three apparently lived in one zoo-geographical province —the Indo-Pacific. As already mentioned, these faunas have only a small degree of resemblance to the Bagh fauna which latter is related to the Baluchistan—Arabian (Mediterranean) Cretaceous fauna. A fairly effective barrier, the Indo-African Gondwana continent, existed, which prevented the free intermingling of the two faunal groups.

The occurrence of Cretaceous rocks in other parts of Assam has not been definitely established. It is however probable that the lower part of the Disang series is of this age. Some limestones found around Akral in Manipur may possibly belong to the Cretaceous. No cretaceous rocks have so far been found in the little-explored sub-Himalayan region of Assam.

BURMA.

In the vicinity of Kalaw in Southern Shan States there are soft friable purple sandstones, known as the 'Red Beds', overlying the Loi-An series. They contain *Turrilites* and *Baculites* which indicate an Upper Cretaceous age. In Upper Burma, Cretaceous rocks are known to exist in the Jade mines tract, in the region of the first defile of the Irrawaddy between Sinbo and Bhamo, and in the second defile in the Bhamo district. The rocks are mostly limestones and calcareous shales containing *Orbitolina* and other foraminifera and molluscan shells.

ARAKAN YOMA BELT.

A wide belt of Cretaceous and Eocene rocks stretches from Assam-Burma border west of the upper reaches of the Chindwin river, along the mountainous tracts of the Arakan Yoma down to Cape Negrais. Our knowledge of this belt is fragmentary, since much of the area is covered by mountains and forests difficult of access.

In the Sandoway district of the Arakan coast there are some argillaceous limestones of creamy colour near Mai-i, from which *Schloenbachia inflata*, a Cenomanian fossil, has been obtained. In the Ramri island near the coast of this region an ammonite identified as *Acanthoceras daviesi* was found, which, according to G de P. Cotter (*Rec.* 66, p. 255, 1932) belongs to the *Acanthoceras coleroonensis* group which is characteristic of the Uttattur stage of Trichinopoly Cretaceous.

The foothills of the Arakan Yoma in the Thayetmyo district have yielded *Cardita beaumonti*, *Orbitoides* and some lamellibranchs. The rocks of the Yoma in Arakan are known to contain *Placenticeras* and *Mortoniceras*.

The NEGRAIS SERIES, consisting of grey sandstones, shales and limestones, occurring on the flanks of the Yoma north of the Cape Negrais, and extending to the Prome District, is considered to be of Cretaceous age. It is intruded by peridotites and serpentines.

The Upper Axial group contains *Cardita beaumonti* and other lamellibranchs and gastropods and is therefore of Cretaceous age in part.

IGNEOUS ROCKS IN THE CRETACEOUS.

Reference has already been made to the presence, in parts of India, of igneous rocks in close association with Cretaceous formations. They comprise acid, basic and ultrabasic types both in the intrusive and extrusive phases.

They occur in the northern zones of the Himalaya, in Kashmir, Baluchistan, Burma and in the Peninsula, the last being the Deccan trap which is dealt with in the next chapter.

Volcanic breccias and lavas of basaltic and andesitic composition are intimately associated with the 'exotic blocks' of Johar, Bhalchdhura and their neighbourhood in Kumaon. They are considered to be of late Cretaceous or early Eocene age. In the Burzil-Dras region of Kashmir marine Cretaceous limestones are seen in association with basic lava flows, ash-beds and agglomerates, and also with intrusive hornblende-granite, porphyry, gabbro and serpentinised ultrabasics. The volcanics have a bedded character and are intercalated with the Cretaceous *Orbitolina*-bearing limestones and shales which have undergone folding. They occupy a large area in the Burzil valley and have a thickness amounting to a few thousand feet.

The sediments and volcanics have been invaded by bosses and veins of hornblende-granite and serpentine which are therefore slightly younger than the volcanic rocks. The hornblende-granite of this region, which appears to be identical with similar granite in other parts of the Himalaya, is therefore of post-Cretaceous, probably early Eocene age.

Pyroclastics, lava flows of basaltic composition and intrusive masses of serpentine are found in association with the Cretaceous of Baluchistan. The serpentines of the Zhob-Quetta area contain workable deposits of chromite.

Late Cretaceous or early Eocene igneous activity is known in the Arakan-Andaman belt. The rocks are intrusive into the Axials or early Eocene beds and comprise peridotites and serpentines which contain chromite in places. Gabbro, serpentines and enstatite-peridotites cover large areas in the Andaman and Nicobar islands and also in Sumatra and Java which lie on the same tectonic belt. At the northern end of Burma, in the

Kamaing sub-division of Myitkyina district, there occur numerous outcrops of serpentinised peridotites, dunites, pyroxenites and amphibolites amidst crystalline schists. They contain masses of chromite and jadeite, the latter being commercially exploited. The deposits of jadeite occur at Tawmaw, Meinmaw, Pangmaw and other places.

SELECTED BIBLIOGRAPHY.

Blanford, H.F., Cretaceous and other rocks of the S. Arcot and Trichinopoly districts. *Mem. 4*, 1862.

Blanford, W.T. Geology of the Taptee and Lower Nerbudda valleys. *Mem. 6*, Pt. 3, 1869 (Bagh beds, p. 45-57).

Clegg, E. L. G. The Cretaceous and associated rocks of Burma. *Mem.* 74, Pt. I, 1941.

Davies, L. M. et al. Fossil fauna of the Samana Range. *Pal. Ind. N. S. XV*, (1-5), 1930.

Douville, H. Les couches a Cardita beaumonti. *Pal Ind. N. S. X.*, (3), 1928-29.

Forbes, E. Report on the fossil invertebrates from South India collected by Kaye and Cunliffe. *Trans. Geol. Soc. London, 2nd Ser. Vol. VII*, Art. 5, 97-174, 1845.

Gupta, B.C. and Mukherjee, P.N. Geology of Gujarat and Southern Rajputana. *Rec.* 73, 164-205, 1938.

Hayden, H.H. Geology of the Provinces of Tsang and U in Tibet. *Mem. 36*, Pt. 2, 1907.

Huene, F. von, and Matley, C.A. The Cretaceous Saurischia and Ornithischia of the Central Provinces. *Pal. Ind. N. S. XXI*, (1), 1933.

Kossmat, F. Importance of the Cretaceous rocks of S. India in estimating the geographical conditions during later Cretaceous times. *Rec. 28*, 39-54, 1895.

Kossmat, F. Cretaceous deposits of Pondicherry. *Rec. 30* 51-110, 1897.

Kossmat, F. Die Bedeutung der Sud-Indische Kreide-Formation. *J. B. K. K. Geol. Reichanstalt, Wien, 44*, (3), 459, 478, 1894.

Kossmat, F. Untersuchungen uber die Sud-Indische Kreide-Formation. *Beitr. z. Pal. Geol. Oster.-Ungarns.* IX, 97-203, 1895; XI, 1-46, 89-152, 1898.

Matley, C.A. The Cretaceous Dinosaurs of the Trichinopoly district. *Rec. 61*, 337-349, 1929.

Matley, C A. Stratigraphy, fossils, and geological relationship of the Lameta beds of Jubbulpore. *Rec.* 53, 142-164, 1921.

Noetling, F. Fauna of Upper Cretaceous beds of Mari hills. *Pal. Ind. Ser. XVI*, Vol. I, (2), 1897.

Rao, L.R. and Pia, J. Fossil Algae from the Niniyur group of the Trichinopoly district. *Pal Ind N. S. XXI*, (4), 1936.

Spengler, E. Contributions to the palæontology of Assam. *Pal. Ind. N. S. VIII*, (1), 1923.

Spitz, A. Lower Cretaceous fauna of the Himalayan Giumal sandstone. *Rec. 44*, 197-217, 1914.

Stoliczka, F. Cretaceous fauna of S. India. *Pal. Ind. Ser. I, III*, Vol I; *Ser V*, Vol. II ; *Ser. VI*, Vol. III ; *Ser. VIII*, Vol. IV ; 1861-73.

Wadia, D.N. Cretaceous volcanics of Astor-Deosai, Kashmir. *Rec. 72*, 151-161, 1937.

Warth, H. Cretaceous formation of Pondicherry. *Rec. 28*, 15-21, 1895.

Vredenburg, E. Geology of Sarawan, Jhalawan, Mekran, etc *Rec. 38*, 189-215, 1910.

CHAPTER XV.

THE DECCAN TRAPS.

GENERAL.

The close of the Mesozoic era was marked by the outpouring of enormous lava flows which spread over vast areas of Western and Central India. They issued from long narrow fissures or cracks in the earth's crust and tapped a large magma basin and are therefore called *fissure eruptions*. The lavas spread out far and wide in nearly horizontal sheets, the earliest flows filling up the irregularities of the then topography. They were erupted sub-aerially, for there are no evidences of sub-aqueous deposition. In recent years a few places have been recorded in Western India—*e.g.*, Pavagad hill, Girnar hill and the neighbourhood of Bombay—where the eruptions were of the 'Central' type, accompanied by differentiates of varying characters. Because of their tendency to form flat-topped plateau-like features and their dominantly basaltic composition, the lavas are called *plateau basalts*. Such flows are called *traps* because of their step-like or terraced appearance, the term being of Scandinavian origin.

DISTRIBUTION AND EXTENT.

The area now occupied by the Deccan Traps is about 200,000 square miles, including Bombay, Kathiawar, Cutch, Central Provinces, Central India and parts of the Deccan. They are found as far as Belgaum in the south, Rajahmundry* in the south-east, Amarkantak, Sirguja and Jashpur in the east and Cutch in the north-west. Rocks of the same age and characters found in Sind are

---

*Rajamahendri, a contraction of Rajamahendravaram, is the correct spelling, which has however been mutilated to the present Rajahmundry The former spelling will be found in Oldham's Manual also considered to belong to them. The present distribution shows that the traps may have occupied some of the areas intervening between the main mass and the outlying patches, but removed by erosion, and that the original extent may well have been half a million square miles. They are thus the most extensive geological formation of Peninsular India with the exception of the metamorphic and igneous complex of Archaean age.

The traps have been divided into three groups—Upper, Middle and Lower, with the Infra-trappean beds or Lametas at their base.

Upper traps (1,500 ft thick)	..	Bombay and Kathiawar; with numerous inter-trappean beds and layers of volcanic ash.
Middle traps (4,000 ft.)	..	Central India and Malwa; with numerous ash-beds in the upper portion and practically devoid of inter-trappeans.
Lower traps (500 ft)	..	Central Provinces and eastern areas; inter-trappean beds, but rare ash-beds.

STRUCTURAL FEATURES.

The trap country is characterised by flat-topped hills and step-like terraces. This topography is a result of the variation in hardness of the different flows and of parts of the flows, the hard portions forming the tops of the terraces and plateaux. In the amygdular flows the top is usually highly vesicular, the middle fairly compact and the bottom showing cylindrical pipes filled with secondary minerals; while in the ordinary flows the top is fine-grained and the lower portion coarser with sometimes a concentration of basic minerals like pyroxene and olivine. Vesicular and non-vesicular flows may alternate with each other, or the flows may be separated by thin beds of volcanic ash or scoriae and by lacustrine sediments known as Inter-trappean beds.

Ash beds are particularly well seen in the upper part of the traps, for instance around Bombay, Poona and in the Western Ghats. They usually reveal a brecciated structure, fragments of the trap being found in a matrix of dusty or fine-grained material. Columnar jointing in the traps may be seen in a few places, for instance in the Salsette Island, near Hoshangabad and in some places in Malwa.

The traps attain their maximum thickness near the Bombay coast where they are estimated to be well over 7,000 feet thick (Manual, Second edition, p. 272). They are very much less thick further east ; at Amarkantak and in Sirguja they are about 500 feet thick, while near Belgaum they are only about 200 feet.

The individual flows vary greatly in thickness, from a few feet to as much as 120 feet. A borehole at Bhusawal, 1,217 feet deep, revealed 29 flows, the average thickness being 40 feet. In the Chhindwara district of the Central Provinces, 15 flows have been identified with an average thickness of 70 feet. In the Sausar tahsil of the same district, the average for 7 flows has been found to be about 55 feet.

The flows have a great superficial extent in comparison with their thickness. Individual flows have been traced for distances of 60 miles and more, as for example between Chhindwara and Nagpur. This extraordinary spread is explained by Fermor as due to a high degree of super-heat in the erupted mass which is believed to have been derived from the basaltic or eclogitic shell of the earth, the heat being due probably to exothermic mineral transformations.

The Deccan traps occasionally show gentle dips as in the vicinity of Bombay. They are known to exhibit slight undulation and folding in the Satpura region of the Central Provinces which are believed to be due to slight disturbances subsequent to their formation. They have also been affected by faulting of post-trappean age—*e.g.*, several faults in the Sausar tract and also the Ellichpur fault at the southern foot of the Gawilgarh hills in Berar.

DYKES AND SILLS.

Dykes and sills of trap are noted in regions where the Deccan trap formation is quite thin, especially in the peripheral region. A large number occur in the Satpura area of the Central Provinces, the sills being particularly abundant in the Upper Gondwanas. In Cutch numerous dykes and sills have been observed cutting into the Jurassic strata. Similar features are observed in the Gondwana basin of Rewa, in Rajpipla State near Broach, in the Gir Forest of Kathiawar and in Southern Bombay. The sills are composed of fairly coarse grained and porphyritic dolerite. The dykes are often of a composite nature, containing both dolerites and basalts, the former sometimes porphyritic. The dykes are to be regarded as feeders for the trap flows and they should be expected to be present also underneath the main mass of traps. In general, the dykes and sills show no great regularity in direction, thickness or size, but some of them are many miles long and several hundred feet thick.

PETROLOGICAL CHARACTERS.

The Deccan traps belong to the type called *plateau basalt* by H.S. Washington. They are extraordinarily uniform in composition over much the greater part of the area and correspond to dolerite or basalt, with an average specific gravity of 2.9. They are dark-grey to dark-greenish grey, but brownish to purplish tints are also met with. The more acidic types found near Bombay and Salsette have a buff to creamy colour. The non-vesicular types are hard, tough, compact and medium to fine-grained and break with a conchoidal fracture. The vesicular types are comparatively soft and break more easily.

As already remarked, the traps are dominantly basic in character, but tachylite or basalt-glass is distinctly rare and may be found only as a thin selvage where the hot lava encountered a cold surface and suddenly became chilled thereby. In parts of Bombay, Kathiawar and Cutch, however, the traps are associated with acid, intermediate and ultrabasic rock types derived through differentiation of the original magma.

In the Girnar and Osham hills of Junagarh State (Kathiawar) there are, besides the usual dolerite and basalt, lamprophyre, limburgite, monchiquite, olivine-gabbro, porphyrite, andesite, monzonite, nepheline-syenite granophyre, rhyolite, obsidian and pitchstone, studied and described by M.S. Krishnan. K.K. Mathur and others who mapped the Girnar hills have expressed the opinion that the basaltic flows of this area were domed up by later intrusives which represent the result of differentiation through progressive crystallisation. In the Gir Forest of Kathiawar also there occur dykes of olivine-dolerite and masses of granophyre and rhyolite. The coastal region of Bombay has been shown to contain a large variety of types—rhyolite, granophyre, trachyte, andesite, ankaramite and oceanite, the acid types being considered to belong to a late phase of igneous activity. From the Pavagad hill in Gujarat, Fermor has described pumice, pitchstone, rhyolite, felsite, quartz-andesite, etc. The rhyolite which caps the hill is considered by Fermor and Heron to be a flow and not a plug-like intrusion as advocated by Mathur and Dubey. (*Rec.* 68, 17, 1934). Acid rocks also occur in the Narbada valley and in the Porbandar State. In parts of Kathiawar where borings have been put down through the traps, very basic types like limburgite and ankaramite are found inter-bedded with normal dolerites and basalts. Investigation of the phenocrysts in the very basic types, by W.D. West, has revealed that they correspond in composition to that of the rocks in which they occur, leading to the view that the phenocrysts are not due to crystal settling but are essential parts of the lavas which had already been differentiated at the time of intrusion.

The ultra-basic types seem to be more or less restricted to the western edge of the trap country in Bombay and Kathiawar as dykes, while the acid types are found mainly along two zones, one running from Pavagad hill to Bombay and the other from the Narbada valley to Porbandar State in Kathiawar.

It is of interest to note here that the traps at Worli Hill, Bombay Island, are associated with bituminous matter, whose presence in cavities is explained by Dr. C.S. Fox as due to the distillation, by the heat of the traps, of the organic matter present in the associated sedimentary beds.

PETROGRAPHY.

The common type of trap is composed of abundant labradorite of the composition $Ab_1 An_2$, and enstatite-augite (pigeonite), the two forming the bulk of the rock. The enstatite-augite is always abundant in the holocrystalline types, its amount decreasing with increase in the content of interstitial glass. It is usually greenish or brownish grey in colour in hand-specimens but practically colourless in thin section. In composition it approximates to a mixture of equal amounts of diopside and hypersthene, thus differing considerably from common augite. The most important character of this mineral is its small optic angle, 2V measuring up to 30° in the plane of symmetry.

Ophitic texture is common, the labradorite laths lying in a mass of more or less anhedral enstatite- augite. The labradorite is almost always the earlier mineral to crystallise, though contemporaneous crystallisation of the two may have taken place to some extent.

The rocks often show phenocrysts of felspar in the doleritic types and interstitial glassy matter in the basaltic types. The proportion of the glassy matter varies a good deal. The glass is often highly corroded and contains abundant dust-like inclusions which are presumably magnetite. The glass is liable to alteration into palagonite, chlorophaeite, celadonite and delessite. Since the augite and magnetite bear an inverse relationship to the glass in thin section, it is obvious that these two minerals are together represented in the glass.

Magnetite is quite a common, though a rather minor, constituent. It occurs usually as discrete grains amidst the other minerals, and as grains, dust and skeletal growths in the glassy groundmass. Some ilmenite and leucoxene are practically always present which is confirmed by the appreciable amount of titanium shown by the analyses, though of course titanium may be present in the augite also.

In some varieties a fair amount of olivine is present but biotite and hornblende are generally absent from normal types. Quartz is rare or absent, but there is generally an excess of silica in the *norm* calculated according to the rules of chemical classification devised by Clarke, Iddings, Pirsson and Washington (C.I.P.W.). Sodic plagioclase and orthoclase are absent, but interstitial granophyric or micrographic patches are fairly frequently seen.

Investigation by Sir Lewis Fermor of the flows encountered in the boring at Bhusawal showed that olivine, and to some extent labradorite, had settled down to the bottom of the flows, apparently through gravitative settling. In the Satpura region of Jubbulpore-Chhindwara, thick sills often show the phenomenon of crystal settling, the lower portions being coarse and holocrystalline and the upper portions finely crystalline and containing quartz and micro-pegmatite. A dyke in this region, which is over 8 miles long, consists of porphyrite containing oligoclase, enstatite-augite, hornblende, quartz and micro-pegmatite. There are, however, other areas where there is no evidence of crystal settling even in thick flows, as mentioned on a previous page.

Secondary minerals are often developed in the traps either as fillings in the amygdular cavities or as products of alteration and replacement.

The minerals of late hydrothermal activity are the zeolites—stilbite, apophyllite, heulandite, thomsonite, chabazite, scolecite, ptilolite, natrolite, laumontite, analcite and prehnite—calcite, chalcedony and its varieties (agate, jasper, carnelian, chrysoprase, heliotrope, onyx, etc.), opal and sometimes quartz and amethyst crystals in drusy cavities. These minerals are generally found in amygdular cavities which may be lined with chlorophaeite and delessite. Amongst the zeolites, radiating and sheaf-like aggregates of stilbite are the most common, though prismatic crystals also occur. Next in importance are apophyllite, heulandite, laumontite and scolecite, excellent crystals of which are not infrequently found. The alteration products are chlorophaeite, palagonite, delessite, celadonite, iddingsite and serpentine, the last two formed from olivine. Several of these are collectively spoken of as "green earth," which is sometimes used as a pigment material.

CHEMICAL CHARACTERS.

As might be expected from the uniformity in mineralogical composition, the chemical composition of the traps also tends to be uniform. Table 36 gives an idea of the average chemical composition of the traps.

The plateau basalts (of the fissure eruption type) when compared with the noraml cone basalts (central eruption type) show a higher iron and titanium content, the iron being dominantly in the ferrous state. Magnesia and the alkalies are also lower. This finds mineralogical expression in the presence, in plateau basalts, of enstatite-augite instead of the diopsidic augite of cone basalts.

The study of the trap flows (Lower traps) of Linga, Central Provinces, by Sir Lewis Fermor reveals the fact that, though the analyses are extraordinarily close to each other, there is, in the normative values, a small but distinct progressive change from below upwards—*i.e.*, decrease in quartz, total iron, total water and an increase in alkali felspars, total felspars and pyroxenes. The same features are also discernible in Washington's analyses as grouped by Fermor into Lower traps and Upper traps.

ALTERATION AND WEATHERING OF THE TRAPS.

The traps weather with characteristic spheroidal exfoliation which gives rise to large rounded boulders on the

TABLE 36.—CHEMICAL COMPOSITION OF THE DECCAN TRAPS.

	All traps.	Lower traps.		Upper traps.
	Mean 11 anal. (H.S.W.)	Mean 4 anal. (H.S.W.)	Mean 4 anal. Linga traps (L.L.F.)	Mean 3 anal (H.S.W.)
SiO_2 ..	50.61	49 51	49 28	51 69
TiO_2 .	1.91	2.34	3 23	0.63
Al_2O_3 .	13 58	13 05	11 69	14 72
Fe_2O_3	3.19	3 06	3 04	2 83
FeO	9 92	10.39	11.56	10 87
MnO ..	0.16	0 22	0 23	0 11
MgO .	5.46	5 71	4 96	4.18
CaO	9 45	10 18	10 49	8 20
Na_2O .	2.60	2 25	2 51	3 25
K_2O ..	0 72	0 51	0 68	0.93
H_2O+	1 70	1 99	1 50	2 01
H_2O- ..	0 43	0.32	0.83	0.58
P_2O_5 ..	0 39	0.37	0 31	0.42
Total	100.12	99 90	100 31	100 42
Sp gr.	—	2 96	2 97	2 91

NORMS.

Quartz	4 14	4 68	3 60	2 40
Orthoclase ..	4.45	2 78	3 89	5.56
Albite	22.01	18 86	20 96	27 25
Anorthite	23.07	24.19	18.90	22.80
Diopside .	17 41	19 70	26 28	12.84
Hypersthene ..	17.78	17 65	13 20	20 57
Olivine .	—	—	—	—
Magnetite .	4 64	4 41	4.41	4.18
Ilmenite ..	3.65	4.41	6.08	1.22
Apatite	1 01	0 93	0 62	0 93

outcrops. The weathering starts along the well-developed joints, first rounding off the angles and corners and then producing thin concentric shells or layers which become soft and fall off gradually. The interiors of the spheroidal masses, are however, quite fresh.

The traps give rise to either a deep brown to richred soil or to *regur* (black cotton soil) which can be seen in many parts of the Deccan. The regur is rich in plant nutrients such as lime, magnesia, iron and alkalies, on which cotton and certain of the 'dry' crops flourish. It has the property of swelling greatly and becoming very sticky when wetted by rain ; on drying it contracts again with the production of numerous cracks. Another product of weathering is laterite, a material from which silica, alkalies and alkaline earths have been leached away, while alumina, iron and manganese have been concentrated. It has a vermicular or pisolitic structure and contains much water. Some of the laterite is highly aluminous, when it becomes bauxite. Laterite plateaux capping the traps are present in Bombay and Central Provinces, some of these containing good deposits of high grade bauxite.

THE LAMETA BEDS.

The Lameta beds, named after the Lameta Ghat near Jubbulpore in Central Provinces, are fluviatile or estuarine beds occurring below the traps at about the same horizon or slightly above that of the Bagh beds of the Narbada valley. They are found to rest on the various older formations such as the Archaeans, the Upper Gondwanas or the Bagh beds.

They are fairly extensively developed though not found everywhere underneath the traps. They usually occur as a narrow fringe around the trap country, particularly in the Central Provinces (*e.g.*, around Nagpur and Jubbulpore), and along the Godavari valley up to Bhopal and Indore and in the western part of the Narbada valley. The chief rock types found in them are limestones, with subordinate sandstones and clays. The limestones are generally arenaceous and gritty, though occasionally pure, but a cherty type containing lumps of chert and jasper may be said to be characteristic. Earthy greenish sandstones are common, after the limestones, while clays which are usually sandy and red or green in colour are also found. The Lameta beds vary in thickness from 20 to 100 feet, the individual beds frequently varying in character when followed horizontally or vertically.

In the type area at Lameta Ghat the following section can be made out, though all the members are not present in the same individual section.

4. Sandstone similar to No. 1, containing bands of flint or thin limestone. The sandstone may occasionally be composed of grains of glassy quartz with a white powdery cementing medium.

3. Pale green or purplish mudstone, often finely laminated, sometimes arenaceous or calcareous.

2. Limestone or indurated marl often earthy and drab to bluish in colour. Has a tufaceous appearance because of vein-like cavities which may be filled with chalcedony or calcium carbonate by infiltration, this marly limestone being the characteristic member.

1. Greenish, not very compact, sandstone, sometimes hard and cherty. These are brownish near Jubbulpore.

In some cases the rock underlying the Deccan traps has been found to be calcified by solutions descending down from the traps, the original rocks being Archaean gneisses and schists. Such altered rocks, though resembling the Lametas, are not strictly to be classed with them. The true Lametas can often be differentiated from them by the occurrence of fragmentary fossil remains.

The Lametas only rarely contain good determinable fossils, though often showing small fragmentary remains. They comprise mollusca, fishes and dinosaurian reptiles.

Mollusca	.	*Melania*, *Physa* (*Bullinus*), *Paludina* and *Corbicula*.
Fishes	.	*Lepidosteus*, *Eoserranus*, *Pycnodus*.
Dinosaurs	..	*Antarctosaurus septentrionalis*, *Titanosaurus indicus*, *Indosaurus matleyi*, *Lametasaurus indicus*, *Jubbulporia tenuis*, *Laplatasaurus madagascariensis*.

The Dinosaurian remains have been found mainly at Jubbulpore and at Pisdura 8 miles north of Warora in Central Provinces. Coprolites are also found in these places. *Physa* (*Bullinus*) *prinsepii* is associated with these reptilian remains at Pisdura, while the other mollusca have been found in a bed at the base of the traps at Nagpur and Ellichpur. According to Von Huene, the age indicated by the Dinosaurs found at Jubbulpore and Pisdura, which are allied to forms recorded from Madagascar, Brazil and Patagonia, is Turonian.

INFRA-TRAPPEAN BEDS.

Allied to the Lametas are the beds occurring below the traps in the Rajahmundry area, and called the Infra-trappeans. They occur only on the right bank of the Godavari river. At Dudukuru, a few miles N.W. of Rajahmundry, they are composed of yellowish, whitish and greenish sandstones overlying the Upper Gondwanas. They are about 50 feet thick, the upper portion being calcareous and containing a fossiliferous limestone, of 1 to 2 feet thickness, at the top. The fauna has undoubtedly a marine aspect and comprises a nautilus, several lamellibranchs and gastropods, the latter including a *Turritella* which seems to be identical with *T. dispassa* of the Ariyalur Stage of the Trichinopoly Cretaceous.

There seems to be a slight unconformity between the Infra-trappeans and the basal basalt flow since the former appear to have been partially denuded before the traps were erupted, and since the upper portion of the fossiliferous bed is occasionally wanting. The Infra-trappeans do not contain, so far as known at present, fossils identical with any in the Bagh beds or the Trichinopoly Cretaceous except the *Turritella* mentioned above. There is, moreover, an absence of any characteristic genera. Oldham states that on the whole the Infra-trappeans have perhaps more affinity with the Cretaceous than with the Tertiary. Recently H. C. Das-Gupta claimed to have found *Cardita* (*Venericardia*) *beaumonti* from the Dudkur (Dudukuru) beds, which also supports this view.

INTER-TRAPPEAN BEDS.

During the considerable intervals of time which elapsed between successive eruptions of lava, there came into existence some rivers and fresh water lakes in the depressions and in places where there was obstruction to drainage. The fluviatile and lacustrine deposits formed in them are intercalated with the lava flows, and are of small horizontal extent and generally 2 to 10 feet thick, though occasionally only 6 inches thick. They contain, in several places, animal and plant remains which should prove to be valuable in the determination of the age of these beds and incidentally of the associated traps. They comprise cherts, impure limestones and pyroclastic materials, and have been recorded from the Godavari, Chhindwara, Nagpur and Jubbulpore districts and parts of Bombay.

The traps of the Rajahmundry area appear on either bank of the Godavari river, with a length of some 35 miles in an E.N.E.—W.S.W. direction, and a thickness varying from 100 to 200 feet. Exposures are found at Kateru on the Rajahmundry side of the river, resting on Archaean rocks, and on the other side (right bank) near Pangadi and Dudukuru, resting often on the Upper Gondwanas. The traps are overlain by the Rajahmundry sandstones (Cuddalore sandstones) all the formations having a general gentle dip towards the south or south-east.

The lower flow of trap is about 50 feet thick. It is overlaid by a fossiliferous bed which is 12 to 14 feet thick near Kateru and only 2 to 4 feet thick near Pangadi. The fossiliferous bed is exposed for about half a mile near Kateru and for over 10 miles on the other side of the river. The fauna is unmistakably estuarine and comprises *Cerithium*, *Potamides*, *Pirenella*, *Cytherea*, etc., some of the characteristic species being *Corbicula ingens*, *Cerithium stoddardi*, *C. leithi*, *Cytherea meretrix*, *Physa* (*Bullinus*) *prinsepii*, *Paludina normalis* and *Lymnaea subulata*. There are no corals, cephalopods or echinoderms to indicate any marine affinities. The fauna is said to have more affinity with the South Indian Cretaceous than with the Eocene, though no cases of identical fossils have yet been established.

Fossil algae found in these beds have been studied by S.R. Narayana Rao and K. Sripada Rao. They state that some of these, like *Neomeris* and *Acicularia*, and the *Charophyta* are Tertiary in age and that therefore the associated traps are at least early Eocene in age.

The inter-trappean beds of Bombay are high up in the Upper Traps, excellent sections of which can be seen on the Malabar hill and Worli hill at Bombay. Here they are about 100 feet thick and consist of brown, grey or dark shales the last being carbonaceous and showing plant impressions and remains of frogs with occasional pockets of bitumen and coaly material. They contain also the fresh water tortoise *Hydraspis* (*Platemys*) *leithi*, the frog *Rana pusilla* (= *Indobatrachus pusillus*) and three species of Cyprides (*Crustacea*) the common one being *Cypris submarginata.*

The Inter-trappeans and Infra-trappeans occur also in some parts of the Central Provinces, where in Chhindwara they have yielded plant remains, among which are palms with distinct Eocene affinities. In Berar and the Narbada valley the beds are found 300 to 500 feet above the base of the traps and contain plant and animal fossils in some places.

AGE OF THE DECCAN TRAPS.

In the previous sections are stated the facts which should enable us to gain an idea of the age of the Inter-trappeans and of the associated traps. At Dudukuru, the traps are underlain by the Infra-trappeans containing gastropods, lamellibranchs and a nautilus. The fossils, though not identical with any found in the Trichinopoly Cretaceous beds, seem to indicate some general affinities with them. Recent work here has revealed the presence of several algae including *Holosporella*, *Dissocladella*, *Neomeris*, *Torquemella*, and *Acicularia*, the last of which has not been recorded from any beds older than the Paleocene. Several foraminifera have also been recorded—*Triloculina*, *Nodosaria*, *Textularia*, *Spheroidinella*, *Nonion*, *Globotruncana*.

In the Narbada valley the Traps are underlain by the Bagh beds of Upper Cretaceous age, possibly in part equivalent to the Lametas. Between the traps and the Bagh beds there is a slight but distinct unconformity.

In Surat and Broach there is said to be a distinct break between the top of the traps and the Nummulitic strata, for the basal Eocene contains materials derived from the denudation of the traps. In Cutch the traps overlie unconformably the Jurassic and Lower Cretaceous beds and are overlain by the Nummulitics. Here also there seems to be an unconformity between the traps and the Nummulitics though this is not very clear.

In Sind, the Bor hill near Ranikot shows a bed of calcareous, gritty to conglomeratic, sandstone overlying the Hippuritic limestone (Upper Cretaceous), in which occurs an inter-stratified bed of basalt 40 feet thick, some 350 to 400 feet above the base of the sandstone. This sandstone is overlaid by olive shales and sandstones, the latter containing some volcanic ash or decomposed fragments of basalt. *Cardita* (*Venericardia*) *beaumonti* occurs in several horizons in the olive shale, but especially abundantly in a bed 200 to 250 feet below the top of the series. In addition to some corals, echinoids and gastropods, *Nautilus bouchardianus*, (which occurs in the Ariyalur-beds of the Trichinopoly district), is also to be found here. The faunal assemblage indicates an age between the Upper Cretaceous and Lower Eocene.

The Cardita beaumonti bed is overlain by another bed or flow of basalt, the thickness of strata separating this and the lower flow being about 600 feet. The upper one is much more extensive than the lower and has been traced for 22 miles from Ranikot to Jakhmari, at the base of the Ranikot beds. This upper flow(lying on the Cardita beaumonti bed) has a thickness varying from 40 to 90 feet, but is itself composed of two individual flows each of which is vesicular at the top. There is no doubt, according to R.D. Oldham, that the basalt is a flow and not an intrusive (Manual, Second edition, p. 289), and it is conformable both to the underlying Cardita beaumonti beds and the overlying Ranikot beds. Though separated by a good distance from the main Deccan trap areas, these trap beds in Sind are considered to belong to the Deccan traps.

Recent work on the Inter-trappean fossils, especially by Prof. B Sahni and collaborators, seems to lend support to a Lower Eocene age for the beds from which the fossils were derived. The chief points in the evidence are: There is a large proportion of palms (*Palmoxylon* predominating) amongst the angiospermous flora; the palms are said to be much more abundant here than in any Cretaceous flora so far studied. The genus *Azolla* found in these beds has not been recorded from any beds earlier in age than the Tertiary. *Nipadites*, a characteristic Eocene genus, occurs in the Inter-trappeans.

Smith Woodward's work on the fish remains from the Lametas has shown that perhaps they are more allied to Eocene than to Cretaceous forms. Dr. S. L. Hora who studied the fossil fishes found at Takli, Paharsingha and other places in the Central Provinces, has identified *Lepidosteus indicus*, *Pycnodus lametae*, *Eoserranus hislopi*, *Nandus*, *Pristolepis*, *Scleropages* and some percoid fishes, from which he favours a Lower Eocene age for the lavas associated with the Inter-trappeans.

The fact still remains that much of the stratigraphical field work on the traps and the associated sedimentaries is old, and it is very desirable to restudy them and make fresh fossil collections. The evidence of age, as it stood in the early nineties of the last century, has been admirably summed up by R.D. Oldham in the second edition of the Manual of the Geology of India (pp. 280-281, 289). The base of the traps lies, in various places, on the Bagh beds (Cenomanian to Senonian), the Lametas (roughly Turonian according to Von Huene and Matley) and the Infra-trappeans or Cardita beaumonti beds (Danian). We do not know how much time interval to allow for any unconformities that may exist. But it seems reasonable to conclude, as Oldham did in the Manual, that the traps commenced to be poured out in the Uppermost Cretaceous and that they continued through the gap of time marked in Europe by the unconformity between the Mesozoic and the Tertiary, which in North America is represented by the Laramie formation. This remains to-day the official view of the Geological Survey of India, but this view can be changed if evidence, based on field and laboratory work, is forthcoming in a convincing manner to push up the whole of the traps into the Eocene.

The recent work on Inter-trappean fossils would seem to place at least a part of the traps in the Eocene. This is reasonable since the traps have a very large thickness (perhaps 7,000 to 10,000 feet in Western India) and since it is recognised now that some of the products of the latest phases of the activity found in Bombay are distinctly later than the main mass. This however leaves the question of the age of the *base of the traps* practically where it was. It is necessary to know by field work where exactly the lowest traps exist and whether there may not be a difference in age between the base of the traps in different places—*e.g.*, in the Central Provinces and in Rajahmundry. It has already been mentioned that the Lower Traps occur in Madras and the Central Provinces and the Middle and Upper traps progressively westward. There is also an opinion current, supported by Dr. C. S. Fox, that the Rajmahal traps and the basic dykes in the coalfields of Bengal and Bihar (which are petrographically practically identical with the Deccan traps and are considered to be of Oolite age) represent an early manifestation of the Deccan trap activity.

Lastly, some work has recently been done on the radioactive characters of the Deccan traps by V.S. Dubey and R. N. Sukheswala. The work of the latter seems to show that the traps range in age from Upper Cretaceous to perhaps as late as Oligocene. There is a great seope for extending this work systematically in order to help in the problem of the age. Though there are still some uncertainties attached to the deductions from radioactive work, it gives supporting evidence which is valuable for the solution of this problem.

Summing up, it would appear that the evidence which has been gathered and put forward in recent years is not conclusive enough to decide on an *entirely* Eocene age for the traps, since, though some of the genera of plants occurring in the Inter-trappeans are identical with those in the Eocene of other parts of the world, there are apparently no identical species. Such being the case, there is no reason why a flora allied to the Eocene of Europe should not have flourished in India in the time interval between the top of the Cretaceous and the base of the Eocene, *i.e.*, in Laramie times, or even in the Uppermost Cretaceous.

Much work remains to be done in the Infra-trappean beds of Rajahmundry and such other areas as exist to the east of Chhindwara, for it is by no means certain that the lowest traps at Chhindwara represent the earliest flows of the Deccan trap. In the present stage, it would seem necessary to await more data from different lines of work—stratigraphical, palæontological and radioactive, before this problem can be regarded as satisfactorily settled.

ECONOMIC GEOLOGY.

Being dense, hard and durable, the Deccan traps are used fairly extensively as building stones in the areas in which they occur in large masses. But, being dark in colour, they are not used to the extent to which their durability will entitle them. The light buff and cream-coloured trachytic rocks found in the Salsette island and the neighbourhood of Bombay are generally more preferred than the dark traps. The commemoration arch called the 'Gateway of India', at the Bombay harbour, is constructed of such trachytic rock obtained from Kharodi and Malad near Bombay. This rock however frequently contains some calcite and pyrite which are liable to produce unsightly brown stains and weakness, on weathering.

As road metal, the Deccan traps are excellent for macadam and tarred roads and are among the best stones obtainable in India. They are hard, tough, wear-resisting and have good binding properties. They are also excellent for use as aggregates in cement concrete.

The Deccan traps of Western India are a great storehouse of quartz, amethyst, agate, carnelian, onyx and other varieties of chalcedony which are used as semi-precious stones. These are made into trinkets, beads, ring stones and ornamental objects. There is a small agate-cutting industry at Ratnagiri, Rajpipla and Cambay, the necessary raw stone being collected from the debris and weathered trap. The supply for Cambay used to come from a Tertiary Conglomerate, the pebbles of which were derived from the traps.

The traps are often capped by ferruginous and aluminous laterite. The latter is in several places—*e.g.*, Kolhapur, Belgaum, Katni, Jubbulpore—rich enough in alumina to be high grade bauxite. The bauxite is used in petroleum filtration, and a beginning has been made in utilising it for the manufacture of alumina and aluminium. It is however generally rich in titania, as much as 10 per cent. or more of this constituent being often present. The ferruginous laterite forms a good building stone and has also been used formerly for iron smelting in indigenous furnaces. There seem to be possibilities also for smelting the ferruginous laterite and obtaining pig iron and cement by a suitable process.

The black soil or *regur* formed over the Deccan trap is a rich soil particularly suitable for raising cotton. It is similar to the Russian *Chernozem*, but is by no means confined to the trap areas, for we find it on gneisses, charnockites, Cretaceous sediments, etc., in South India. This would suggest that it is not only the chemical composition of the parent rock but also climatic factors that play an important part in their formation.

SELECTED BIBLIOGRAPHY.

(DECCAN TRAP AND INTER-TRAPPEAN BEDS.)

Blanford, W.T. Traps and Inter-trappean beds of Western and Central India. *Mem.* 6, Pt. 2, 1867.

Crookshank, H. Geology of the northern slopes of the Satpuras between Morand and Sher Rivers. *Mem. 6* , Pt. 2, 1936.

Chatterjee, S.K. Petrology of igneous rocks from the West Gir Forest, Kathiawar. *Jour Geol. 40*, 154-170, 1932.

Fedden, F. Geology of Kathiawar. *Mem. 21*, Pt. 2, 1884.

Fermor, L. L. Lavas of Pavagad hill. *Rec. 34*, 148-166, 1906.

Fermor, L. L. and Fox, C. S. Deccan trap flows of Linga, Central Provinces. *Rec. 47*, 81-136, 1916.

Fermor, L. L. Basaltic lavas penetrated by deep boring for coal at Bhusawal. *Rec. 58*, 93-240, 1926.

Fermor, L. L. Deccan traps of Linga, Central Provinces. *Rec. 68*, 344-358, 1934.

Hora, S. L. Fossil fish scales from the inter-trappeans at Deothan and Kheri, Central Provinces. *Rec. 73*, 267-292, 1938.

Krishnan, M.S. Petrography of rocks from the Girnar and Osham hills, Kathiawar. *Rec. 58*, 380-424, 1926.

Mathur, K. K. Problems of petrogenesis in the Deccan traps. *Proc. 21st Ind. Sci. Cong* 329-344, 1934.

Mathur, K. K *et al.* Magmatic differentiation in the Girnar hills. *Jour. Geol. 34*, 289-307, 1926.

Rao, S. R. Narayana and Rao, K. Sripada. Foraminifera of the Inter-trappean beds near Rajahmundry. *Rec. 71*, 389-396, 1936.

Rao, S. R. Narayana and Rao, K Sripada. Fossil Charophyta from the Kateru Inter-trappeans. *Pal. Ind. N. S. XXIX*, (2), 1940.

Washington, H.S. Deccan traps and other plateau basalts. *Bull. Geol. Soc. Amer. 33*, 765-804, 1922.

CHAPTER XVI.

THE TERTIARY GROUP.

General.—The last great group of formations in the history of the earth was formed during the Tertiary or Kainozoic (Cenozoic) era, interrupted by stupendous earth movements in certain parts of the globe. The records of this era and the relics of organisms which flourished then are more clearly seen than those of the earlier ones because of their proximity in time to the present.

The Break-up of Gondwanaland.—The transition from the Mesozoic to the Kainozoic is generally marked, in many parts of the world, by an abrupt change in lithology and fauna. This coincided, in India, with igneous action on a large scale. More or less contemporaneously with this, the Gondwanaland was broken up into its component parts, partly by the drifting away of these from one another and partly by the faulting down of some segments into the subcrust.

Faunal and floral changes.—The great changes which took place at the close of the Mesozoic era affected animal and vegetable life profoundly. The giant reptiles of the Mesozoic which roamed over the lands and the luxuriant ammonites which peopled the seas became practically extinct at the dawn of the new era. The physiographic and environmental changes which took place were apparently too drastic for them to adapt themselves to. New groups of animals and plants took the place of those which had perished, and gradually grew in importance. The mammals among the animals began to gain importance and multiplied in rich variety. The Pteridosperms and Cycads, which were the dominant plants of earlier eras were replaced by the flowering plants.

Elevation of the Himalayas.—The great Mediterranean sea, the Tethys, was first shallowed and its floor raised up and compressed into mountain ranges during the Tertiary. This Tertiary mountain system extended from the Pyrenees on the west to the Himalayas and the Malay arc on the east.

This rise of the Himalayas took place in a series of four great movements separated by intervals of quiescence. The first can be dated in the Upper Eocene, after the deposition of the Kirthar beds. After the Nari, Gaj and Murree strata were laid down, there occurred a second upheaval in Middle Miocene times. This was probably the most powerful of all the disturbances since the Himalayas appear to have acquired their major features as a result of this. The shallow marine basins which remained after the first uplift were all obliterated, but an important but shallow trough seems to have been formed along the region where the Peninsular mass and the Himalayas met. In this trough were deposited sediments from both sides, and especially from the newly risen mountain mass on the north. These sediments constitute the Siwalik system in the Himalaya while their counterparts in Sind and Burma are called the Manchhar and Irawaddy formations respectively. At the end of the Siwalik sedimentation, *i.e.*, towards the close of the Pliocene, the third upheaval took place; this, together with the incoming of the Pleistocene Ice Age, brought about the virtual extinction of the spectacularly rich mammalian fauna of the Siwalik times though a small part of the fauna managed to migrate to other areas and survive. The final phase, a feeble one compared to the earlier ones, took place in later Pleistocene. It was during this that the Pir Panjal range in the north-western Himalaya attained its present height, for we find Pleistocene deposits on its flanks elevated to a height of several thousand feet. There is very clear evidence in the north-western Himalaya that minor movements occurred almost down to Sub-Recent geological times for some of the beds affected by them were formed since the advent of man and contain stone implements.

Fluviatile and marine facies.—The Tertiary rocks have an early marine facies and a later fluviatile facies, not only in the Himalayas but also in the Burmese and Baluchistan arcs. The original marine basins of deposition were filled up and shallowed and later become estuarine and deltaic. In the north-western Himalaya, for instance, the Eocene was marine, the succeeding Murree sediments estuarine while the Siwaliks were distinctly fluviatile (*i.e.*, fresh-water) in nature.

Distribution.—The Extra-Peninsular region shows a great development of Tertiary rocks continuously from the Mekran coast of Baluchistan, through the mountainous frontier tracts of Sind and N.W.F.P., to Kashmir and thence along the Himalayan foot-hills to the Brahmaputra gorge in the extreme north-east of Assam. It is probably continuous, underneath the Brahmaputra alluvium, with the broad Tertiary belt of Eastern Assam and Arakan. This is separated from the Burmese Tertiary belt by a zone of Cretaceous (and older) rocks forming the central parts of the Arakan Yoma. In Peninsular India Tertiary rocks are developed in comparatively small areas in Cutch, Gujarat and Travancore on the western coast and in several places along the eastern coast up to Mayurbhanj in Orissa.

To enable the reader to form a comprehensive idea of the Tertiary succession in the different areas, a summarised account is first presented before proceeding with the detailed descriptions.

SIND AND BALUCHISTAN.

The Sind-Baluchistan region is in many respects the type area of the Tertiaries, not only because of the excellent development of the divisions but also because it was one of the earliest areas to be studied in detail. The Eocene and Oligocene are particularly well-developed as grand marine formations. The Lower Miocene Gaj series shows two facies while the succeeding Manchhar series (the equivalent of the Siwaliks) is entirely of fresh water origin. This has, however, marine equivalents further west in Baluchistan.

TABLE 37.—TERTIARY SUCCESSION IN SIND AND BALUCHISTAN.

Upper Manchhar (5,000 ft.)	Sandstones, conglomerates and clays	Pliocene.
Lower Manchhar (3,000-5,000 ft.)	Conglomerates and sandstones with mammalian fossils	Upper to Middle Miocene.
Upper Gaj (500 to 1,000 ft.)	Red and green shales, occasionally gypseous	Lower Miocene.
Lower Gaj (500-1,000 ft.)	Limestones and shales with marine fossils (represented by fluviatile Bugti beds in Baluchistan)	
Upper Nari (4,000-6,000 ft.)	Thick unfossiliferous sandstones and shales	Up. Oligocene.
Lower Nari	Fossiliferous marine limestones	Lr. Oligocene.
Kirthar (5,000-9,000 ft.)	Upper—(Spintangi limestone) massive limestones, poorly developed in Sind Middle—Limestone Lower—Shales and sandstones, practically absent from Sind	Middle Eocene.
Laki (500-2,500 ft.)	Ghazij shales Dunghan limestone Meting shales and limestones — Shales and limestones with coal seams and sometimes oil seepages.	Middle to Lower Eocene.
Upper Ranikot (800 ft.)	Buff to brown Nummulitic limestone and shales	Lower Eocene
Lower Ranikot (1,000-1,500 ft.)	Gypseous shales and sandstones with lignite and coal	Paleocene.
Cardita beaumonti beds		Danian to Maestrichtian.

THE SALT RANGE.

The Punjab Salt Range shows a fine development of Tertiary rocks. The top of the scarp over the greater part of the range is formed of Eocene limestone, mainly of Laki age, while the Ranikot series is seen as a shaly facies in the eastern part. The limestones are intercalated with marls and are overlain, with a pronounced unconformity, by the Murree series of Lower Miocene age, and this in turn by rocks of the Siwalik system.

TABLE 38.—TERTIARIES OF THE SALT RANGE.

Siwalik system.	Conglomerates, grits, sandstones and shales.	Pliocene to Upper Miocene.
Murree series (2,000 ft.)	Pseudo-conglomerates, sandstones and purple shales	Lower Miocene.
Laki	*Bhadrar beds* (100-300 ft.) shales, limestones and marls *Sakesar limestone* (200-500 ft.) Scarp limestone *Nammal limestone and shales* (100-200 ft.) Limestones, shales and thin marls	Middle to Lower Eocene.
Ranikot	*Patala shales** (100-250 ft.) Shales with thin limestones and sandstones and a coal seam at the base. *Khairabad limestone* (50-500 ft.) Nummulitic limestones and calcareous shales *Dhak Pass beds* (20-100 ft.) Sandstones and shales and hæmatitic beds	Lower Eocene.

*Part of the Patala shales is of Laki age.

THE POTWAR PLATEAU.

The northern slopes of the Salt Range merge into the Potwar plateau which forms the type area of the Siwalik formations. The Siwaliks are divided into several stages on lithological and faunal characters since they enclose a rich mammalian fauna. The succession is shown below :

TABLE 39.—TERTIARIES OF THE POTWAR REGION.

Siwaliks.	Upper (6,000 ft.)	Boulder conglomerate.	Conglomerates, sandstones and clays	Lr Pleistocene.
		Pinjor stage	Coarse sandstones	Up Pliocene.
		Tatrot stage	Sandstones	
	Middle (6,000 ft.)	Dhok Pathan stage.	Sandstones and shales	Lr Pliocene.
		Nagri stage	Sandstones and shales	Up. Miocene.
	Lower (5,000 ft.)	Chinji stage	Pseudo-conglomerates, red shales and grey sandstones.	Mid Miocene.
		Kamlial stage	Pseudo-conglomerates, grey sandstones and shales.	Mid. Miocene.
Murree series.			Sandstones and purple shales	Lr Miocene.

OUTER HIMALAYA OF JAMMU AND THE PUNJAB.

Tertiary rocks are developed all along the Himalaya, the Siwalik strata forming a practically constant zone of outer hills. Older Tertiary rocks are also known in the Western Himalaya, where they are best developed in Jammu and the neighbourhood. The sequence here is :

TABLE 40.—TERTIARIES OF THE JAMMU STATE.

Siwaliks	Upper (6,000 ft.) Middle (6,000 ft.) Lower (5,000 ft.)	
Murrees	Upper (3,000 ft.) Lower (5,000 ft.) Basal—Fatehjang zone of ossiferous conglomerates.	
	Unconformity	
Chharat stage	Nummulitic shales, limestones and marls	Upper to Middle Eocene
Hill Limestone (1,500 ft.)	Massive Nummulitic limestones with coaly layers	Middle to Lower Eocene

In the foot-hill region of the Simla-Garhwal Himalaya, the Eocene is represented by the Subathu beds, consisting of grey to red shales, often gypseous, and some limestones. The Lower and Upper Murrees are represented by the Dagshai and Kasauli beds respectively which are brackish or lagoonal deposits having a total thickness of 7,000 or 8,000 feet. The Tertiary rocks of the Eastern Himalayas have been visited by geologists only in a few places and our knowledge of them is meagre.

ASSAM.

Eastern and south-eastern Assam show excellent development of Tertiary rocks but there is a good deal of variation in the succession of the different areas. There is a well-marked and wide-spread unconformity in the Upper Oligocene, between the Barail and the Surma series. Another is inferred or suspected in the Upper Miocene between the Tipam series (Middle to Upper Miocene) and the Dihing series (Pliocene). The general succession in Assam is given in table 41.

BURMA.

The succession in Burma resembles that of Assam in some measure. Eocene beds are developed in the

TABLE 41.—TERTIARY SUCCESSION IN ASSAM.

Age.	Central and Lower Assam		Upper Assam.
Pontian	Dihing series.. (5,000 ft.)	Pebble beds with sands and clays.	Dihing series.
	~~ Unconformity ~~~		
Vindobonian to Burdigalian.	Tipam series (12,000 ft.)	Dupi Tila stage—Sands and clays	Num Rong Khu stage.
		Girujan clay—Mottled clays and sandstones.	Girujan clay.
		Tipam sandstones—Ferruginous sandstones and subordinate clays.	Tipam sandstone.
Burdigalian to Chattian.	Surma series (13,000 ft)	Boka Bil stage—Sandy shales and sandstones	Surma series (much reduced).
		Bhuban stage—Conglomerates, sandstones and shales.	
	~~ Unconformity ~~~		
Chattian to Auversian	Barail stage (15,000 ft)	Renji stage—Hard massive sandstone.	Tikak Parbat stage.
		Jenam stage—sandstones and carbonaceous shales.	Baragoloi stage.
		Laisong stage—Sandstones and subordinate shales.	Naogaon stage
Lutetian ..	Jaintia series (3,000 ft)	Kopili stage—Carbonaceous shales	Disang series.
		Sylhet limestone—Nummulitic limestone.	
	~~ Unconformity ~~~		
	Upper Cretaceous rocks		

mountainous region of the Arakan Yoma, closely following the Cretaceous rocks. The Oligocene and Lower Miocene are represented by the Pegu series, corresponding to the Murrees and to the Nari and Gaj beds of north-western India. The beds above these constitute the Irrawaddy system, corresponding to the Siwalik system.

A marine facies is observed in the greater part of the succession in the south, but when the same beds are followed northward, they show estuarine and fresh-water facies. This is due to the fact that a Tertiary gulf existed in the region between the Arakan Yoma on the west and the Shan plateau on the east. This gulf was gradually filled up, the waters receding southward as deposition proceeded.

TABLE 42.—TERTIARY SUCCESSION IN BURMA.

Irrawaddy system (5,000 ft.)	Fluviatile deposits with mammalian fossils and fossil wood.	Pliocene to Upper Miocene.
~~	~~~Unconformity~~~	~~~~~~
Upper Pegu series	Obogon sands and clays (3,000 ft.)	Vindobonian.
	Kyaukkok sandstone (5,000 ft.)	Burdigalian
	Pyawbwe clays (3,000 ft.)	Aquitanian
~~	~~~Palæontological break~~~	~~~~~~
Lower Pegu series	Okhmintaung sandstone (3,000 feet)	Chattian
	Padaung clays (2,500 ft.)	Stampian
	Shwezetaw sandstones (2,000—4,000 ft.)	Lattorfian
Eocene system	Yaw shales (2,000 ft.)	Bartonian-Ludian.
	Pondaung sandstone (6,000 ft.)	Auversian
	Tabyin clays (5,000 ft.)	Upper Lutetian.
	Tilin sandstone (4,000 ft.)	Lower Lutetian.
	Laungshe shales (10,000 ft.)	Ypresian
	Paunggyi conglomerate (3,000 ft.)	Londinian.

EASTERN COAST OF INDIA.

Associated with the Cretaceous of the Pondicherry area there are rocks which have recently yielded Eocene Foraminifera, but the extent of these rocks is not known.

Overlying these unconformably there are Miocene rocks called the Cuddalore sandstones. They extend from Madura in the south to Pondicherry in the north. The Rajamahendri sandstones in the Godavari district and the Baripada beds of Mayurbhanj State in Orissa are also of about the same age as the Cuddalore sandstones.

TRAVANCORE AND KONKAN.

Fossiliferous Miocene beds are found near Quilon and Varkala in Travancore, overlain by current-bedded sands and variegated shales with lignitic matter (Warkalli beds). They resemble the Cuddalore sandstones and are covered by a thickness of laterite. Similar beds also occur near Ratnagiri in Southern Bombay. Beds younger than these and of Pliocene age have been met with in borings at Karaikal in the Tanjore district.

WESTERN INDIA AND RAJPUTANA.

Gujarat.—Small inliers of Eocene age occur in the coastal region of Surat and Broach amidst the alluvium. They are overlain by thick deposits of gravel and ferruginous sandstones containing pebbles of agate and Deccan trap. These are of Gaj age. The low-lying tract east of Kathiawar is composed of Pleistocene deposits.

Kathiawar.—Small outcrops on the western and eastern coasts of Kathiawar, consisting of clays, sandstones and conglomerates, belong to the Tertiary system. In the Piram island lying off the eastern coast of Kathiawar they contain mammalian remains of Middle Siwalik age. At the western extremity of Kathiawar are the Dwarka beds, composed of yellow, gypseous clays below, and foraminiferal sandy limestones above. Below them are the Gaj beds. A sub-Recent foraminiferal limestone, called the Porbander stone, also occurs in this area.

Cutch.—In Cutch there are well-developed Tertiary strata including the Laki, Kirthar, Gaj and Manchhar. These attain greater extent and thickness than in Kathiawar and Gujerat.

Manchhar beds (500 ft.)	Conglomerates, sands and clays.	Pliocene.
Gaj beds (1,200 ft.) ..	Shales, marls and sandstones.	Burdigalian.
Kirthar (700 ft.) ..	Nummulitic limestones	Upper to Middle Eocene.
Laki (200 ft.) ..	Shales, often bituminous and pyritous.	Middle Eocene.
Deccan traps ..	Lavas.	

Rajputana.—In Bikanir and Jaislamer there are Eocene strata consisting of nummulitic limestones associated with beds containing lignite and fuller's earth. The Palana lignite field of Bikaner is situated in these rocks. The rocks are underlain by Cretaceous and Jurassic strata.

This short summary of the Tertiary group will now be followed by more detailed and systematic descriptions of the different systems which form its constituent parts. The inter-relationship of the strata of the different areas will be apparent from Table 43 which gives at a glance the correlation of the Tertiary rocks.

SELECTED BIBLIOGRAPHY.

Barber, C.T. Tertiary igneous rocks of the Pakokku district. *Mem. 68*, Pt. 2, 1936.

Blanford, W T Geology of Western Sind. *Mem 17*, Pt. 1, 1878.

Bose, P.N. Geology of the Lower Narbada valley. *Mem. 21*, Pt. 1, 1884.

Clegg, E. L. G Geology of parts of Minbu and Thayetmyo. *Mem. 72*, Pt. 2, 1938.

Cossman, M. and Pisarro, G. The Mollusca of the Ranikot series. *Pal. Ind. N. S. III*, (1), 1909; *X*, (2), 1927; *X*, (4), 1928.

Cotter, G. de P. The Lamellibranchs of the Eocene of Burma. *Pal. N. S. VII*, (2), 1923

Cotter, G. de P. Geology of parts of Minbu, Myingyan, Pakokku and Lower Chindwin districts. *Mem. 72*, Pt. 1, 1938.

Cotter, G. de P. Notes on the geological structure and distribution of oil-bearing rocks of India and Burma. *World Petroleum Congress, Proc. I*, 7-13, 1933.

Davies, L M. *et al.* The fossil fauna of the Samana Range. *Pal. Ind N.S., XV*, (6-8), 1930.

Davies, L. M. and Pinfold, E.S. Eocene beds of the Punjab Salt Range. *Pal. Ind. N S. XXIV*, (1), 1937.

Duncan, P. M. and Sladen, W. P. Tertiary and Upper Cretaceous fauna of Western India. *Pal. Ind. Ser. VII* and *XIV*, 1871-1885.

Evans, P. Tertiary succession in Assam. *T. M. G. I. I. 27*, (3), 1932.

Evans, P. and Sansom, C.A. Geology of the Burmese oilfields. *Geol. Mag. 78* (5), 321-350, 1941.

Lepper, G.W. Outline of the geology of the oil-bearing regions of the Chindwin-Irrawaddy valley and of Assam-Arakan. *World Petroleum Congress, Proc. I*, 15-23, 1933.

Medlicott, J.G. Tertiary and alluvial deposits of the central portion of the Narbada valley. *Mem. 2*, Pt. 2, 1860.

Medlicott, H.B. Sub-Himalayan ranges between the Ganges and the Ravi. *Mem. 3*, Pt. 2, 1864.

Middlemiss, C.S. Geology of the Sub-Himalaya of Garhwal and Kumaon. *Mem. 24*, Pt. 2, 1890.

Mukherjee, P. N. Fossil fauna of the Tertiary of the Garo Hills, Assam. *Pal. Ind. N. S. XXVIII*, (1), 1939.

Noetling. Petroleum in Burma and its technical exploitation. *Mem. 27*, Pt. 2, 1897.

Noetling, F. Fauna of the Miocene beds of Burma. *Pal. Ind. N. S. I.* (3), 1901.

Nuttall, W. L. F. Stratigraphy of the Upper Ranikot series of Sind *Rec. 65*, 306-313, 1932.

Nuttall, W. L. F. Stratigraphy of the Laki series. *Q. J. G. S.* (London) *81*, (3), 1925.

Pascoe, E. H. Oil fields of Burma. *Mem. 40*, Pt. 1, 1912.

Pascoe, E. H. Petroleum occurrences of Assam and Bengal. *Mem. 40*, Pt. 2, 1914.

Pascoe, E.H. Petroleum in the Punjab and N. W. Frontier Province. *Mem. 40*, Pt. 3, 1920.

Pilgrim, G.E. Vertebrate fauna of the Gaj series in the Bugti hills and the Punjab. *Pal. Ind. N. S. IV*, (2), 1912.

Pilgrim, G. E. The Perissodactyla of the Eocene of Burma. *Pal. Ind. N. S. VIII*, (3), 1925.

Pilgrim, G.E. The Artiodactyla of the Eocene of Burma. *Pal. Ind. N. S. XIII*, 1928.

Pilgrim, G. E. and Cotter, G. de P. Eocene Mammals from Burma. *Rec. 47*, 42-77, 1916.

Pinfold, E.S. Structure and stratigraphy of N. W. Punjab. *Rec. 49*, 137-160, 1918.

Stamp, L.D. Outline of the Tertiary geology of Burma. *Geol. Mag. 59*, 481-501, 1922.

Theobald, W. Geology of Pegu. *Mem. 10*, Pt. 2, 1873.

Vredenburg, E. Geological sketch of the Baluchistan desert and part of Eastern Persia. *Mem. 31*, Pt. 2, 1901.

Vredenburg, E. Considerations regarding the age of the Cuddalore Series. *Rec. 36*, 321-323, 1908.

Vredenburg, E. Geology of Sarawan, Jhalawan, Mekran and Las Bela, *Rec. 38*, 189-215, 1910.

Vredenburg, E. Classification of the Tertiary system of Sind. *Rec.* *34*, Pt. 3, 1906.

Vredenburg, E. Description of Mollusca from the Post-Eocene Tertiary Formations of N. W. India *Mem* 50, 1925-28.

Wadia, D.N. Geology of Poonch State, Kashmir, *Mem.* *51*, Pt. 2, 1928.

Wadia, D.N. Tertiary geosyncline of N. W. Punjab. *Q. J. G. M. M.* S.I , 4 (3), 1932.

Wynne, A.B. The salt region of Kohat. *Mem.* *11*, Pt 2, 1875.

TABLE 43.—CORRELATION OF THE TERTIARY FORMATIONS.

Standard		Sind, Baluchistan.	Salt Range	Potwar, Attock	Simla Hills	Burma	Assam	E Coast.
PLEISTOCENE PLIOCENE PONTIAN		*Third*	*upheaval*	*of the*	*Himalayas*			
		U. Manchhar	U. Siwalik	U. Siwalik		Irrawaddy system	Dihing	Karikal beds
	Sarmatian	L. Manchhar	M. Siwalik	M Siwalik				
			L. Siwalik	L. Siwalik		Break	Tipam	Cuddalore & Rajamahendri sandstones
Miocene.	Vindobonian	*Second*	*upheaval*	*of the*	*Himalayas*			
	Burdigalian	U. Gaj	Murree	Murree Fatehjang Zone	Kasauli	U. Pegu	Surma	
	Aquitanian	L. Gaj			Dagshai			
	Chattian	U. Nari	Break	Break	Break	L. Pegu		
Oligocene.	Stampian							
	Lattorfian	L. Nari						
	Ludian	*First*	*upheaval*	*of the*	*Himalayas*		Barail	
	Bartonian	Kirthar	— — —	Chharat	Subathu			
	Auversian							
Eocene.	Lutetian	Laki	Laki			Eocene system		Eocene of Pondicherry
	Londinian	U. Ranikot	U. Ranikot	Hill Limestone			Jaintia	
	Thanetian							
	Montian	L. Ranikot	L. Ranikot					

CHAPTER XVII.

THE EOCENE SYSTEM.

General.—The end of the Cretaceous period was marked by a widespread marine regression which was, to a large extent, responsible for the destruction of the specialised groups of animals like the ammonites and the coralloid lamellibranchs—the *Rudistae*. This change was similar to that at the close of the Palæozoic era when the *Goniatites* and specialised brachiopods disappeared from the scene of life. The changes which happened on the surface of the land were similarly responsible for the sudden end of many of the Mesozoic reptiles.

This marine regression accounts for the stratigraphical gap, with erosion unconformity, which separates the Cretaceous from the Tertiary formations in many parts of the world. In India the Eocene begins with the Ranikot stage (Lower Eocene) which is developed in Sind and further north. The overlying Laki and Kirthar stages (Middle to Upper Eocene) are developed much more extensively in north-western India. The Uppermost part of the Eocene coincided with the first Himalayan upheaval, so that it is unrepresented by deposits in many parts of the Tertiary belt. The Eocene underwent some uplift and disturbance before the deposition of the Oligocene began.

Distribution.—The Eocene comprises three facies—deep sea, coastal and fluviatile. The first is well-developed in Western Sind and adjoining parts of Baluchistan, parts of the N. W. Frontier Province, Hazara, Kashmir and along the northern zone of the Himalaya up to the meridian of Lhasa ; and also in the Arakan Yomas on the borders of Burma. The coastal facies is developed in south Kashmir, and the sub-Himalaya from Jammu to near Naini Tal ; in Gujarat, Cutch, Rajputana and to the south of the Shillong Plateau. The freshwater facies is seen in Upper Burma and in north-western Punjab.

SIND AND BALUCHISTAN.

The Kirthar, Laki, Suleiman and other ranges of the Sind-Baluchistan border show an excellent development of Eocene rocks The upper part of the Kirthar range exposes upper Eocene rocks which are appropriately named after the range. The eastern flanks expose successively younger beds, *viz.*, Nari, Gaj and Manchhar, dipping towards the Indus plains. To the west, in Kalat, older Eocene rocks are seen, which attain a thickness of 10,000 feet. The disposition of the strata in the Laki range also is similar.

RANIKOT SERIES.

The lowest division of the Eocene is called the Ranikot series, after Ranikot in Sind. They rest on the Deccan traps or the *Cardita beaumonti* beds and show a stratigraphical break at the junction. The lower Ranikot beds, which are 1,000-1,500 feet thick, comprise soft sandstones, shales and variegated clays. Gypsum and carbonaceous matter frequently occur in them, while in one place there is a coal seam 6 feet thick. The fossils found in them are dicotyledonous leaf impressions and oysters in an oysterbed at the base.

The Upper Ranikots, which have a thickness of 700-800 feet, consist of fossiliferous brown limestones interstratified with sandstones and clays. Nummulites first appear in the upper part of the upper division, the most characteristic species being *Nummulites planulatus* and *Miscellanea miscella.* These indicate a Cuisian age, the rest of the beds being probably referable to the Londinian.

The fauna of the upper Ranikot comprises foraminifera, corals, echinoids and molluscs, the earliest Nummulites occurring together with the last Belemnites—*Styracoteuthis orientalis.* The Eocene genus *Belosepia* which forms a link between Belemnites and the modern cuttle-fish is also present. A large species of *Calyptrophorus* (gastropod), which is characteristic of the uppermost Cretaceous and lowermost Eocene is found in the lowest bed of the Upper Ranikot. The following are the chief Ranikot fossils :

Foraminifera	..	*Nummulites planulatus*, *Miscellanea miscella*, *Lockhartia newboldi*, *Assilina ranikoti*, *Operculina* cf *canalifera*.
Corals	..	*Montlivaltia*, *Isastraea*, *Thamnastraea*, *Feddenia*, *Cyclolites*, *Trochosmilia*, *Stylina*.
Echinoids	..	*Phyllacanthus sindensis*, *Cyphosoma abnormale*, *Salenia blanfordi*, *Dictyopleurus haimei*, *Conoclypeus sindensis*, *Plesiolampas placenta*, *P. ovalis*, *Eurhodia morrisi*, *Hemiaster elongatus*, *Schizaster alveolatus*.
Lamellibranchs	..	*Ostrea* cf. *multicostata*, *O. bellovacensis*, *O. talpur*, *Flemingostrea haydeni*, *Spondylus roxanae*, *Venericardia hollandi*, *Cardium sharpei*, *Meretrix morgani*, *Corbula vredenburgi*
Gastropods	..	*Surcula polycesta*, *S vredenburgi*, *Pleurotoma jhirakensis* *Calyptrophorus indicus*, *Conus blagrovei*, *Athleta noetlingi*, *Volutocorbis eugeniae*, *Lyria feddeni*, *Clavilithes leilanensis*, *Strepsidura cossmanni*, *Murex sindiensis*, *Gisortia jhirakensis*, *Rostellaria morgani*, *Rhinoclavis subnuda*, *Turritella halaensis*, *Natica adela*, *Crommium dolium*, *Velates affinis*.
Cephalopods	..	*Nautilus subfleuriausianus*, *N. deluci*, *N. cossmanni*, *N. sindiensis*.

LAKI SERIES.

The Laki beds are well developed in the calcareous zone of Baluchistan and also in South Waziristan, Kohat, Salt Range, Attock district, Jammu, Bikaner, Cutch and Assam. They succeed the Ranikot beds and may sometimes be found directly overlying the Cretaceous. The base is sometimes marked by a zone of ferruginous laterite indicating sub-aerial weathering of the underlying beds. The Lakis are the chief oil-bearing beds of Northwestern India. They are divided into three divisions :

Upper	..	Ghazij beds (2,000 ft.)	Gypseous clays, greenish sandstones and clays of the flysch facies, with occasional limestones and coal seams.

Middle ..	Dunghan limestone (500-800 ft.)	White or pale, massive, nodular limestone in Sind (dark coloured in Baluchistan).
Lower ..	Meting shales and limestones (50-250 ft.).	White chalky limestones and shales.
	Basal laterite.	Thin crust of ferruginous laterite.

The full succession is nowhere seen at one place. The METING SHALES are observed only in the Laki range in association with a fine development of Dunghan limestone which is overlain by the Kirthar series, the Ghazij shales being absent. In other places the Meting shales are absent but the other two stages are well developed. The Ghazij shales have a flysch-like aspect and contain some coal seams less than 3 feet thick, which have been worked at Kohat and other places. The coal, though of fair bituminous quality, has a variable ash and sulphur content and is generally crushed by earth movements.

The DUNGHAN LIMESTONE (formerly called Alveolina limestone and for which Col. L. M. Davies advocates the term BOLAN LIMESTONE) is developed typically in the Bolan Pass and also in the Bugti hills, Dera Ghazi Khan and the borders of Waziristan, over a distance of about 200 miles. It is a massive, well bedded, hard, tough limestone, sometimes nodular. The thickness is variable but may reach a maximum of several hundred feet. In the Bugti hills it is intercalated with olive shales. In Sind it is a soft, white limestone, generally nodular. The Eocene of Waziristan bears little resemblance to that of Sind, the estuarine shales developed in the former probably being the equivalents of the Ghazij shales. There is nothing corresponding to the Dunghan limestone in Kohat and the Salt Range. The Lakis of the Salt Range are the scarp limestone and associated marls and shales.

The Laki series is characterised by *Nummulites atacicus*, *Assilina granulosa* and *Alveolina oblonga*. The Ghazij shales are rarely fossiliferous but the Dunghan limestones contain a rich echinoid fauna. There are also plant fossils including seeds and leaf impressions.

Foraminifera .. *Assilina granulosa, A. exponens, Nummulites atacicus, N. irregularis.*

Echinoids .. *Leiocidaris canaliculata, Porocidaris anomala, Cyphosoma macrostoma, Micropsis venustula, Conoclypeus alveolatus, Echinocyamus nummuliticus, Amblypygus sub-rotundus, Eolampas excentricus, Echinolampas rotunda, E. obesa, Hemiaster nobilis, H. carinatus, Metalia sowerbyi, M. depressa, Schizaster symmetricus, Macropneustes speciosus. Euspatangus* sp.

The following mollusca are found in the Laki and Kirthar beds and may probably be common to both :

Lamellibranchs *Ostrea vesicularis, Pholadomya halaensis, Vulsella legumen.*

Gastropods .. *Turritella angulata, Nerita schmideliana, Natica longispira, Terebellum plicatum, Rosetellaria angistoma, R. prestwichi, Ovulum murchisoni.*

KIRTHAR SERIES.

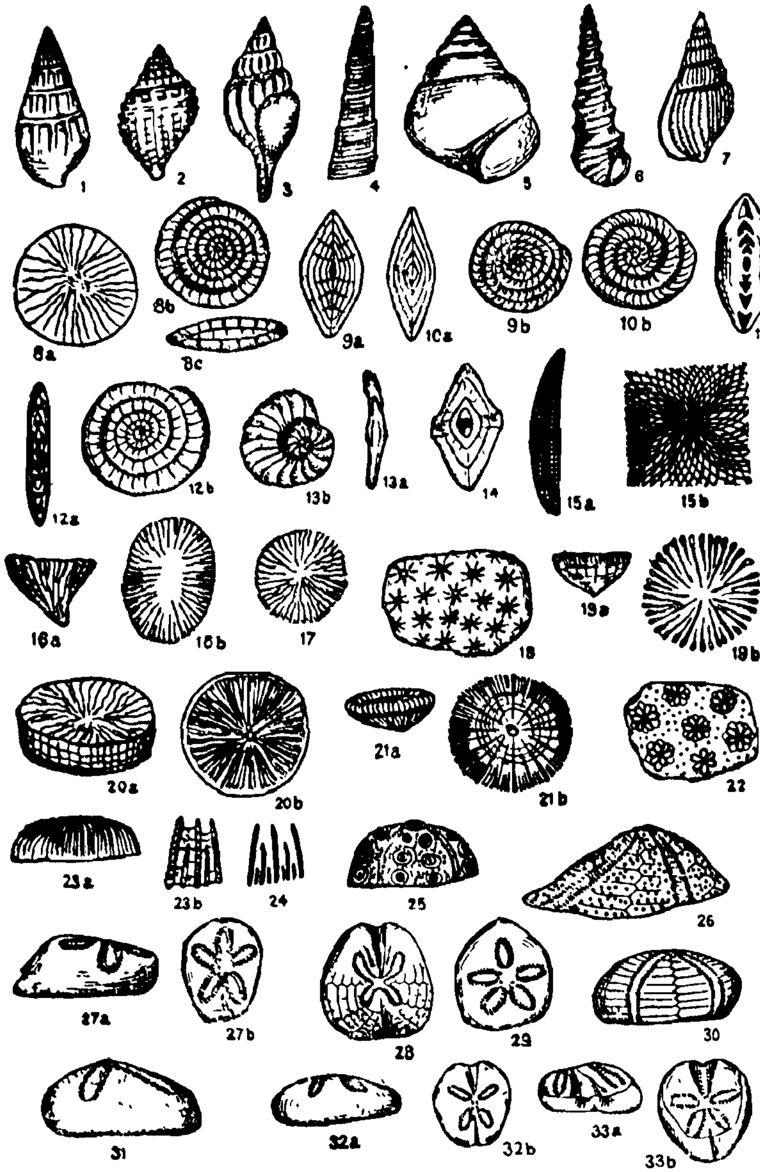
The Lakis and Kirthars are exposed in the hilly tract of Northwestern Sind, both containing similar-looking massive limestone. The Kirthars are exposed in the Kirthar, Dumbar and Kimbu ranges while the Lakis are seen to their southeast in the Laki, Sumbak, Surjana and Kara ranges.

The Kirthar series consists of three divisions, the lower mainly shaly, the middle calcareous and transitional, and the upper mainly calcareous. The lower shaly division is chiefly of the flysch facies, consisting of thin-bedded greenish shales and some sandstones and limestones, attaining a thickness of several thousand feet.

There is a distinct stratigraphical and faunal break between Laki and Kirthar, marked by brecciated limestone strata. The basal beds in Baluchistan are locally the GHAZABAND LIMESTONES, named after a hill 15 miles from Quetta. They contain *Nummulites irregularis, N. laevigatus* and *Assilina exponens.*

PLATE XXII.

LOWER TERTIARY FOSSILS.



EXPLANATION OF PLATE XXII

1. *Drillia jhirakensis* (2/3). 2. *Volutospina sykesi* (1/2). 3. *Fusus* (*Pagodula*) *colpophorus* (2/3). 4. *Turritella halaensis* (1/3) 5 *Ampullina* (*Crommium*) *polybathra* (1/3). 6. *Turritella angulata* (1/3) 7. *Rimella fusoides* (1/2) 8 *Nummulites nuttalli* (*a*, specimen, *b*, equatorial and *c*, meridional sections) (5). 9. *Nummulites atacicus* (4). 10. *Nummulites lahirii* (3). 11. *Assilina dandotica* (7).

The Middle Kirthars form a passage zone to the massive upper Kirthar limestones, and may in fact be considered as their lower part. They are characterised by *Nummulites gizehensis*, *N. beaumonti*, *Discocyclina javana*, *D. undulata* and *Asslina spira*, the last extending into the upper Kirthar. Only the middle portion of the Kirthars is well developed in Sind, the lower beds and the uppermost beds being often missing. But all the divisions are well developed in Baluchistan.

The Upper Kirthars, also known as the SPINTANGI LIMESTONES in Baluchistan, attain locally a thickness of 3,000 feet. Their characteristic foraminifer is the large form *Nummulites complanatus*.

The equivalents of the Kirthars are found in many places in the Tertiary Alpine belt of Western Asia and the Mediterranean region. The Kirthars are rich in fossils. Amongst the more important of them are:

Foraminifera .. (Lower) *Nummulites laevigatus*, *N obtusus*, *N. atacicus*, *Assilina exponens*.

(Middle) *Nummulites gizehensis*, *N. acutus*, *N. beaumonti*, *N. murchisoni*, *N. discorbina*, *N. perforatus*, *Dictyoconoides cooki*, *Discocyclina javana*, *D. dispansa*, *D. undulata*, *Assilina exponens*, *A. spira*, *A. papillata*, *Alveolina elliptica*.

(Upper) *Nummulites perforatus*, *N. complanatus* *N. biarritzensis*.

Echinoids .. *Cyphosoma undatum*, *Conoclypeus rostratus*, *Sismondia polymorpha*, *Amblypygus tumidus*, *A. latus*, *Echinolampas sindensis*, *Echinanthus intermedius*, *Micraster tumidus*, *Schizaster simulans*.

---

12. *Assilina granulosa* (3). 13. *Operculina subsalsa* (5). 14 *Miscellanea miscella* (8) 15 *Lepidocyclina* (*Polylepidina*) *punjabensis* (*a*, meridional section and *b*, equatorial section) (16) 16. *Blagrovia simplex* (1). 17 *Montlivaltia vignei* (2/3). 18. *Astrocoenia ramosa* (3) 19. *Montlivaltia ramkoti* (*a*. specimen ; *b*, section (1). 20. *Trochocyathus nariensis* 21 *Trochocyathus nariensis* 21 *Trochocyathus burnesi* (1). 22. *Stylophora pulcherrima* (4). 23 *Cyclolites vicaryi* (*b*, septa enlarged) (1) 24 *Cyclolites ramkoti* (3/2). 25 *Salenia blanfordi* (2/3) 26 *Conoclypeus declivis* (1/4) 27 *Eurhodia morrisi* (2/3) 28 *Schizaster alveolatus* (1/3) 29 *Sismondia polymorpha* (3/2). 30. *Amblypygus subrotundus* (1/3) 31 *Echinolampas rotunda* (1/3). 32. *Metalia depressa* (1/3) 33. *Euspatangus avellana* (1/2).

TABLE 44.—FORAMINIFERA OF THE EOCENE OF WESTERN INDIA. (AFTER W. L. F. NUTTALL).

v.a. = very abundant a = abundant c = common f = frequent p = present or rare	Upper Ranikot.	Laki.			Kirthar.		
		Meting and Dunghan Limestone	Middle Laki Limestone	Ghazij shales	Lower.	Lr.-Middle.	Up-Middle.
Species.							
Nummulites planulatus Lmk. ..	f						
N. aff *guettardi* D'arch. ..	c						
Siderolites misella (D'Arch & Haime)	f						
Assilina ranikoti Nuttall .	a						
Operculina canalifera D'Arch .	f						
O. hardiei D'Arch. & Haime ..	c						
Dictyoconoides conditi Nuttall ..	p						
Alveolina oblonga D'orb. ..		c	c				
Flosculina globosa (Leym) ..	-	v a					
Alveolina subpyrenaica Leym ..	-	v a	v a				
Nummulites irregularis Desh ..	-	p		f			
Assilina granulosa D'Arch. ..	-	a	a	a			
Nummulites atacicus Leym ..	-	a	f	a	a	a	
Orbitolites complanata Lmk. .	-	a	c	p	p	p	
Assilina exponens (Sow) ..	-	-	-	-	c	c	
Nummulites obtusus (Sow) ..	-	-	-	-	p	a	c
Nummulites acutus (Sow) ..	-	-	-	-	-	f	
N. beaumonti D'Arch. and Haime ..	-	-	-	-	-	f	
N. stamineus Nuttall ..	-	-	-	-	-	f	
Dictyoconoides cooki (Carter) ..	-	-	-	-	-	a	
Discocyclina dispansa (Sow.) ..	-	-	-	-	-	a	
D *javana* var. *indica* Nuttall ..	-	-	-	-	-	v.a	
D. undulata Nuttall ..	-	-	-	-	-	p	
D sowerbyi Nuttall ..	-	-	-	-	-	c	
Alveolina elliptica (Sow) ..	-	-	-	-	-	c	p
Nummulites laevigatus (Brug.) ..	-	-	-	-	-	p	a
N aff. *scaber* Lmk. ..	-	-	-	-	-	-	a
N carteri D'Arch. & Haime ..	-	-	-	-	-	-	p
N. gizehensis (Forksal) ..	-	-	-	-	-	-	p
Assilina cancellata Nuttall ..	-	-	-	-	-	-	f
A. papillata Nuttall ..	-	-	-	-	-	-	c
A. spira de Roissy ..	-	-	-	-	-	-	f

Since the foraminifera are of great importance in the zonal sub-division of the Eocene Table 44 gives the chief forms and their distribution in Sind-Baluchistan.

SALT RANGE.

The Eocene strata of the Salt Range are intermediate in character between the deep sea facies of Sind and the

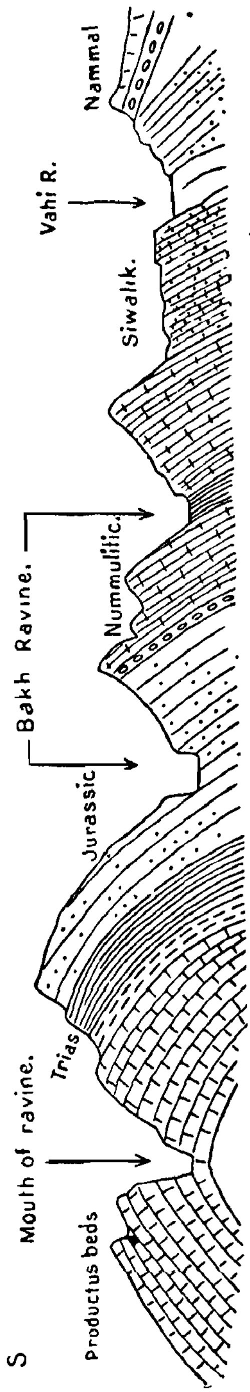


FIG. 12 SECTION THROUGH THE BAKH RAVINE SALT RANGE (*After* A. B. WYNNE. *Mem.* 14.)

coastal facies of the Sub-Himalaya. The greater part of the Eocene is well developed here, the beds generally thickening towards the west. The beds overlap the older formations and are overlain by the Murrees or Siwaliks.

The following succession (in the descending order) has been established.

Laki	*Bhadrar beds* (100-300 ft.)—Sandstones, limestones, marls and clays. *Sakesar Limestones* (200-300 ft.)—Massive limestone with chert nodules. *Nammal limestones and shales* (100-200 ft.)—Limestones, marls and shales.
Ranikot	*Patala shales* (100-250 ft.)—Carboneceous shales, limestones and sandstones. *Khairabad limestones* (50-500 ft.)—Nodular limestones. *Dhak Pass beds* (20-100 ft.)—Sandstones and shales, carbonaceous and gypseous with subordinate limestones. Laterite horizon at base.

Dhak Pass beds.—The earliest Eocene beds are seen at Dhak Pass near Nammal, where the Jurassic rocks are overlain by a pisolitic ferruginous band. Resting on this band, or directly overlying the Jurassics, are the Dhak Pass beds consisting of sandstones and shales which are often carbonaceous and sometimes gypseous, and also some thin limestones. Their fossil contents include:

Foraminifera ..	*Operculina* cf. *canalifera*, *O. subsasla*, *Miscellanea miscella*, *lockhartia conditi*, *L. haimei*.
Gastropods ..	*Cassidaria* cf. *archiaci*, *Megalocypraea ranikotensis*, *Velates noetlingi*.
Lamellibranchs ..	*Crassatella salsensis*, *Diplodonta* cf. *hindu*, *Lucina vredenburgi*.

Khairabad Limestone.—Resting over the Dhak Pass beds there are nodular limestones named after Khairabad near Kalabagh. They are 500 feet or more thick in the western Salt Range but gradually thin down eastwards. The following are the chief fossils in this division:

Foraminifera ..	*Nummulites nuttalli*, *N. thalicus*, *N. sindensis*, *Assilina dandotica*, *Operculina subsalsa*, *O.* cf. *canadifera*, *O. jiwani*, *Miscellanea miscella*, *M. stampi*, *Lock-*

	hartia newboldi, Lockhartia conditi, Alveolina vredenburgi, A. ovoidea, Dictyoconoides flemingi, Lepidocyclina (Polylepidina) punjabensis.
Echinoderms ..	*Eurhodia morrisi, Hemiaster elongatus, Plesiolampas ovalis.*
Gastropods .	*Velates noetlingi, V. perversus.*
Lamellibranchs ..	*Lucina mutabilis, L. noorpoorensis, L.* cf *bellardi.*

Patala shales.—These form the upper Ranikot beds, comprising dark grey shales, often carbonaceous, with subordinate limestones and sandstones. The coal seams worked at Dandot, Makarwal, Pidh and elsewhere belong to this division. The shales are alum-bearing on account of the action of the sulphuric acid derived from decomposing pyrite contained in them, the alum being extracted by the solution of the shales in water.

There is a marked change in the foraminiferal fauna in the middle of this division, the earlier forms like *Miscllanea miscella, Lockhartia haimei* and *Lepidocyclina punjabensis* becoming scarce in the upper portion, and forms like *Operculina patalensis, Assilina dandotica* and *Discocyclina ranikotensis* becoming abundant. The fossils in the Patala shales include :

Foraminifera ..	*Operculina patalensis, O* cf. *canalifera, O. salsa, O. subsalsa, Assilina dandotica, A spinosa, Discocyclina ranikotensis, Nummulites globulus, N* cf *mamilla, Alveolina globosa, A vredenburgi, A. ovoidea.*
Corals .	*Astrocoenia blanfordi, Trochocyathus* cf *epithecata.*
Gastropods ..	*Turritella ranikoti, T. hollandi, T. halaensis, Measlia fasciata, Rimella jamesoni*
Lamellibranchs .	*Crasstella salsænsis Ostrea pharaonum* var. *aviculina.*

Nammal limestones and shales.—These consist of limestones, marls and shales, a fine section being seen in the Nammal gorge. The characteristic fossils are *Nummulites atacicus, N.* cf. *mamilla, N. irregularis, Assilina granulosa.* Some long-range forms like *N. lahirii, Lockhartia tipperi, Discocyclina ranikotensis, Assilina subspinosa* and *Ostrea flemingi* are also found in them.

Sakesar limestone.—This is a massive limestone, 200 to 400 feet thick, containing numerous chert nodules in places. It is the characteristic member of the Laki series, forming high cliffs like the Sakesar hill, towering above the scarp. Occasionally it is seen to pass into gypsum, as near Kalabagh. On account of its massiveness and well-developed joints, it weathers into steep and irregular masses having the appearance of ruined fortress walls. The weathered surface shows numerous Nummulites. The chief fossils found are:

Nummulites atacicus, N. cf. *mamilla, Assilina granulosa, A. spinosa Lockhartia tipperi, L. conditi, Alveolina oblonga, A. ovoidea, A. globosa.*

Bhadrar beds.—These constitute the uppermost Laki division, overlying the Sakesar limestone. They consist of sandstones, limestones, clays and marls varying in thickness in different places from 200 feet to a few feet. In some places they are associated with the red clays characteristic of the Chharat beds of the Kala Chitta hills. Massive gypsum, regarded as derived from Laki limestone, occurs at the base of this division near Mari-Indus. The characteristic foraminifera are *Orbitoides complanatus* and *Assilina* cf. *pustulosa*, together with longer range forms like *Nummulites* cf. *mamilla, N. atacicus, Assilina subspinosa, Lockhartia conditi, L. tipperi, Alveolina ovoidea, A. oblonga.*

KOHAT DISTRICT.

In the Kohat district, north-west of the Salt Range, there occur beds of rock salt overlain by massive gypsum, the latter being altered limestones of Laki age. The salt of this region is grey or dark owing to inclusions of bituminous matter. The Laki limestone and gypsum are intercalated with greenish shales and are succeeded by Kirthar rocks which consist mainly of limestones and red clays.

Near Kohat itself the Lakis consist of greenish shales at the base, succeeded by the SHEKHAN LIMESTONE (upper Laki) and by red gypseous clays. The overlying Kirthars comprise a lower division of KOHAT SHALES and limestones and an upper division including Nummulitic shales and ALVEOLINA LIMESTONES.

TABLE 44-A.—EOCENE FORAMINIFERA OF THE SALT RANGE. (AFTER DAVIES AND PINFOLD, *Pal. Ind.* XXIV, I, p. 67, 1937.)

*present only in a small part of the strata. x present throughout or in greater part.	Ranikot.			Laki.		
Species.	L	M	U	L	M	U
Nummulites nuttalli Davies ..	-	x	x	-	-	-
,, *thalicus* Davies .	-	x	x	-	-	-
,, *sindensis* (Davies) ..	-	x	x	-	-	-
,, *globulus* Leym. ..	-	*	x	-	-	-
,, cf *Mamilla* (Fich. & Moll) ..	-	*	x	x	x	x
,, *atacicus* Leym. .	-	-	-	x	x	x
,, *lahiri* Davies ..	-	-	-	x	-	-
,, *irregularis* Desh. ..	-	-	-	x	-	-
,, *subirregularis* De la Harpe ..	-	-	-	x	-	-
Assilina dandotica Davies ..	-	*	x	-	-	-
,, *granulosa* D'Arch. .	-	-	-	x	x	-
,, *spinosa* Davies	-	-	-	-	x	x
,, *subspinosa* Davies ..	-	*	x	x	x	x
,, cf *pustulosa* Don	-	-	-		-	x
Operculina cf. *canalifera* D'arch. .	x	x	x	-	-	-
,, *salsa* Davies .	-	-	x	-	-	-
,, *subsalsa* Davies ..	x	x	x	-	-	-
,, *patalensis* Davies ..	-	x	x	-	-	-
,, *jiwani* Davies ..	-	x	x	-	-	-
Miscellanea stampi (Davies) .	-	x	x	-	-	-
,, *miscella* (D'A. & H.) ..	x	x	x	-	-	-
Lockhartia haimei Davies ..	x	x	x	-	-	-
,, *newboldi* (D'A & H.) .	-	x	x	x	x	x
,, *conditi* (Nuttall) .	x	x	x	x	x	x
,, *tipperi* (Davies) .	-	x	x	x	x	x
Sakesaria cotteri Davies	-	-	-	*	*	-
Dictyoconoides flemingi Davies	-	x	-	-	-	-
Heterostegina cf *ruida* Schw. .	-	-	-	-	*	-
Lepidocyclina (*Polylepidina*) *punjabensis* Davies .	-	x	x	-	-	-
Discocyclina ranikolensis Davies .	-	x	x	x	-	-
Orbitolites complanatus Lamk	-	-	-	-	-	x
Alveolina vredenburgi Davies ..	-	*	x	-	-	-
,, *oblonga* D'Orb. ..	-	-	-	-	x	x
,, *ovoidea* D'Orb .	-	*	x	-	x	x
,, *globosa* Leym.	-	*	x	-	x	-

SAMANA RANGE.

Quartzites and Hangu Shales. — In the Samana Range, which lies some distance to the northwest of the Kohat area, the lowermost Eocene consists of about 150 feet of white quartzitic sandstones followed by the Hangu shales which are 15 feet thick and full of fossils. The Hangu shales form a useful marker horizon in this region. The fossils show affinities with those of the Cardita beaumonti beds, but the absence of cephalopods and of the larger foraminifera shows that they belong to early Eocene age, *i.e.*, Lower Ranikot. All the fossils found in them are new except a few which have a long time range.

Corals ..	*Blagrovia simplex, Placotrochus tipperi, Euphyllia thalensis, Astrocoenia (Platastrocoenia) ranikoti, A. blanfordi, Cyclolites vicaryi, C. striata, Placosmilia wadiai.*
Gastropods ..	*Campanile brookmani, Turritella daviesi, T. ranikoti, Mesalia fasciata, Tibia samanensis, Rimella levis, Euspira roei, Globularia brevispria, Architectonia mainwaringi, Hemifusus montensis, Murex wadiai, Strepsidura tipperi, Voluta vredenburgi, Athleta (Volutocorbis) deviesi, Lyria samanensis.*
Lamellibranchs ..	*Cardita hanguensis, Cardium inaequiconvexum, Meretrix indica, Trapezium daviesi, Crassetellites exiguus, Corbula samanensis.*

Lockhart Limestone and Hangu breccia.—The overlying rocks show two facies, one being a massive grey limestone of 200 feet thickness (Lockhart limestone) and the other a limestone breccia. The larger foraminifera make their first appearance here, species of *Dictyoconoides* (*D. haimei*, *D. newboldi* and *D. conditi*) being common.

Upper Ranikot.—Above the Lockhart limestones are clays, shales and impure limestones having a thickness of 70 feet, capped by a limestone-breccia which is 30 feet thick. The most important fossils in these are *Nummulites nuttalli*, *N. thalicus*, *Operculina* cf. *canalifera* and *Discocyclina* sp. The Upper Ranikot contains several corals including the following :

Parachyathus altus, Feddenia jacquemonti, Astrocoenia blanfordi, A. ramosa, Thamnastrea balli, Diploria flexuosissima, Pachyseris murchisoni, Trochoseris obliquatus, Isis ranikoti.

POTWAR PLATEAU.

Hill Limestone.—The lowest zone in the Tertiaries of the Kawagarh and Kala Chitta hills is a ferruginous pisolite associated with unfossiliferous shales of Lower Ranikot age. This is overlain by the Hill limestone, a massive limestone with shale intercalations, including both the Ranikot and Laki series. The shaly beds in the Hill Limestone occasionally contain layers of coal. They attain a thickness of several hundred feet but vary from place to place, the upper portion containing the Laki fossil *Assilina granulosa.*

Chharat series.—The Hill Limestone is succeeded by the Chharat series in the Kala Chitta hills, where the following divisions have been recognised :

3. Nummulitic shales (50-200 feet).
2. Thin bedded limestones and green shales (100-200 feet).
1. Variegated shales and limestones (300-500 feet).

The passage bed between the Hill limestone and the variegated shales in a chalky limestone with gypsum, showing oil seepages near Chharat. The Variegated shales and limestones show fragments of reptilian and mammalian fossils and shells of *Planorbis.* The middle division contains *Nummulites* and molluscs including *Cardita* (*Venericardia*) *subcomplanata.* The Nummulitic shales contain numerous *Assilina papillata* and *Discocyclina javana.* It is therefore considered to represent the lower part of the Middle Kirthar. The upper Kirthar is absent.

Kuldana beds.—Some calcareous conglomerates and red shales which are found between the Nummulitics and the Murrees were described by Wynne as the Kuldana series and regarded as the equivalents of the Subathus. Pinfold showed later that they are approximately of the same age as the Chharat series.

HAZARA.

The southeastern border of the mountains of Hazara shows a well developed zone of Eocene rocks. At the base is a band of laterite followed by beds of sandstone and clay containing inferior coal. These are overlain by massive dark limestones interbedded with shales belonging to the Laki series. Above these are shales, marls and nodular limestones bearing some resemblance to the Chharats and containing large *Nummulites* referable to Kirthar age.

Overlying these with an unconformity is a band of shales, clays and marls, 15 to 20 feet thick, known as the Kuldana beds. They are purple to deep brown in colour and contain *Nummulites* derived from the denudation of the older beds. These beds are succeeded by the Murree series.

KASHMIR.

Eocene rocks similar to those of Hazara are developed on the southern flanks of the Pir Panjal. They consist of limestones resembling the Hill limestone, followed by a large thickness of variegated shales containing a few coal seams in the lower part. The limestones are thin-bedded, pale grey and cherty, containing a few *Nummulites* of Ranikot age and gastropods. They attain a thickness of 300 to 500 feet. The overlying beds are pyritous, coaly and ferruginous shales with thin carbonaceous beds. These are succeeded by thin-bedded dark limestones containing *Nummulites*, *Assilina* and *Ostrea*, and these in turn by variegated shales of several hundred feet thickness with sandstone intercalations. This shale and limestone formation is similar to the Chharats in characters.

Chharat	Variegated red and green shales (800 ft.).
	Dark thin-bedded lenticular nummulitic limestone (100 ft.).
	Pyritous and carbonaceous shales with ironstone (50 ft.).
Ranikot	Thin bedded, pale grey, cherty limestones with a few *Nummulites* and gastropods (400 ft).

To the south of the Pir Panjal there is a series of outcrops of Eocene rocks near Riasi and Jammu. These contain a basal zone of laterite succeeded by grey and green pyritous and carbonaceous shales and Nummulitic limestones. They attain a thickness of 600 feet or more and are similar to the Subathu beds of Simla foothills further east. The laterite is often highly aluminous and may therefore be useful as an ore of aluminium. The shales overlying them contain seams of coal which are workable but are more or less crushed and graphitic. The Nummulitic limestone is dark and thin-bedded, but when followed westwards becomes paler, more massive and thicker and contains *Nummulites atacicus* and *Assilina granulosa*.

SUB-HIMALAYA OF SIMLA.

The Jammu belt of Eocene rocks continues southeastwards along the foothill zone of the Simla and Garhwal region as far as Naini Tal. The deposits thin down and are of coastal facies. They are called the Subathu beds in this region, and contain a basal pisolitic laterite overlain by greenish grey and red gypseous shales with occasional sandstones and a few lenticular impure limestone bands. The Subathus are roughly the equivalents of the Kirthars.

NORTHERN HIMALAYA AND TIBET.

Eocene rocks are found in Ladakh in the Upper Indus valley along a zone parallel to the Himalayan trend from Kargil to Leh, Hanle and beyond. They consist of felspathic grits, green and purple shales and limestones containing badly preserved *Nummulites* and other fossils. The rocks have been subjected to folding and crushing and igneous intrusions on a large scale. From the fossil evidence it is known that the sediments extend in age from the Cretaceous to Oligocene.

Eocene rocks occur over large areas in Southern Tibet and form part of the Kampa system. The sub-divisions recognised by Hayden are given in Table 45.

The ferruginous sandstone is similar to the Dhak Pass beds of the Salt Range. The succeeding three beds are the equivalents of the Khairabad limestone, and all contain foraminifera, especially the Operculina limestone. The chief foraminifera in these are *Miscellanea miscella*, *Nummulites sindensis*, *N. thalicus*, *Operculina subsalsa*, *Lockhartia haimei*, *L. newboldi*, *L. conditi*, *Dictyoconoides* cf. *flemingi*, *Lepidocyclina* (*polylepidina*) *punjabensis*, *Verneuilia* sp., and these bear a striking resemblance to the fauna of the Salt Range. The mollusca found in these beds include *Megalocypraea ranikotensis*, *Gosavia humberti*, *Hippochrenes* cf. *amplus*, *Campanile brevis*, *Velates perversus*, *Vulsella legumen*, *Ostrea* (*Liostrea*) *flemingi*.

TABLE 45.—EOCENE SUCCESSION IN KAMPA DZONG.

6.	Dzong-buk shales (150 ft.). Sandy micaceous shales with thin sandstone layers ..	Laki.
5.	Orbitolites limestone (50 ft.). Limestone full of *Orbitolites* and *Alveolina* ..	Laki.
4.	Spondylus shales (150 ft.). Fine-grained, greenish grey and black shales	Upper Ranikot.
3.	Operculina limestone (150 ft.). Shaly nodular limestone full of foraminifera	Upper Ranikot.
2.	Gastropod limestone (300 ft.). Hard, dark, massive limestone, thin bedded at base, with a shale band 40 ft. thick just above the middle.	Upper Ranikot.
1.	Ferruginous sandstones (200 ft.). ..	Lower Ranikot.

ASSAM.

Disang series.—The Eocene is well represented in Assam. In Upper Assam and Eastern Assam (Sadiya tract, Manipur and Naga Hills) it is represented by the Disang series which is of Lower and Middle Eocene age and possibly also extends down into the Cretaceous. It consists of splintery dark grey shales intercalated with sandstones, passing up into well-bedded sandstones. The shales are found to be metamorphosed to hard slates in the Naga hills region. The Disang series is confined to the south of the Haflong-Disang fault which is a prominent feature across Assam.

Jaintia series.—Along the southern border of the Shillong Plateau and in North Cachar and Mikir Hills a different facies appears, called the Jaintia series. The lower part of this is the SYLHET LIMESTONE STAGE of Upper Laki to Lower Kirthar age, composed of foraminiferal limestones intercalated with sandstone beds. This attains a thickness of nearly 1,000 feet near Therria Ghat but thins down to the east, appearing as a thin strip below the overlying Barail series.

The upper portion is the KOPILI STAGE consisting of grey shales, ferruginous shales with ironstone, and sandstones. Near Cherrapunji and Laitryngew it contains coal seams, while near Lumding warm sulphurous springs issue from it. This stage is of Middle Kirthar age and is not known in Upper Assam

Jaintia Series (Lutetian to Up. Londinian).	*Kopili stage* (1,000 ft.) Fine grained sandstones, dark grey shales, ironstones, carbonaceous shales and local limestones.	Upper Lutetian.
	Sylhet Limestone stage (600 ft.) Foraminiferal limestones and sandstones.	L. Lutetian to Up. Londinian.

GARO HILLS.

Eocene rocks occur along and to the south of the Tura range in the Garo Hills. The lowest beds, constituting the TURA STAGE, comprise sandstones and shales with coal seams. Two good seams of coal are found in the Garo Hills, estimated to contain 1,000 million tons within a depth of 1,000 feet from the surface. The rocks form an anticline to the south of the Tura range, then flatten and finally dip steeply southward towards the plains under the Surma series of Upper Tertiary age.

The TURA STAGE is conformably overlain by the SIJU LIMESTONE which on fossil evidence is correlated with the Sylhet limestone. The Siju limestone is in turn overlain by the REWAK STAGE which is the equivalent of the Kopili stage.

In the Khasi and Jaintia hills the Cretaceous rocks are overlain by unfossiliferous CHERRA SANDSTONE of Lower

Eocene age. The Cherra sandstone gradually passes up into the Sylhet limestone.

Kopili or Rewak stage	Sandstones and marine shales	4,000 ft.
Sylhet or Siju stage	Marine shales and limestones	500 ft.
Cherra or Tura stage	Upper sandstone	200 ft.
	Upper coal seam	2-4 ft.
	Middle sandstone	180 ft.
	Lower coal seam	5-6 ft.
	Lower sandstone	210 ft.

Barail series.—In Upper Assam, the Disang series is overlain by the Barail series which is divided into three stages.

Barail series	*Tikak Parbat stage* (1,000-2,000 ft.). Carbonaceous shales and coal seams.	Coal Measure sub-series.
	Baragoloi stage (9,000 ft.). Sandstones, carbonaceous shales and coal seams.	
	Naogaon stage (3,000-3,500 ft.). Sandstones.	

The NAOGAON STAGE consists of hard, thin bedded, flaggy sandstones forming prominent hills. The BARAGOLOI STAGE shows grey sandstones intercalated with shales, carbonaceous shales and coal seams as in the Baragoloi colliery. The TIKAK PARBAT STAGE consists of alternating sandstones, sandy shales and shales associated with coal seams such as those worked in the Nazira, Makum, Namdang-Ledo and Tikak coal fields. There is a lateral variation when these stages are followed from Upper Assam to the Naga Hills and the Surma valley.

The Barail series occupies a large area north-west of the Haflong-Disang fault. It is of varying extent in different areas but well developed south-west of Lumding and in North Cachar. The name is derived from the Barail range which forms the water-shed between the Brahmaputra and the Surma valleys.

In the area to the south-east of the Haflong-Disang fault, in the southern part of Khasi and Jaintia hills and part of North Cachar, the Barail series shows a different development, as shown below :

Barail series	*Renji stage* (2,000-3,000 ft). Hard massive sandstones ..	Chattian.
	Jenam stage (3,000-4,000 ft). Sandstones alternating with shales and carbonaceous shales .	Lattorfian.
	Laisong stage (6,000-8,000 ft.). Hard, well bedded sandstones and subordinate shales ..	Bartonian to Auversian.

The Naogaon stage is the equivalent of the lower Laisong stage ; the Baragoloi stage represents the upper Laisong and lower Jenam stages and the Tikak Parbat stage represents the upper Jenam and lowermost Renji stages.

The Barails show well-marked lateral variation, though the arenaceous element predominates on the whole. The sandstones increase in coarseness in a north-westerly direction. The argillaceous and carbonaceous content increase north-eastwards, the latter to a marked extent. There are no coal seams in the Surma valley. They begin to develop east of the main part of the Dhansiri valley, the seams being often 10 feet thick north-east of the Dayang valley.

The maximum development of coal in the strata is in the neighbourhood of Ledo. Though carbonaceous matter and thin seams are widely distributed, the thicker seams are restricted to a comparatively small range of thickness in the Baragoloi and Tikak Parbat stages. Oil seepages also occur in the Barails, the oil-bearing horizons being mostly below the thick coal seams.

The Barails are poor in fossils, though there are abundant plant remains in the upper stages. The lowest Barails are regarded as Upper Lutetian. The Laisong stage is the equivalent of the Pondaung sandstone of Burma, of Upper Eocene age (Auversian to Bartonian). The Jenam stage is mainly Lattorfian, *i.e.*, Lower Oligocene, while the upper limit of the Barails is Chattian. There is a very well marked unconformity above the Barail series all over Assam.

BURMA.

Eocene rocks are found in a belt stretching from the Dutch East Indies through the Nicobar and Andaman Islands and the Arakan Yoma to Upper Burma.

The Andaman and Nicobar Islands are composed, for the most part, of Eocene rocks. The lower beds are conglomerates and sandstones resting on rocks resembling the Axials. They contain *Nummulites atacicus* and *Assilina* and are therefore of Laki age. The same series is represented by limestones in Sumatra and Java.

Lower Burma.—The eastern foothills of the Arakan Yoma in Lower Burma show Eocene rocks apparently faulted against the pre-Tertiary rocks. They comprise alternating sandstones, sandy shales and bluish shales containing some carbonaceous matter and thin coal seams. The sandstones are sometimes used as a building stone. The shales contain fish scales and plant fossils. The shales and thin limestones occurring in the upper beds contain *Nummulites*. Coal seams occur in Eocene sandstone in the Henzada district but the coal is crushed and friable and of little economic value.

Upper Burma.—The Eocene rocks of Upper Burma comprise the following divisions :

6. Yaw shales (2,000 ft.). Marine blue shales with fossils .	Bartonian-Ludian.
5. Pondaung sandstones (6,000 ft.). Conglomerates, sandstones and variegated clays with mammalian fossils ..	Auversian.
4. Tabyin clays (5,000 ft.). Green clays and sandstones with coal ..	Up. Lutetian
3. Tilin sandstones (5,000 ft.). Greenish sandstones, sparsely fossiliferous	L. Lutetian..
2. Laungshe shales (9,000-12,000 ft.). Blue Nummulitic shales, gypseous and concretionary, with bands of sandstone	Ypresian.
1. Paunggyi conglomerates (2,000-4,000 ft.). Conglomerates, grits and sandstones	Thanetian to Danian.

The basal beds are grits and conglomerates which unconformably rest on phyllites and slates of older age. Because of their inconstancy, they are regarded by G. de P. Cotter as the lower part of the overlying Laungshe shale stage. The LAUNGSHE SHALES are thin-bedded blue clays, often concretionary and gypseous, with bands of sandstone. They contain *Nummulites atacicus*, *Operculina canalifera* and some mollusca and correspond in age to the Lakis, whereas the Paunggyi conglomerate may represent part of the Ranikots. The TILIN SANDSTONES are marine in the south and fluviatile in the north and increase in thickness northward. They are sparsely fossiliferous, containing *Ampullina*, *Arca*, *Ostrea*, *Cerithium*, *Turritella* and *Volutilithes* and also fossil wood in places. The succeeding TABYIN CLAYS are dark blue coloured shales with sandstones and pebble-beds. They contain septarian nodules, lignitic and carbonaceous nests and some coal seams especially in the Pondaung range. The marine development in the south contains the characteristic middle Kirthar fossils *Nummulites vredenburgi* and *N. acutus*.

The PONDAUNG SANDSTONES are typically developed in the Pondaung range, the lower part being conglomerates, greenish sandstones and clays, and the upper part greenish, purplish and variegated shales. As with other formations they are marine in the south and brackish to fresh-water in the north. They enclose fossil wood which is usually carbonised in the lower part of the stage, and partly carbonised and partly silicified in the upper part. The conglomerate bed at the base contains *Cardita mutabilis*, *Arca pondaungensis*, *Alectryonia newtoni*, *Corbula daltoni* and some gastropods. The freshwater facies consists of red, buff, and cream coloured earths interstratified with sandstones. The earthy beds contain reptilian and mammalian remains in the Pakokku district, the chief mammalian fossils being :

Primates ..	*Pondaungia cotteri*, *Amphipithecus mogaungensis*.
Brontotheridæ .	*Sivatitanops birmanicum*, *S. cotteri*.
Tapiridæ ..	*Indolophus guptai*, *Deperetella birmanicum*.

Anthracotheridæ	*Anthracothema pangani, A. crassum, A. rubricae, Anthracokeryx hospes, A. birmanicus, A. tenuis, A. bambusae, Anthracohyus choeroides.*
Tragulidæ ..	*Indomeryx cotteri, I. arenae.*

The fossils indicate an upper Eocene (Auversian) age.

The YAW SHALES rest on the Pondaung sandstones and comprise bluish grey shales of essentially marine character, though the fluviatile representatives with coal seams are developed in the Minbu district. They often show thin bands of impure calcareous matter, septarian nodules, phosphatised coprolites and fish remains, foraminifera and molluscs. The chief fossils are:

Foraminifera	*Nummulites yawensis, Orthophragmina omphalus, O. sella, Gypsina globulus, Operculina canalifera.*
Lamellibranchs .	*Solen manensis, Corbula subexarata, C. paukensis, Meretrix (Callista) yawensis, Venus pasokensis, Tellina salinensis, Cardium kanleanum, Lucina yawensis, Ostrea minbuensis, Leda silvestris.*
Gastropods ..	*Velates schmideliana, Cypraedia birmanica, Gosavia birmanica, Lithoconus gracilispira, Athleta rosalindae, A archiaci, Volutilithes arakanensis, Clavilithes cossmanni, Velates perversus, Ampullina* cf. *grossa.*

This fauna bears a distinct resemblance to that of the Upper Eocene of Java and to the Upper Kirthar of Western India.

RAJPUTANA.

The comparatively lowlying tracts of Bikaner and Jaisalmer in south-western Rajputana were under the sea in Eocene times. The strata exposed here belong to the Laki series and especially its middle division, and comprise a considerable thickness of white or pale buff limestone with *Nummulites atacicus* and *Assilina garnulosa.*

The Eocene beds contain lignite beds which are successfully worked at Palana in Bikaner, and also an earthy brown shale used as fuller's earth.

CUTCH.

The Eocene marine invasion has left deposits in Cutch belonging to the Laki and Kirthar series. One of the two bands is in the interior and rests upon the Deccan trap, while the other, nearer the coast, overlaps on to the Jurassic rocks.

The lower beds are gypseous, pyritous and carbonaceous shales of Laki age overlain by Kirthar limestones which attain a thickness of several hundred feet and enclose Nummulites, echinoderms and other fossils. The Kirthars are succeeded by shales, calcareous shales and marls containing numerous lamellibranchs and gastropods which indicate a Gaj (Lower Miocene) age.

GUJARAT.

There are two exposures of Eocene rocks in the area between Surat and Broach, separated by the alluvium of the Kim river. The smaller southern exposure extends for 10 miles northward from the Tapti and is 15 miles at its widest. The larger exposure, between the Kim and the Narbada, is 30 miles long (N.E.-S.W.) and 12 miles wide. The basal beds are impure limestones and some laterite and contain such characteristic Ranikot Nummulites as *Nummulites thalicus*, *N. globosus* and *Discocyclina* aff. *ranikotensis*. The beds above these contain *Assilina exponens*, *Nummulites ramondi*, *Ostrea flemingi*, *Rostellaria prestwichi*, *Natica longispira* and *Vulsella legumen* which are regarded as indicating a Kirthar age.

A large thickness (4,000-5,000 feet) of gravel, conglomerate, sandstones and shales, overlies the Eocene limestones near Ratanpur east of Broach. The conglomerate contains pebbles of agate and other forms of silica derived from the denudation of the traps, these being excavated and worked as semi-precious stones in Cambay. This upper group is evidently of Gaj age as it contains the valves of *Balani* common in the Gaj series of Sind.

PONDICHERRY AREA.

The discovery of Lower Eocene foraminifera (*Nummulites* and *Discocyclina*) was announced by L. Rama Rao in

1939 in some limestones in the Pondicherry area which was hitherto known to contain only Cretaceous rocks. Upper Eocene rocks with fossils of Lutetian to Bartonian age have also been found in some borings near Pondicherry. It may therefore be expected that an Eocene sequence will be found in this area overlying the Cretaceous rocks, possibly partly under the Cuddalore sandstones of Miocene age.

RAJAMAHENDRI (RAJAHMUNDRY).

The infra-trappean sandy limestone of the Rajamahendri area contains a fauna whose age appears to be doubtful but more probably Upper Cretaceous according to Medlicott and Blanford. The Inter-trappeans have yielded a rich algal flora containing *Acicularia*, *Neomeris*, *Chara*, etc. which have a decided Eocene aspect. The age of these beds must remain in doubt until the results of more detailed work are available.

CHAPTER XVIII.

OLIGOCENE AND LOWER MIOCENE SYSTEMS.

General.—The uppermost part of the Eocene was marked by an orogenic upheaval which marked the commencement of the formation of the Alpine-Himalayan system of mountains. The great thickness of sediments which had accumulated in the Tethyan basin was now compressed, corrugated and raised up and the sea was shallowed up and restricted in extent. In the Oligocene, *however, sedimentation still continued but the large* thickness of sandstones and gritty shales which were laid down bear evidence of shallow water deposition, the floor of the sea sinking gradually as sedimentation proceeded. These calcareous sandstones and greenish shales are singularly uniform in appearance and constitute the bulk of the 'flysch' formation similar to the Oligocene flysch of southern Europe. Similar beds were deposited during the Eocene and even in the Upper Cretaceous but the thickness of these was much smaller than that of the Oligocene rocks. This sedimentation continued until the Middle Miocene when a second upheaval took place which obliterated the Tethys but left a series of lagoons in front of the Himalayas and connected arcs.

The Oligocene and lower Miocene rocks therefore make up one stratigraphic unit. This is represented by the Nari and Gaj beds of Sind-Baluchistan hills, the flysch of Baluchistan, the Murree system of northwestern India and the Pegu system of Burma. The coastal regions of the Peninsula also experienced marine sedimentation in certain restricted areas. The Oligocene-Lower Miocene deposits may therefore be grouped under four principal types, *viz.*, (1) an open-sea calcareous facies, (2) a shallow marine flysch facies, (3) a lacustrine facies deposited towards the Peninsula side of the mountains and (4) the coastal facies of the Peninsula.

SIND AND BALUCHISTAN (CALCAREOUS FACIES).

The Calcareous facies of the Oligocene-Miocene is developed in the Sind and Baluchistan mountains on the eastern side of the Eocene strata. Two main divisions are recognised, *viz.*, the Nari and Gaj series both named after rivers on the Sind frontier. Both are characterised by massive limestones but sandstones and shales also occur, especially in the upper portion. When followed northwards the arenaceous element in the beds increases, showng the approach to land in that direction.

Lower Nari.—The Nari series is well developed on the eastern flanks of the Kirthar range and also to the west of the Laki range throughout Lower Sind. It is divisible into two sub-series. The lower Nari is variable in thickness, from 100 to 1,500 feet, and consists mostly of limestones. The lower beds are white and massive but the upper are brown and yellow, inter-bedded with bands of shale and layers of sandstone.

Upper Nari.—The Upper Nari beds reach a maximum thickness of 4,000 to 6,000 feet and consist of thick-bedded grey sandstones and subordinate shales and conglomerate. The rocks are mostly unfossiliferous but certain bands are crowded with *Lepidocyclina* (*L. dilatata* group) of very large size; often 2 inches or more across.

The Nari series corresponds with the Stampian and Chattian, covering the greater part of the Oligocene. Amongst its leading fossils, most of which come from the lower division, are :

Foraminifera	*Nummulites intermedius, N. vascus, Lepidocyclina dilatata*
Corals ..	*Montilvaltia vignei.*
Echinoids ..	*Breynia multituberculata, Eupatagus rostratus, Echinolampas discoideus, Clypeaster simplex.*
Lamellibranchs ..	*Ostrea fraasi, O. orbicularis, O. angulata, Pecten labadyei, P. articulatus, Arca semitorta, Lucina columbella, Crassatella sulcata, Callista splendida, C. exintermedia, Venus puerpera*, var. *aglaurae, V. multilamella, Pitar porrectus.*

Gastropods .. *Terebra narica*, *Ancilla indica*, *Volutospina sindiensis*, *Lyria anceps*, *Cypraea subexcisa*, *Cerithium sindiens*, *C. bhagothorense*.

Gaj series.—The Nari series is overlain conformably by the Gaj series which attains a thickness of 1,500 feet and consists of yellow and brown limestones, either massive or rubbly, with intercalations of white arenaceous limestones, clays and gypsum. The lithology indicates that the area of deposition was first marine and later became gradually estuarine. The two divisions of the Gaj have several fossils in common but there are also some species exclusively found in each division.

The following fossils are found throughout:

Echinoids .. *Breynia carinata*, *Eupatagus patellaris*, *Echinolampas jacquemonti*, *Clypeaster profundus*, *Echinodiscus placenta*.

Gastropods *Vicarya verneuili*, *Turritella angulata*, *Telescopium sub-trochleare*, *Olivancilla nebulosa*.

Lamellibranchs .. *Pecten scabrellus*, *P. senatorius*, *Dosinia pseudoargus*, *Venus granosa*, *Clementia papyracea*, *Discors triformis*, *Lucina columbella*, etc.

The species found in Lower Gaj are *Ostrea angulata*, *Pecten labadeyi*, *P. articulatus* and *Lepidocyclina marginata*. Those in the Upper Gaj are *Ostrea latimarginata* (characteristic), *O. gajensis*, *O. imbricata*, *O. gingensis*, *O. vestita*, *Pecten placenta*, *P. subcorneus*, *Arca peethensis*, *A. burnesi*, *A. semitorta* and also some remains of Rhinoceros. The age of the Lower Gaj is Aquitanian and that of the Upper Gaj Burdigalian, both being Lower Miocene, and they correspond respectively to the Rembang and Njalindung series of Java.

BALUCHISTAN (FLYSCH FACIES).

Khojak shales.—Beyond the calcareous zone, in Baluchistan, there occurs a vast series of sandstones, shales, and sandy shales constituting the flysch zone which includes the hills of the Zhob and Pishin valleys, the Khwaja Amran range west of Quetta and almost the whole of the Mekran province. This region is occupied by close-set ridges consisting mostly of a monotonous series of folded sandstones and slaty shales of a greenish colour known as the Khojak shales which resemble the Oligocene flysch of Europe. In the coastal region of Mekran the strata are friable clays. The typical Khojak shales contain fossils only rarely. Amongst them are *Nummulites* (*Camerina*) *intermedius*, *N. vascus*, *Lepidocyclina* (*Eulepidina*) *dilatata*, *Rotalia*, *Triloculina*, *Globigerina*, etc. They are apparently the equivalents of the Nari series.

Hinglaj sandstons.—Large masses of sandstones with shale beds rest conformably upon these Oligocene clays and make up the Peninsula of Ormara and Gwadar, the Hinglaj mountains and other hills of the Mekran coast. The shale intercalations sometimes contain fossils, especially in the uppermost and lowermost horizons. The lowest beds contain *Turritella javana*, *Ostrea gingensis*, *Arca burnesi*, *Dosinia pseudo-argus*. The uppermost beds contain *Pecten vasseli* as the commonest fossil and also *Vertagus bonneti*, *Crepidula subcentralis*, *Ostrea frondosa*, *O. cucullata*, *Arca divaricata*, *A. squamosa*, *A. tortuosa*. The beds in the middle contain *Turritella angulata*, *T. bantamensis*, *T. bandoengensis*, *Ostrea virleti*, *O. petrosa*, *O. digitalina*, *Arca inflata*, *Clementia papyracea*, *Circe corrugata*.

A large proportion of the Hinglaj species occurs in the Miocene of Java and Burma, the fauna of the upper portion bearing some resemblance to that of the Karikal beds on the Madras coast. The Hinglaj beds correspond to a part of the Lower Manchhars and are of Burdigalian to Helvetian age.

NORTH-EASTERN BALUCHISTAN.

Bugti beds.—In the Bugti hills of Baluchistan the marine element of the Nari series becomes very reduced, being represented by a small thickness of brown arenaceous limestone containing the characteristic *Nummulites*. These are succeeded by a series of fluviatile sandstones with the characteristic Gaj *Ostreae* at the base, the beds above containing a rich vertebrate and fresh-water lamellibranch fauna including the ribbed Unios (*U. cardita, U. Vicaryi, U. cardiformis.*)

The vertebrates include:

Anthracotherium bugtiense, A. ingens, Telmatodon bugtiensis, Brachyodus giganteus, B. hyopotamoides, Paraceratherium bugtiensis, Hemimeryx speciosus, Aceratherium bugtiens, Teleoceras blanfordi, Cadurcotherium indicum, Baluchitherium sp., *Pterodon bugtiensis, Amphicyon shahbazi, Rhinoceros gajensis.*

These beds are of Gaj age, and the Lower Siwaliks rest on them with an unconformity.

POTWAR PLATEAU AND JAMMU.

North-western Punjab and the adjoining regions of Jammu and Kashmir contain one of the most complete Tertiary sequences in India. This region was once a basin of large dimensions in which were laid down very thick deposits of brackish and fresh-water origin during the Oligocene and Miocene times. The earlier deposits (Lower Murrees) are of brackish water origin while the late ones (Upper Murrees) are fresh-water deposits.

Fatehjang zone.—The Chharat series of Upper Eocene age is overlain, with an unconformity marked by a bed of conglomerate about a foot thick, by the Fatehjang zone which belongs to the basal part of the Murree series. This zone consists of brown and grey sandstones and pseudo-conglomerates. The numerous large *Nummulites* with which their exposures are covered have been derived from the denudation of the earlier beds. Several mammalian fossils, indicating a lower Burdigalian age, are found in the Fatehjang zone:

Anthracotherium bugtiense, Hemimeryx sp. *Brachyodus* cf *africanus Palaeochoerus pascoei, Teleoceras fatehjangense.*

Murree series.—The Fatahjang zone passes upward into the Lower Murrees which consist of bright purple shales, hard purple and grey sandstones and pseudo-conglomerates. They contain sparse fossils including leaf impressions (*e.g., Sabal major*) and some lamellibranchs. The red colour of the rocks points to heavy oxidation and rather dry conditions in the areas from which the sediments were derived.

The upper Murrees are distinct from the lower, especially in the Salt Range, being composed of soft, pale coloured sandstones resembling the Chinji (Lower Siwalik) sandstones to some extent. They contain impressions of dicotyledonous leaves and remains of mammalia including primitive rhinoceros.

The Murrees are typically seen at and near the hill station of Murree and attain a maximum thickness of more than 8,000 feet. They are developed in the eastern part of the Salt Range and are succeeded by the Siwaliks. They are regarded as of Burdigalian to Helvetian age (*i.e.*, Middle Miocene) and as the equivalents of the Upper Pegu rocks of Burma.

The Murrees are the reservoir rocks of petroleum in the Khaur oil field of the Potwar plateau, though the petroleum probably originated from the underlying Eocene rocks.

SIMLA HIMALAYA.

When followed eastwards from the Jammu area, the Murrees diminish in thickness and are represented in the Simla hills by the Dagshai and Kasauli beds which are roughly the equivalents of the Lower and Upper Murrees respectively. These beds, together with the underlying Subathus, used to be included formerly under the SIRMUR system.

Dagshai beds.—The Subathus are overlain by the Dagshai beds which comprise a series of very hard, fine-grained grey or purplish brown quartzitic sandstones intercalated with seams of red clay. The clays predominate in the lower part but the sandstones gradually increase in proportion and thickness in the upper part. The sandstones are massive, 5 to 20 ft. in thickness, and scarcely show any stratification. The clays are purplish brown, mottled with grey, and are harder than either the Kasauli or Nahan (Lower Siwalik) clays. Though no disconformity is apparent between the Subathus and the Dagshais, the former is Upper Eocene and the latter Lower Miocene in age and there is a stratigraphical gap between. The transition between the two is somewhat abrupt and is marked by pisolitic marl (a red clay containing calcareous concretions) purple shale and white sandstone with ferruginous concretions.

Kasauli beds.—The Dagshai beds pass conformably up into the Kasauli beds in which there is an absence of bright red clays. The Kasaulis are essentially a sandstone group with minor argillaceous bands, the sandstones being grey to greenish in colour and generally softer, coarser and more micaceous than the Dagshai sandstones. The argillaceous bands are gritty, greenish or brown and weather into angular splintery chips. The Kasaulis are poor in fossils, impressions of palm leaf (*Sabal major*) and *Unio* shells being found. The lithology indicates that the Dagshais are brackish water deposits and the Kasaulis fresh-water ones.

ASSAM.

The rock groups falling into the Oligocene and Miocene in Assam are the Barail and Surma series. The Barail series has already been dealt with under the Eocene system. The upper limit of the Barails is about Chattian (Upper Oligocene) where a widespread unconformity occurs throughout Assam.

Surma series.—The Surma series rests on a denuded and irregular platform of Barail rocks and includes the rocks between the Barail and Tipam series. In the Surma valley the following sub-divisions have been recognised :

Boka Bil stage (3,000-5,000 ft.)	Sandy shales, silts, sandstones and ferruginous sandstones.	Burdigalian.
Bhuban stage (4,000-8,000 ft.)	Upper : Sandstones, sandy shales and conglomerates.	Acquitanian,
	Middle : Shales and sandy shales and occasional conglomerates.	
	Lower : Sandstones, sandy shales and conglomerates.	Chattian,

The Surma series is developed in the Surma valley, North Cachar hills, Manipur and parts of Upper Assam. The rocks are mainly arenaceous but the sandstones are strikingly different from the fairly coarse, massive ferruginous and false-bedded sandstones of the overlying Tipam series. Good but not complete sections are seen in the Jenam valley. The Bhuban stage takes its name from the prominent scarp of the Bhuban range in North Cachar. The Boka Bil stage is seen as long strips of narrow ridges in the marshy ground of the Hailakandi valley and other places. The Surma series is of less thickness in Upper Assam and is absent from large areas, the Tipams overlapping them. It is poor in carbonaceous material, contrasting thus with the coal-bearing Barails below and the lignite-bearing Tipams above. Fossils are locally abundant but fragmentary, *e.g.*, near Kanchanpur, where a fauna of the upper Bhuban stage is found which is closely allied to Upper Pegu forms of Aquitanian age (Lower Gaj). In the Garo hills fossils have been obtained from a higher horizon—Burdigalian.

The Miocene fauna from the Garo Hills recently described by P. N. Mukherjee (*Pal. Ind. N. S.* XXVIII, No. 1, 1939), includes :

Lamellibranchs ..	*Nucula alcocki, Lucina pagana, Mactra protoreevesii Cardium protosubrugosum, C. minbuense, Macrocallista erycina, Dosinia subpenicillata, Clementia papyracea, Trisidos semitorta, Barbatia bataviana, Anadara craticulata, A. garoensis, Chlamys senatoria, Ostrea latimarginata.*
Gastropods ..	*Architectonica* cf. *nitens, Calyptraea rugosa, Natica pellis tigrina, Sinum protoneritoideum, Turritella angulata, Siphonalia subspadicea, Mitra chinensis, Oliva australis, Olivancillaria nebulosa, Terebra woodwardiana, Turricula promensis, Conus odengensis.*

BURMA : PEGU SERIES.

The Pegu series occupies the tract between the Irrawaddy and Sittang rivers including a large part of the

Pegu Yomas. It is also found west of the Irrawaddy between the Eocene strata and the later Irrawaddian beds. It is marine in the south but fluviatile to continental in the north, and, because of the lateral variation, the correlation of beds in different areas is not an easy matter. Table 46 shows the classification of the Pegus adopted by the Geological Survey.

TABLE 46.—THE PEGU SERIES (G. S. I.).

Akauktaung stage	Grits, conglomerates, sandstones and some shales.	Vindobonian (L. Siwalik)
Pyalo stage (1,500 ft)	.. Sandstones, shales and pebble beds containing *Ostrea latimarginata*	Burdigalian (Up. Gaj.).
Kama stage (1,500-2,000 ft).	.. Sandstones and shales with rich gastropod fauna.	Acquitanian (Lr. Gaj).
Singu stage (1,500 ft.)	.. Sandstones and shales with numerous molluscs.	Chattian (Up. Nari).
Sitsayan stage (1,500-3,000 ft.)	.. Shales and sandstones with *Lepidocyclina*.	Stampian (Lr. Nari).
Shwezetaw stage (3,000 ft.)	.. Sandstones with *Ampullina birmanica*.	Lattorfian.

The Shwezetaw stage consists of shales in Lower Burma but becomes arenaceous when followed northwards. In the Minbu district it is a shallow-water sandstone. Thin coal seams of poor quality with numerous sandy partings occur near the Yaw river. Near Shinnadaung, north of Pakokku, the sandstones contain *Ampullina birmanica*. Other fossils found are *Cardita* cf. *mutabilis*, *Ostrea* spp., *Vicarya* sp., etc.

The Sitsayan shales are well developed in the Henzada and Prome districts. They are mainly blue clays with poorly developed bedding but contain beds of marl and thin sandstones especially in the upper part. Amongst the fossils are *Tritonidea*, *Corbula*, *Pecten*, etc., while *Lepidocyclina theobaldi* occurs in the upper part.

The Padaung Clays of the Minbu district which are blue clays with some grey limestones, are their equivalents and contain *Nucula alcocki*, *Tellina indifferens*, *Genota irravadica*, *Cypræa subexcisa*, *Clavilithes seminudus*, *Hindsia pardalis*, *Athleta theobaldi*, *Lyria varicosa*.

Singu stage.—The Pegu rocks exposed in the Singu and Yenangyaung oil-fields are typical of this stage, being sandstones and shales. This stage is represented in the Minbu district by shallow marine deposits and in Pakokku by estuarine deposits. Among the fossils of this stage are :

Corals	..	*Dendrophyllia digitalis*, *D. macroriana*.
Lamellibranchs	..	*Lima protosquamosa*, *Pteria suessiana*, *Septifer nicobaricus*, *Nucula alcocki*, *Cardita scabrosa*, *Trachycardium minbuense*, *Pitar protolilacina*, *Corbula rugosa*.
Gastropods	..	*Architectonica maxima*, *Sigaratus neritoideus*, *Turritella angulata*, *Vicarya verneuili*, *Cassis*, *birmanica*, *Tritonidea martiniana*, *Athleta jacobsi*, *Mitra singuensis*, *Ancilla birmanica*, *Genota irravadica*, *Conus odengensis*.

Kama stage.—This stage is named after Kama, 18 miles from Prome and consists, in Lower Burma, of blue shales and sandy shales with occasional sandstones. It has been called the Padaukpin clay in the Thayetmyo district. It consists of soft sandstones and shales with brackish and fresh-water fauna. The fauna of the Padaukpin clays includes—*Leda virgo*, *Carbula socialis*, *Turritella acuticarinata*, *T. angulata*, *Rimella javana*, *Pyrula promensis*, *Cassidaria echinophora*, *Ranella antiqua*, *Conus odengensis*, *Drillia protocincta*.

The mammalian fossils found in this stage are :

Anthracotheridae	..	*Telmatodon* sp.
Rhinoceratidae	..	*Cadurcotherium* sp.
Tragulidae	..	*Dorcatherium birmanicum*.

Pyalo stage.—This is an arenaceous stage found in Lower Burma around Pyalo on the Irrawaddy, and characterised by the occurrence of *Ostrea latimarginata*. *Terebra promensis*, *Turritella pinfoldi* and *Terebra myaunguensis* also occur.

Akauktaung stage.—Named after the Akauktaung hills in the Henzada district, this stage comprises grits, conglomerates and yellow sandstones with bands of blue shales and calcareous sandstone. The marine fossils in this stage include *Ostrea gingensis*, *O. virleti*, *Arca burnesi*, *Cytherea erycina*, *Dione dubiosa*, *Turritella acuticarinata*, *T. simplex* and *Conus literatus*. The fresh-water representatives of these beds in Upper Burma have yielded *Cyrena petrolei* and *Batissa crawfordi*.

The geologists of the Burmah Oil Company have adopted a different classification of the Pegus in which the two lowermost divisions are the same as those in the Geological Survey classification. An unconformity and palæontological break occurs in the middle of the series, the portion below it corresponding to the Oligocene and that above to the Miocene. The classification, as published by G. W. Lepper, is shown below :

TABLE 47.—THE PEGU SERIES (B.O.C.).

MIOCENE.	*Obogon alternations* (3,000 ft.). Rapidly alternating thin beds of sands and sandy clay or clay. Often missing in the north ..	Vindbonian.
	Kyaukkok sandstones (5,000 ft.). Include the Prome sandstones and the highest Pegu sandstones of the central oilfields. Yellowish brown sandstones and subordinate sandy shales with a rich lamellibranch fauna ..	Burdigalian.
	Pyawbwe clays (3,000 ft.). Concretionary blue sandy clays and thin sandstones with gypsum. Fossils abunadnt ..	Aquitanian.
	Unconformity	
OLIGOCENE.	*Okhmintaung sandstones* (3,000 ft.). Massive sandstones, sandy shales with thin grey clays ..	Chattian.
	Padaung clays (2,500 ft.). Blue-grey clays with limestone bands ..	Stampian.
	Shwezetaw sandstone (2,000-4,000 ft.). Arenaceous in the north and argillaceous in the south ..	Lattorfian.

The Pegu strata show a great deal of variation in constitution from place to place, the marine facies of the southern areas gradually changing northwards into brackish and fresh-water facies in Upper Burma. The upper beds in the north contain fossil wood, which may be carbonaceous, calcareous, siliceous or ferruginous, but less abundant than in the overlying Irrawaddy system.

Economic Importance : Petroleum.—The Pegus contain the chief petroliferous horizons of Burma. The petroleum has apparently migrated from older beds into the anticlinal crests in the Pegu sandstones. The petroleum and gases are kept in by beds of impervious argillaceous strata capping the sands.

The most productive oil-fields of Burma are those of Upper Chindwin, Yenangyat in the Pakokku district, Singu in Myingyan, Yenangyaung in Magwe and minor fields in Mibu and Theyetmyo. The main Chindwin-Irrawaddy valley is a syncline with a monocline on the west and a series of broad folds on the east. The main oilfields are situated on the first anticline east of the main syncline. Yenangyaung is the most productive field in Burma and has maintained its high production (about 130 million gallons per year) for a long period. Singu ranks second with a production of 90 million gallons, the producing sands here being at depths of 1,400, 1,800, 3,000 and 4,500 feet depth. Lanywa is on the structural continuation of Singu. Yenangyat and Sabe are on a structure slightly to the east of the Singu one. The Indaw field in Upper Chindwin is the most northerly field now worked, while the southernmost group includes the Minbu, Yethaya and Palanyon fields.

Many seepages of oil and gas occur on the Arakan coast and the neighbouring islands. The chief fields in Assam are in the Lakhimpur district of Upper Assam (Digboi), Surma valley (Badarpur) and at Masimpur.

Numerous oil and gas seepages are known in North-western India but the structures in general are either too

Khaur and Dhulian are from dome-like structures. The deepest producing zone here is over 7,700 feet deep. The oil is believed to have originated in the Nummulitic strata and migrated into the Murrees.

IGNEOUS ACTIVITY.

The Extra-peninsular region bears evidence of considerable igneous activity, especially of the plutonic phase, in Lower Tertiary times. Several types of rocks are known but the dominant ones are granite and granodiorite. The hornblende—and tourmaline-granites of the main Himalayan range were probably intruded mainly as a result of earth movements of the first Himalayan Upheaval and some of them may belong to the second upheaval.

THE PENINSULA.

Cutch.—Two bands of Tertiary rocks occur in Cutch. The Eocene is overlain by Nari and Gaj strata comprising buff coloured limestone with interbedded variegated shales and marls. These beds are over 1,000 feet thick and dip towards the coast.

The Lower Nari contains *Nummulites intermedius* and the Upper Nari *Lepidocyclina.* The Gaj strata are rich in fossils including—*Breynia carinata, Ostrea angulata, O. gingensis; Terebra kachhensis, Pleurotoma bonneti, Drillia kachhensis, Lithoconus odengensis, Oliva australis* var. *indica, Athleta dentata, Lyria jugosa, Ranella bufo, Rimella subrimosa, Turritella angulata.*

They are overlain by the equivalents of the Siwalik system.

Kathiawar.—They are highly fossiliferous Gaj beds at the western extremity of Kathiawar, overlain by soft gypsiferous clays and sandy foraminiferal limestones which are called DWARKA BEDS. They have not been studied in detail but are supposed to represent the Hinglaj beds of Baluchistan. In eastern Kathiawar and especially in the island of Piram, there are Siwalik sandstones which have yielded mammalian fossils.

Gujarat.—In the Surat-Broach area the Eocene rocks are succeeded by gravels, conglomerates, sandy clays and calcareous and ferruginous sandstones, about 3,000-5,000 feet thick. The conglomerate contains abundant pebbles of agate and trap. The fossils found in these beds (*e.g.*, *Lepidocyclina canelli*, *Nephrolepidina sumatrensis*) indicate a Gaj age.

Ratnagiri.—On the Ratnagiri coast, south of Bombay, beds of Gaj age are exposed, overlain by laterite. The Gaj beds are bluish clays with sandy and gravely layers, sometimes with lignitic material and nodules of resin and pyrites.

Baripada beds.—At Molia near Baripada, the capital of the State of Mayurbhanj in Orissa, there are exposed yellow and yellowish brown limestones full of shells of *Ostrea* (resembling *O. gajensis*). These limestones pass upwards into thin-bedded greysih white or pale greenish clays. Similar sections are seen around Baripada under a varying thickness of laterite averaging 20 feet. A boring at Baripada traversed through 150 feet of these rocks without reaching the bottom. Several fossiliferous beds were traversed, especially one layer full of *Rotalia* at a depth of 142 feet. These beds are regared as of Miocene age (Gaj). Beds of about the same age occur near Cuttack and in the Midnapur district of Bengal.

Durgapur beds.—Railway and road cuttings near Kalipur and Khairasol east of the Raniganj coalfield in Bengal expose coarse yellow and white felspathic grits with beds of white, bluish grey and mottled clays, and thin bands of hard ferruginous grit. They occupy a large area between the Damodar and Ajai rivers but are largely covered by laterite. Lithologically these rocks resemble the Cuddalore sandstones (Miocene) of the east coast though there is a possibility of their being of Upper

Gondwana age. Similar beds occur further north near Muhammad Bazar.

Rajamahendri sandstones.—Tertiary rocks which are correlated with the Cuddalore sandstones occur near Rajamahendri. They are red and yellow sandstones, grits, and conglomerates with pockets of ironstone and earthy ochre, resting unconformably on the Deccan trap or older rocks.

Conjeevaram gravels.—A fairly large area of grits, gravels and shingles occurs between the laterite and Upper Gondwanas of the Madras region north of Conjeevaram. Their age is not known and may be anything from Miocene to Pleistocene.

Cuddalore sandstones.—Overlying the Upper Cretaceous rocks of the Trichinopoly and South Arcot districts, there are ferruginous sandstones and mottled grits extending from Pondicherry to Madura and further south. They are named after Cuddalore in South Arcot at the mouth of the Ponnaiyar river. The rocks include some argillaceous and silicified sandstones and contain lumps and veins of chert, and have a gentle seward dip. They contain algal, foraminiferal and molluscan remains (*Ostrea*, *Fusus*, *Terebra*, *Oliva*, *Conus*, etc.) and at Tiruvakkarai near Pondicherry a number of large silicified tree trunks (*Peuce schimidiana*). A few miles south of Tanjore they contain rounded pebbles of transparent quartz used locally for making beads and spectacle lenses.

Quilon and Warkalli (Varkala) Beds.—A series of current-bedded sandstones and variegated clays with thin seams of lignite form the coastal fringe from Quilon to Warkalli (Varkala). They are capped by laterite and are thought to be of the same age as the Cuddalore sandstones (Miocene).

At Padappakkara near Quilon, some beds consisting of limestones, sands and clays have been met with in wells at a depth of a few feet. The limestone is seen in a cliff near the coast and also at depths up to 40 feet, in the neighbourhood of Quilon. The limestone beds contain corals and molluscus and are often full of the foraminifera *Orbiculina malabarica*. Some of the fossils in them are:

Corals	.	*Stylopora pulcherrima*, *Leptocyathus* cf. *epithecata*.
Lamellibranchs	..	*Parallelopipedum prototortuosum*, *Arca theobaldi*, *Nucula cancellata*, *Pectunculus sindiensis*
Gastropods	.	*Strombus fortisi*, *Conus catenulatus*, *C. hanza*, *Rimella subrimosa*, *Voluta jugosa*.

The fauna is essentially upper Miocene to Pontain and bears some resemblance to the Gaj and Karikal faunas. Since the Karikal beds are assigned a Pliocene age they are described in the next chapter.

Ceylon.—Upper Miocene to Pontian rocks occur along the north-western coastal strip of Ceylon and are known as the Kudremalai and Jaffna series. They comprise limestones and mottled sandy shales. The limestones have yielded several foraminifera and mollusca (E.J. Wayland and A.M. Davies *Q.J.G.S.*, LXXIX, p.577-602, 1923) which point to a Tortonian-Pontian age. The beds are correlated with the Quilon beds and are regarded as older than the Karikal beds. Amongst the fossils of these beds are:

Foraminifera	..	*Orbiculina malabarica*, *Operculina* sp. *Flosculinella* sp. *Miliolidae* (several).
Echinoderms	..	*Clypeaster depressus*, *Schizaster* sp.
Lamellibranchs	..	*Arca peethensis*, *Avicula* cf. *suessiana*, *Spondylus rouaulti*, *Pinna pachyostraca*, *Cardium sharpei*, *Cardita intermedia*, *Ostreat virleti*.
Gastropods	..	*Trochus cognatus*, *Phasianella oweni*, *Natica rostalina*, *Cerithium* cf. *rude*, *Ovula ellipsoides*, *Oliva pupa*, *Conus brevis*.

CHAPTER XIX.

MIDDLE MIOCENE TO LOWER PLEISTOCENE.

NORTH-WESTERN INDIA : THE SIWALIK SYSTEM.

Introduction.—The close of the Murree period coincided with the main period of Himalayan orogeny. There were already the remnants or an arm of the sea in front of the ranges and this extended as an almost continuous narrow basin in the areas now occupied by the Himalayan foothills over the whole length of the Himalaya. This depression (the 'fore deep') was the site of the deposition of the Siwalik strata commencing with the Middle Miocene and extending through Pliocene to Lower Pleistocene. The sediments bear the characters of deposition in fresh water and their immense aggregate thickness (over 16,000 feet) indicates that the site of deposition kept sinking as the sediments accumulated. This was probably aided by the tangential compression of the crust which should have been active at least intermittently, during the period of sedimentation.

Distribution.—The Siwalik system takes its name from the Siwalik hills of the Hardwar region between the Ganges and Jumna rivers. It extends continuously along the foot of the Himalaya from the Brahmaputra valley on the east to the Potwar plateau and the Bannu plains on the west. Its equivalents intervene between the Indus plains and the early Tertiaries of the Sind-Baluchistan hills. The re-entrant angle near Quetta exhibits a complete development of these rocks, the Zarghun mountain mass in this region forming a synclinal of these rocks. Similarly, in the Burmese, arc, we see their equivalents on both sides of the Arakan Yomas, both in Assam and in Burma.

The rock groups have received different names in the different areas. They form the Siwalik system along the outer Himalayas; the Manchhar system in Sind; the Mekran series in the Mekran region of Baluchistan; the Dihing series in Assam and the Irrawaddy system in Burma.

Constitution.—The Siwalik system is made up of sandstones, grits, conglomerates, pseudo-conglomerates, clays and silts having the characters of fluviatile deposits of torrential streams and floods in shallow fresh-water basins. The fossils included in them show that the earlier beds were deposited in a somewhat brackish environment as compared with the later ones. Some of the latest deposits may be continental, *i.e.*, left on dry land by temporary heavy floods. There is a considerable amount of ferruginated matter, especially in some of the older horizons, which indicates that the sediments were derived partly from an old and well oxidised terrain. Coarser and finer sediments alternate. The sandstones show poor stratification and are generally ungraded as to grain size. They are felspathic, micaceous and current-bedded and some of them have clearly been derived from the breakdown of the central Himalayan granites.

The Siwaliks have been involved in the later phases of Himalayan orogeny, for we find them often folded, faulted, overthrust and lying at steep angles against other formations. Where overthrust, there is often an inversion of the normal order of superposition. The main overthrust in which the Siwaliks are involved used to be called the 'Main boundary Fault' but recent work has shown that there are at least three major thrusts in the Himalaya in addition to less important local ones. These thrusts may, in some instances, mark the limits of deposition of the older series involved, but there has been so much movement that even within the Siwaliks the older strata are found thrust over younger ones and lying with very abnormal dispositions.

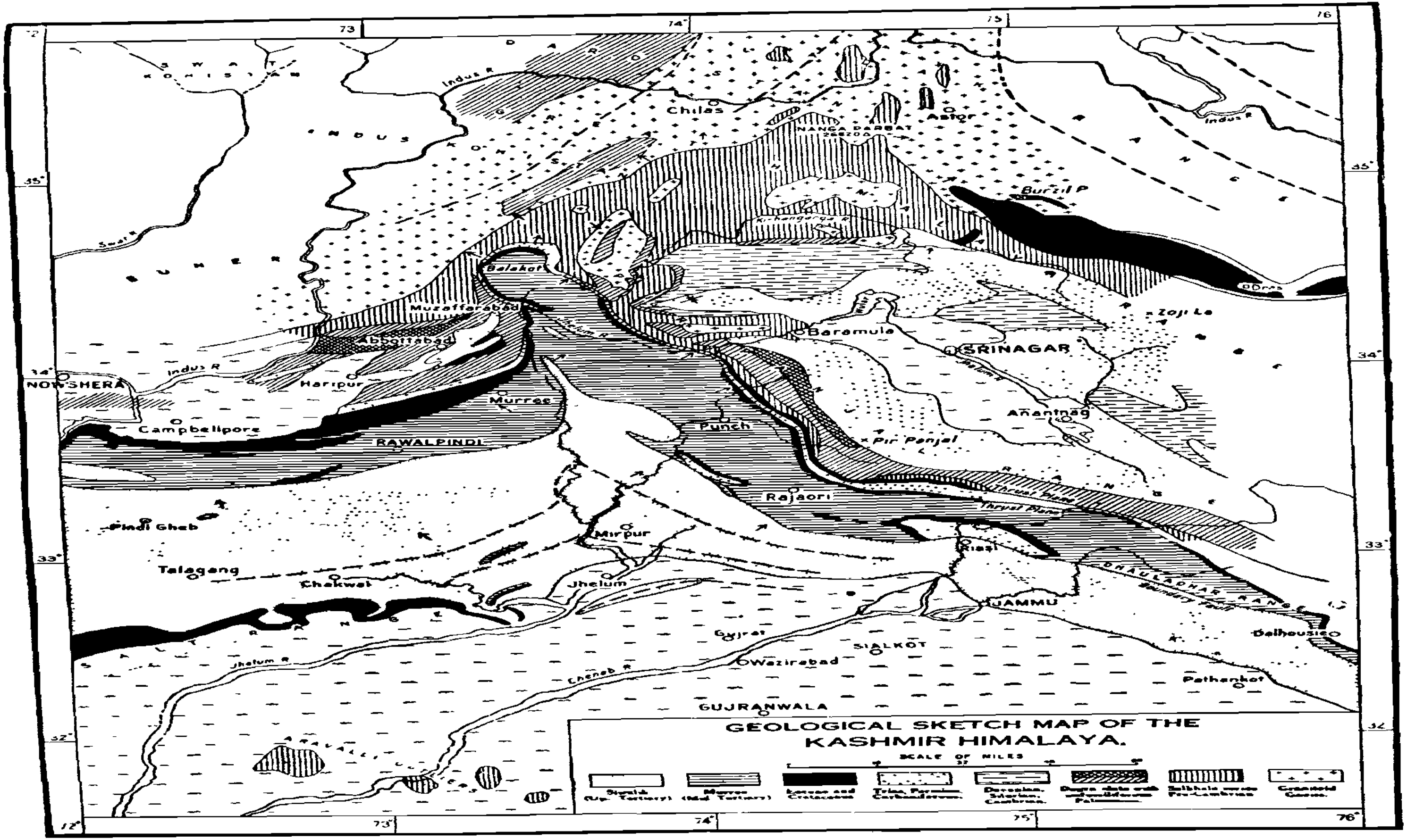
Conditions of deposition.—The coarse and often ungraded sandstones show that they must have been borne by rapidly flowing and large masses of water and laid down in wide depressions of shallow water or in swampy areas. The alternation of coarse and fine sediments suggests seasonal deposition, the coarse materials during floods of the wet season and the fine sediments during the drier season. The extraordinary similarity of the deposits over long distances along the strike would show that the source rocks were similar and that the basin of deposition was practically continuous. The large thickness of the coarse materials makes us infer that the area of deposition was sinking in pace with the sedimentation. At the same time there was a gradual southward shift of the basin with each fresh pulse of the uplift. It is almost certain that the Siwaliks extend down for several miles underneath the alluvial cover of the Indus and Ganges valleys.

The occurrence of this important strip of fluviatile rocks all along the foot-hill regions of the Himalaya from Assam to Punjab and thence to Sind has led to the view, advocated by Sir E.H. Pascoe and Dr. G.E. Pilgrim, that the Siwaliks were laid down in the flood plains of a single large river (the Indobrahm or Siwalik River) which rose in Assam and followed the present line of distribution of these deposits. The present author and N. K. N. Aiyengar have discussed this question (*Rec.* 75, Paper No. 6, 1940) and shown that the available evidence points to the basin of deposition being a continuous lagoon or foredeep formed in front of the Himalayan range.

Climatic conditions.—The Siwalik deposits give evidence of a warm humid climate through the greater part of the period of sedimentation. The coarse materials, which are often fresh, may have been derived from the north and the finer ferruginous clays from the ancient Peninsular area to the south, the one contributing material during the wet flood season and the other during the dry season. Some chemical decay may have also taken place under the swampy conditions in which the sediments were laid down. The earlier Siwalik period—that of the Lower Siwaliks and the lower part of the Middle Siwaliks—was apparently a wet period, or alternatively, the sediments were deposited in shallow water. In Dhok Pathan times there is evidence that the humidity was less and that the sedimentation took place in partly marshy and partly dry land. The disturbance at the end of the Middle Siwalik times raised the deposits into dry land and shifted the basin southwards. The Upper Siwaliks again show the return of wetter conditions. Towards the end of Tatrot times another uplift took place and the climate became distinctly cooler. The animals which lived in the marshes and valleys migrated away or died, as the subsequent deposits were of semi-glacial character.

Organic remains.—The great bulk of the Siwalik formations is unfossiliferous but certain areas are rich in fossils. These include plants, mollusca, fishes, reptiles and mammals. The plant remains consist of leaf impressions in clays and tree trunks in sandstones. The tree trunks are silicified but in most cases the finer woody structures are not preserved. The mammalian remains are the most important fossils as they are of great help in dividing the formations into stages and as they indicate the stages of development through which the animals passed before they disappeared from the scene of life. The present day mammals in India are but the poor remanants of the rich variety that lived formerly in the swamps and forests of the Siwalik basin. The relics consist of hard, bony parts, skulls, jaws and teeth. Their abundance testifies to the very favourable conditions of claimate and hydrology, abundance of food and suitable environment for entombment of the remains.

The detailed study of the mammalian remains in many countries has thrown much light on the origin, evolution and migration of the animals. Some groups like the pigs, hippopotamus and ancestral elephants are believed to have originated in Africa and later migrated into Asia. The horse is supposed to have come from North America through Alaska and a land bridge across the Behring straits. It is


GEOLOGICAL SKETCH MAP OF THE
KASHMIR HIMALAYA.
SCALE OF MILES
Chilas
Astor
NANGA PARBAT
Burzil P
Indus R
INDUS
Swat R
Balakot
Muzaffarabad
Abbottabad
Haripur
NOWSHERA
Campbellpore
Murree
RAWALPINDI
Baramula
SRINAGAR
Zoji La
Anantnag
Punch
Pir Panjal
Rajaori
Thrust Plane
Mirpur
Riasi
Pindi Gheb
Talagang
Chakwal
Jhelum
JAMMU
DHAULADHAR RANGE
Boundary Fault
Dalhousie
Gujrat
SIALKOT
Wazirabad
Jhelum R
Chenab R
Pathankot
GUJRANWALA
73
74°
75
76
35°
34°
33°
32°

an interesting fact that the horse became extinct in N. America by the Pleistocene and was reintroduced there by man from Europe.

Divisions.—The Siwalik system is divided into three series, Lower, Middle and Upper. There is a definite, though not always well-marked, break between the middle and upper series and other local breaks are known. The lithological characters are not always helpful because of the repetition of the same deposits, but palæontological characters constitute the chief criteria for classification. The chief sub-divisions and stages are given in Table 48 together with their lithology and age.

TABLE 48.—SIWALIK SUCCESSION (N. W. INDIA).

(AFTER G. E. PILGRIM).

Upper Siwalik (6,000-8,000 ft.)	*Boulder Conglomerate.* Coarse conglomerates, sands, grits and some clays.	L. Pleistocene (Cromerian).
	Pinjor stage. Coarse grits, sandstones and conglomerates.	Villifranchian.
	Tatrot stage. Soft sandstones, drab clays and some conglomerates.	Astian.
Middle Siwalik (6,000-8,000 ft.)	*Dhok Pathan stage.* Brown sandstones, gravel beds, orange clays and drab shales.	Pontian.
	Nagri stage. Hard grey sandstones and subordinate shales.	Sarmatian.
Lower Siwalik (5,000 ft.)	*Chinji stage.* Bright red shales and sandstones.	Up. Tortonian.
	Kamlial stage. Hard red sandstones, purple shales and Pseudo-conglomerates.	L. Tortonian.

Kamlial stage.—This is named after Kamlial (33°15′ 72°30′) near Khaur and consists of hard red sandstones with clay nodules (pseudo-conglomerates) and purple shales, the sandstones forming conspicuous strike-ridges. The Kamlials of the Jammu area are not easily separable from the Murrees, especially as they are also poorly fossiliferous. The chief mammalian remains are :

(Carnivora) *Amphicyon* and *Hyaenelurus*; (Proboscidea) *Dinotherium*, *Trilophodon*; (Suidæ) *Palaeochoerus* and *Listriodon*. The earlier Proboscidea like *Moeritherium* and *Hemimastodon* as well as the Rhinoceratids like *Diceratherium*, *Teleoceras*, *Baluchitherium* and *Aceratherium*, and Griffids like *Progiraffa* which were present in an earlier age had disappeared.

Chinji stage.—Taking its name from Chinji (32°41′: 72°22′), this stage shows alternating soft light grey sandstones and red shales. The sandstones are rather subordinate in the Potwar area but are predominant in the Jammu hills where they are not easily distinguished from the Kamlials. This stage is 3,000 feet thick and of longer duration than the previous one and contains a large number of animal remains and also fossil wood. The mammals include:

(Primates) *Dryopithecus*, *Sivapithecus*, *Bramapithecus*, (Carnivora) *Dissopsalis*, *Amphicyon*, *Martes*, *Eomellivora* *Sivalictis*, *Lycyaena*, *Sansanosmilus*, *Vishnufelis*; (Proboscidea) *Dinotherum*, *Trilophodon*, *Serridentinus*, *Synconolophus*, *Anancus*, *Stegolophodon*; (Equidæ) *Hipparion*; (Chalicotheridæ) *Macrotherium*; (Rhinoceratidæ) *Gaindatherium*, *Aceratherium*; (Suidæ) *Conohyus*, *Listriodon*, *Propotamochoerus*, *Dicoryphochoerus*, *Santherium*; (Anthracotheridae) *Hyoboops*, *Hemimeryx*, *Telmatodon*, (Tragulidæ) *Dorcabune*, *Dorcatherium*; (Giraffidæ) *Giraffokeryx*, *Propalaeomeryx*, *Giraffa*.

Of these, *Macrotherium*, *Hipparion* and *Gaindatherium* are supposed to have migrated into India from America. Numerous reptiles like crocodiles, turtles, pythons and lizards are found in these rocks as also shells of *Unio*. In the Hardwar area the Lower Siwaliks have been called *Nahan beds* and they correspond mainly to the Chinji stage.

Nagri stage.—This stage (after Nagri, 32°46′; 72°21′ in the Attock district) consists of hard grey sandstones with a small proportion of shales and clays. It is poorly fossiliferous, many of the animals of the previous stage having apparently disappeared. Several Primates—*Bramapithecus*, *Sivapithecus*, and *Sugrivapithecus* are present. Among the Carnivores, *Amphicyon* and *Sivanasua* persist and *Crocuta* appears. No Proboscidea have been found. *Hipparion, Gaindatherium* and *Aceratherium* continue. Several of the pig family are found such as *Palaeochoerus Conohyus, Listriodon, Lophochoerus, Propotamochoerus, Dicoryphochoerus, Hippohyus* and *Sus*. *Hemimeryx* (Anthracotheroid), *Dorcabune, Dorcatherium* (Tragulid) and *Giraffokeryx* have also been found.

Dhok Pathan stage.—This is named after Dhok Pathan (33°8′ : 72°21′) on the Soan river and comprises brown sandstones drab shales, orange clays and some beds of gravel. It is the richest fossiliferous stage of the Siwaliks and has yielded a large number of fossils amongst which are :

(Primates) *Macacus, Sivapithecus* , (Rodentia) *Rhizomys* and *Hystrix* ; (Ursidæ) *Agriotherium, Indarctos* ; (Mustelidæ) *Promellivora, Enhydriodon, Sivaonyx* ; (Hyaenidæ) *Ictitherium, Lycyaena, Crocuta* , (Felidæ) *Aleuropsis, Mellivorodon, Paramachoerodus, Felis*, (Proboscidea) *Dinotherium, Trilophodon, Tetralophodon* , *Synconolophus* , *Stegolophodon* , *Stegodon* ; (Equidæ) *Hipparion* ; (Rhinoceratidæ) *Aceratherium, Rhinoceros* ; (Suidæ) *Listriodon, Tetraconodon, Propotamochoerus, Dicoryphochoerus, Hyosus, Hippohyus, Sus* , (Anthracotheridæ) *Choeromeryx, Merycopotamus*, (Hippopotamidæ) *Hippopotamus* ; (Tragulidæ) *Dorcabune, Dorcatherium, Tragulus* , (Cervidae) *Cervus* ; (Giraffidæ) *Hydaspitherium, Vishnutherium, Bramatherium, Giraffa* ; (Bovidæ) *Taurotragus, Perimia, Tragocerus, Boselaphus, Proleptobos*.

Several of the giraffe family and the short-jawed proboscidean *Synconolophus* are confined to this stage while the *Bovidæ* first make their appearance here.

Tatrot stage.—This stage, named after Tatrot (32° 52′ : 73°21′) is made up of conglomerates, soft sandstones and drab and brown clays. At its base is a conglomerate indicating a phycisal break. The sediments are distinctly coarser than before, possibly on account of an uplift of the area from which they were derived and higher gradients. The animal remains in this are represented by *Pentalophodon* and *Stegodon*. A true (one-toed) horse, *Equus sivalensis*, the pigs *Hippohyus* and *Sus* and also *Hippopotamus* have been found in this stage.

Pinjor stage.—This stage (named after Pinjor near Kalka in the Simla foot-hills) shows distinctly coarse sediments composed of pebble beds and sandstones. It contains a rich fauna which can be regarded as the immediate ancestors of the present-day animals :

(Primates) *Papio, Semnopithecus, Simia* ; (Rodentia) *Rhizomys, Nesokia, Hystrix* ; (Carnivora) *Canis, Agriotherium, Simictis, Mellivora, Lutra, Enhydriodon, Viverra, Hyaenictis, Crocuta, Megantereon, Panthera,)Felis;* Proboscidea) *Pentalophodon, Stegodon, Stegolophodon, Archidiskodon, Hypselephas* ; (Equidæ) *Equus* ; (Rhinoceratidæ) *Rhinoceros, Coelodonta*; (Suidæ) *Tetraconodon, Potamochoerus, Dicoryphochoerus, Hippohyus, Sus* ; (Anthracotheridae) *Mericopotomus* ; *Hippopotamus, Camelus* and *Cervus* ; (Giraffidæ) *Sivatherium, Camelopardalis, Giraffa* ; (Bovidæ) several including *Cobus, Capra, Leptobos, Bubalus, Bos* and *Bison.*

Boulder conglomerate.—This is the topmost stage characterised by very coarse conglomerates and mixtures of boulders, pebbles and fine material. The Pleistocene glaciation had already set in and the Himalayan glaciers seem to have descended almost down to the plains, making the whole region unsuitable for the existence of highly developed mammalian life. Some remains of Bovids are found in the sediments of this age.

With the onset of the glacial conditions the fauna suffered heavily, but some species were able to migrate to warmer regions. The giraffes are, at the present day, found only in Africa. Though many species of the elephant family lived during the Siwalik times, all that is left of them at the present day is the Indian elephant and the African elephant.

Correlation.—Since the Siwaliks are fresh-water (and partly land) deposits, the determination of the age of the stages is a matter of some uncertainty. It is definitely established that the Middle Siwaliks are closely allied to the Pikermi beds of Greece where they are associated with marine Pontian strata.

In Table 49 is given the correlation adopted by G.E. Pilgrim of the Geological Survey of India compared with that of E. H. Colbert and G. E. Lewis. It will be noticed that the ages assigned to the divisions by the American authorities are younger than those adopted by Pilgrim. This is perhaps attributable partly to the hypothesis that the *Hipparion* (primitive horse) migrated to India from N. America.

TABLE 49.—CORRELATION OF THE SIWALIK STRATA.

Divisions.		Pilgrim 1934-40	Colbert 1935.	Lewis 1937	Europe.	North America.
PLEISTOCENE	Upper					
	Middle			Tawi		
	Lower	Boulder cgl	Boulder cgl Pinjor	Break Tatrot	Cromerian	Rock creek Sheridan
PLIOCENE.	Upper	Pinjor	Tatrot Dhok Pathan	Break	Villeferan-chain	San Pedro
	Middle	Tatrot	Nagri	Dhok Pathan	Astian	Blanco GoodNight
	Lower	Dhok Pathan	Chinji	Nagri	Pontian	Republican River. Valentine
MIOCENE	Upper	Nagri	Kamlial	Chinji	Sarmatian	Barstow
	Middle	Chinji Kamlial		Kamlial	Tortonian Helvetian	
	Lower				Burdigalian Aquitanian	

SIND : MANCHHAR SERIES.

The highest formations of the Tertiary group in Sind are called the Manchhar series, after the Manchhar Lake. They resemble the Siwaliks to a large extent.

Lower Manchhar.—The Manchhar series attains a thickness of 10,000 feet and comprises two divisions. The Lower Manchhars are composed of grey sandstones associated with red sandstones and conglomerates. The conglomerates contain pebbles of sandstone and nodules of clay. The lowest horizon has yielded vertebrate fossils which indicate a Helvetian zone, *i.e.*, lower than that of the Lower Siwaliks.

Upper Manchhar.—The upper division is well exposed near Larkhana and consists of conglomerates, sandstones and orange and brown clays. It contains pebbles of Gaj and Nummulitic limestones.

The Manchhars of the Kirthar range appear to follow conformably on the older (Gaj) rocks whereas those to the east of the Laki range lie unconformably on Kirthar beds. They are mainly fluviatile, but as we follow them southwards they become gradually estuarine and marine. Vredenburg divides the Manchhars into three portions which are respectively Vindobonian, Pontian and Pliocene in age.

MEKRAN, BALUCHISTAN.

The Upper Tertiary rocks developed in the Mekran region are called the Mekran series and comprise thick pale grey clays with thin intercalations of shelly limestone and sandstone. Vredenburg has divided them into a lower TALAR STAGE of Middle Siwalik age and an upper GWADAR STAGE of Upper Siwalik age. The Mekran series contains a fairly rich marine fauna which bears a great resemblance to that of Odeng stage (=Talar) and Sonde stage (=Gwader) of Java. It is inferred that the Indian seas were completely cut off from the European seas during Mekran times as there is not much resemblance to the European marine fauna. Many of the Mekran species are found in the Karikal beds. The molluscan fauna of the Mekran series includes the following :

Gastropods .. *Surcula tuberculata*, *Terebra aspera*, *Pleurotoma haydeni*, *Drilla mekranica*, *Lithoconus djarianensis*, *Clavailithes verbeeki*, *Melongena ponderosa*, *Purpura angulata*, *Cassidia mekranica*, *Dolium* sp., Terebralia mekranica, Natica globosa, Rimella javana.

Lamellibranchs .. *Corbula mekranica, Dosinia pseudoargus, Cardium unicolor, Arca newtoni, Pectunculus gwadarensis, Ostrea pseudodigitalina, O. virleti, O. frondosa, O Crenulifera, Pecten vasseli.*

CUTCH AND KATHIAWAR.

Overlying the Gaj beds of Cutch there is a large thickness of sandstones and clays which are correlated with the Manchhar strata.

In the Piram Island of the eastern coast of Kathiawar there are Siwalik rocks which have yielded mammalian fossils. These indicated a Middle Siwalik age.

MADRAS.

Karikal beds.—Richly fossiliferous upper Tertiary beds have been found at a depth of 350 feet at Karikal on the Tanjore coast. The rich fauna, which has been described by Cossmann (*Jour. de Conchyliologie*, XLVIII, p. 14, 1900; LI, p. 105, 1903; LVIII, p. 34, 1910) consists entirely of gastropods including the following:

Actaeon (Solidula) solidulus, A. bonneti, Terebra (Myurella) martesi, T. (M.) cancellata, Hemipleurotoma bonneti, Surcula javana, Drillia karikalensis, D. sinensis, Conus (Dendroconus) figulinus, C. (Lithoconus) literatus, C. (Leptoconus) karikalensis, Cancellaria verbeeki, Oliva cheribonensis, Agaronia acuminata, Ancilla cinnamomea, Marginella bonneti, Mitra (Cancella) flammea, Fusus perplexus, Turbinellarapa, Nassa ovum, N. (Hinia) karikalensis, Murex bonneti, Renella margaritula, Hindsia tjemoraensis, Strombus karikalensis, Rostellaria fusus, Rimella cancellata, Cerithidea trifunata, Turritella djadjariensis, Architectonica maxima, Crepidula cf. *walshi, Natica rostalina, N. globosa, Solariella ambligoniata.*

The assemblage is distinctly Pliocene (post-Pontian) and somewhat younger than the fauna of the Quilon and Jaffna beds. According to Vredenburg, the Karikal beds are the equivalents of the Mekran series and especially its upper (Gwadar) stage. It would appear therefore that there is probably a complete upper Tertiary sequence underneath the Cauvery alluvium in the Tanjore district.

ASSAM.

The Siwalik system is represented in Assam by the Tipam and Dihing series.

The Tipam series extends over a large area from the Arakan coast to the Surma valley and in North Cachar and Upper Assam. It is dominantly arenaceous and in several places shows lignite ' pebbles ' and silicified and carbonised fossil wood. It is divided into three stages, as shown below:

Tipam series (9,000-14,000 ft.)	*Num Rong Khu stage.* Lignitic conglomerates, grits & clays (=Dupi Tila stage of Surma valley, comprising ferruginous sandstones with pebble beds) *Girujan clays.* Mottled clays and subordinate sandstones with fossil wood and lignite.	Vindobonian.
	Tipam sandstones Coarse gritty sandstones, blue to green coloured, and weathering brown ; with some conglomerates and shale partings ; occasional fossil-wood and lignite.	Burdigalian.

Dihing series.—The Tipam series is succeeded by a great thickness of pebble beds with thick intercalations of clay and sand, called the Dihing series. At its base there is an unconformity and the beds overlap the older formations. This series is seen in the Dihing valley, frontier tracts, Naga Hills and Sylhet district. Its age is probably Pontian or younger, corresponding mainly to the Upper Siwaliks.

BURMA : THE IRRAWADDY SYSTEM.

Overlying the Pegu series, generally with an unconformity, is a series of fluviatile sandstones of large thickness originally called the *Fossil-wood Group* by Theobold, because of its abundant content of fossil-wood. This name has now been replaced by the term Irrawaddy system, since the sediments lie in the valley of the Irrawaddy river.

Distribution.—The Irrawaddy system is extensively distributed along the central north-to-south tract of Burma. It is found in the north in Katha, Upper Chindwin, and Myitkyina, and extends as far south as Rangoon. Parts of the area are covered by Pleistocene and younger alluvia but it is likely that the Irrawaddy rocks extend under all the alluvium of the delta.

Lithology.—The lower beds often contain ferruginous conglomerates indicative of a period of subaerial weathering. The main formations are sandstones, often current-bedded, with pebbles, boulders and numerous ferruginous concretions. The concretions consist of hæmatite and limonite with some manganese oxide. Calcareous sandstones and calcareous and siliceous concretions are also met with. Fossil wood occurs profusely in certain areas, often well silicified. The rocks weather into fantastic shapes with the formation of intricate gullies and 'bad lands.' The total thickness of the system is of the order of 10,000 feet.

Fossils.—The Irrawaddians contain a fairly rich variety of vertebrate fossils, mainly, mammalian, but including also crocodiles, tortoises, etc. Both monocotyledonous and dicotyledonous fossil woods are found, the latter including *Dipterocarpoxylon burmense*. The chief vertebrate fossils are :

Lower Irrawaddy beds.—

(Equidæ) *Hipparion antilopinum* ; (Rhinoceratidæ) *Aceratherium lydekkeri* ; (Suidæ) *Tetraconodon minor* ; (Giraffidæ) *Hydaspitherium birmanicum*, *Vishnutherium iravaticum* ; (Bovidæ) *Pachyportax latidens*, *Proleptobos birmanicus*.

Upper Irrawaddy beds.—

(Proboscidea) *Stegolophondon latidens*, *Stegodon elephantoides*, *Stegodon insignis birmanicus*, *Hypselephas hysudricus* ; *Elephas planifrons* (Rhinoceratidæ) *Rhinoceros sivalensis* ; (Anthracotheridae) *Merycopotamus dissimilis*, (Hippopotamidæ) *Hexaprotodon iravaticus*, *H.* cf *sivalensis* ; (Bovidæ) *Leptobos*, *Bubalus*

The Irrawaddy system is the equivalent mainly of the middle and upper Siwaliks. The lower fossiliferous beds are correlated with the Dhok Pathan stage (Pontian) and the upper fossiliferous beds, which are separated from the lower by 4,000 feet of strata, are of Pinjor age.

SELECTED BIBLIOGRAPHY

Falconer and Cautley. Fauna antiqua sivalensis. London, 1846.

Lydekker, R. Indian Tertiary and post-Tertiary verbetrata. *Pal. Ind. Ser. X*, Vols. I to IV, 1874-1887.

Pilgrim, G E. Teritiary and post-Tertiary fresh water deposits of Baluchistan and Sind. *Rec. 37*, 139-166, 1908.

Pilgrim, G.E The fossil giraffidæ of India. *Pal Ind. N.S.* IV, (1), 1911.

Pilgrim, G.E Revised classification of the Tertiary fresh water deposits of India. *Rec. 40*, 185-205, 1910.

Pilgrim, G.E. Correlation of the Siwaliks with the mammal horizons of Europe. *Rec. 43*, 262-326, 1913.

Pilgrim, G.E. New Siwalik primates, *Rec 45*, 1-74, 1915.

Pilgrim, G.E. The fossil suidæ of India. *Pal. Ind N.S.* VIII (4), 1926.

Pilgrim, G.E. The fossil carnivora of India. *Pal. Ind N.S.* XVIII, 1932.

Pilgrim, G E. The fossil bovidæ of India. *Pal. Ind. N.S.* XXVI, 1939.

Wadia, D.N. and Aiyengar, N.K.N. Fossil anthropoids of India. *Rec. 72*, 467-494, 1938.

CHAPTER XX.

THE PLEISTOCENE SYSTEM.

Pleistocene Ice Age.—The Quaternary era was heralded by the general lowering of temperature, in all the Northern Hemisphere, resulting in the formation of ice sheets which extended southward from the Arctic regions. The temperate north latitudes of the present day experienced a frigid climate and evidences of the advance and retreat of glaciers have been well established in parts of Europe and N. America. The fauna of the period was thereby very adversely affected, a large number of species suffering extinction.

Being much nearer to the equator, India shows less distinct evidences of glaciation than northern Europe. The country must have experienced a generally cooler climate than at present, and it is possible that there are evidences of glaciation concealed under the later alluvia. The Himalayas were for the most part covered by glaciers which probably descended down to very low levels. Evidences of extensive glaciation such as moraines, facetted boulders, grooved rock surfaces, etc., are found in many parts of Kashmir, Garhwal and other regions. The glaciers descended to as low an altitude as 5,000 feet or lower. The morains left by the glaciers have formed obstructions to drainage and given rise to lakes around which the evidences of glaciation could be studied.

Dr. H. De Terra has recorded the evidences of several advances and retreats of the glaciers in Kashmir. The first glaciation is the most marked, the later ones becoming gradually less and less distinct. Man had already appeared in Kashmir in the second period of ice advance which De Terra correlates with the Boulder Conglomerate stage of the Siwaliks and the Chello-Acheulian of Europe.

As evidence of the mildness of climate in the Peninsula, W. T. Blanford cites the spread of certain plants and animals from the Himalaya southward. The remnants of these—such as some species of rhododendron and some mammals including one or two species of goat—are now isolated in the higher altitudes of the mountains of South India, Bihar and Assam, none of these being found in the plains or lower altitudes of the intervening country.

Bain Boulderbed.—Associated with the Siwaliks of the Marwat Kundi and Shekh Budin hills in the Trans-Indus continuation of the Salt Range there is a boulder-bed about 70 feet thick (the Bain boulder-bed) intercalated with the Marwat formation. The boulder-bed is of glacial origin and the associated formation contains a fauna which is of Villefranchian to Lower Pleistocene age according to T. O. Morris (*Q.J.G.S.* XCIV, p. 385, 1938).

Eratics of the Potwar Plateau.—There are several localities in the Attock district where large blocks of rock are found amidst boulders, gravel and finer sedimentaries. Several of these occur near Nurpur Kamalia, a few miles from Campbellpur, one being a granite block of 50 feet girth and another a basalt block with a girth of 48 feet. Some of the blocks show grooved surfaces. They now lie amidst alluvial country, there being, for miles around, no rock outcrops from which they could have been derived.

These ' erratic ' blocks seem to have come from the Himalaya, transported through the agency of ice. It is believed that large bodies of water were frozen up behind barriers of rock and moraine which obstructed river valleys during the glacial times, the barriers giving way suddenly when the ice partly thawed. The glacial floods which spread out would have brought with them unassorted material including large sized boulders. There are many records of severe floods of the Indus during historic times owing to its valley being dammed up by rock debris.

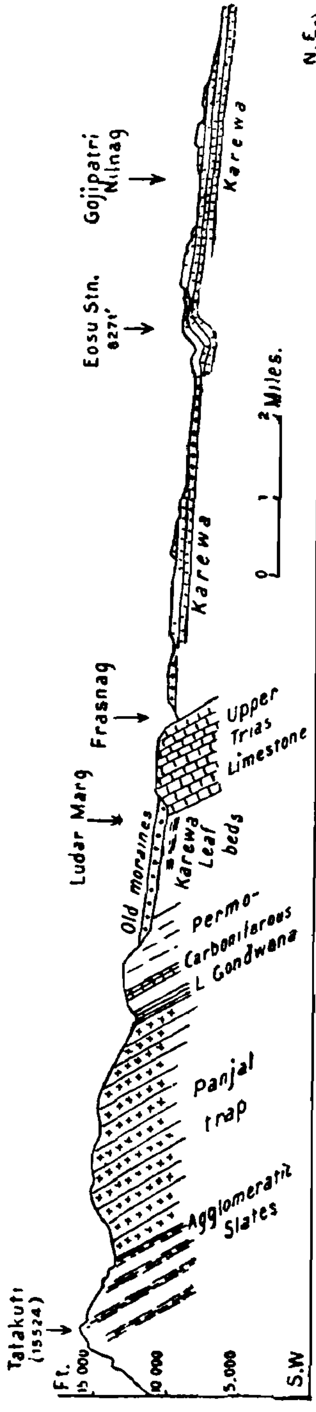


FIG. 13.—SECTION ACROSS THE PIR PANJAL FROM TATAKUTI TO NILNAG. (*After* C. S. MIDDLEMISS, *Rec.* 41.)

Similar floods, but glacial in character, could therefore have taken place during the Pleistocene times.

THE KAREWA FORMATION.

The Kashmiri name *Karewa* is applied to the fairly flat terraces or platforms which cover a good part of the Jhelum valley in Kashmir. Sections of this can be seen between Srinagar and Gulmarg, especially on both sides of the Ferozpur nala and on the northeastern slopes of the Pir Panjal range. The deposits consist of sands, clays, loams, gravel and boulder beds, the finer deposits sometime showing very fine lamination of the nature of glacial *varves* deposited alternately in winter and summer.

The Karewas are found over the greater part of the Kashmir valley extending for a length of 50 miles in a N.W.-S.E. direction and occupying 3,000 square miles. They attain a thickness of some 5,000 feet on the northern flanks of the Pir Panjal. The lower beds are more or less of a sandy constitution, while the upper ones are much coarser and contain boulders and gravels and also layers of lignitic coal which occur in workable quantities in two or three places. They are practically horizontal and undisturbed over by far the greater part of the area in the valley. Where they abut on the Pir Panjal they show sharp flexures and are tilted up at angles up to 40°. The highest altitude to which they reach is about 11,500 feet, *i.e.*, 5,500 feet above the general level of the Kashmir valley.

The Karewas were originally regarded as of lacustrine origin, but recent work shows that this might hold for the upper beds while the lower beds are more likely to be of fluviatile origin. They include also interbedded glacial strata and several definite glacial episodes can be made out. According to De. Terra, the Karewa lake in which the Upper Karewas were deposited occupied at least 2,000 square miles of the Kashmir valley between the main Himalayan ranges on the north and a low ridge on the south which latter has since been elevated as the Pir Panjal. The Karewas always dip towards the valley, the dip decreasing as one follows the bed down from the hill towards the valley. The uplift of the Pir Panjal is of post-Karewa age. The last stage of the uplift, which must have been of the order of 6,000 feet, is believed to have occurred since the advent of early man. This upheaval has not only elevated the Pir Panjal and folded and tilted the Karewas, but has also affected the rocks of the Potwar and the Salt Range.

The Lower Karewas contain a large number of well-preserved plant remains among which are pine, oak, birch, beech, alder, willow, poplar, rose, rhododendron, holly and cinnamon, indicating a cold temperate climate. There are also some types of aquatic plants such as *Trapa*, *Vallisneria* and *Charophyta*. Amongst the animal remains are fresh-water shells, fishes and mammalia—*Equus*, *Elephas namadicus*, *Bos*, *Sivatherium*, *Rhincoerso*, *Cervus*, *Sus*, *Felis*. These indicate a correlation with the Pinjor stage of the of Upper Siwaliks.

Traces of Palæolithic stone culture exist in the Potwar, Kashmir and in Little Tibet beyond the Kashmir Himalaya. De Terra states that there were at least five advances of glaciation in northwestern India, the second advance being contemporaneous with the deposition of the Boulder Conglomerate which is, according to him, of Middle Pleistocene age.

There is clear and indisputable evidence according to archaeologists that Baluchistan was enjoying a wet climate even in Chalcolithic times, about 3,000 B.C., and that desiccation set in between then and 300 B.C.

Potwar silt.—About the Boulder conglomerate zone of the Siwaliks there are some deposits to which the name Potwar silt has been given. It consists of a lower gravel and sand deposit and an upper yellow silt which in places attains a thickness of 350 feet. The lower part is of fluviatile origin while the upper part is a uniform loess-like material mainly deposited by wind but somewhat re-arranged by rain water. Its distribution is independent of natural obstacles as it is found both in valleys and on top of ridges and watersheds.

In the Soan valley there is a system of five terraces of which the third is composed of Potwar silts. This third terrace is cut into the moraine of the third glaciation in Jammu and Poonch, so that the Potwar silts may be regarded as contemporaneous with the third inter-glacial period.

Early Palæolithic stone tools—hand axes, choppers and flakes—are found at the top of the Boulder Conglomerate which De Terra correlates with the Middle Pleistocene. The first glaciation occurred before the Karewas were deposited, the Lower Karewas representing the first inter-glacial period. Then an uplift occurred followed by the second glaciation and deposition of Upper Karewas and a further uplift. Then followed a period of erosion and subsequently the third glaciation set in. The last three terraces are associated with three consecutive advances of the ice-front. These advances are now indicated by the respective moraines.

Alluvial deposits of the Upper Sutlej valley.—Large stretches of alluvial terraces exist in the Sutlej valley in the Hundes Province of the Central Himalaya. These are composed of sands, gravels and clays which have yielded remains of mammalia such as *Bos*, *Equus*, *Capra*, *Pantholops*, etc., most of which belong to genera now living in Tibet. The river has cut through these deposits to a depth of a few hundred feet.

Narbada alluvium.—The Narbada and Tapti rivers flow in a large basin covered by extensive Pleistocene and Recent deposits. The main part of the Narbada plain, between Jubbulpore and Harda, covers an area 200 miles long and 35 miles wide. Further down the river. there is another plain from Barwai to Harin Pal near Bagh. The plain of Tapti in Khandesh is also similar and extends from

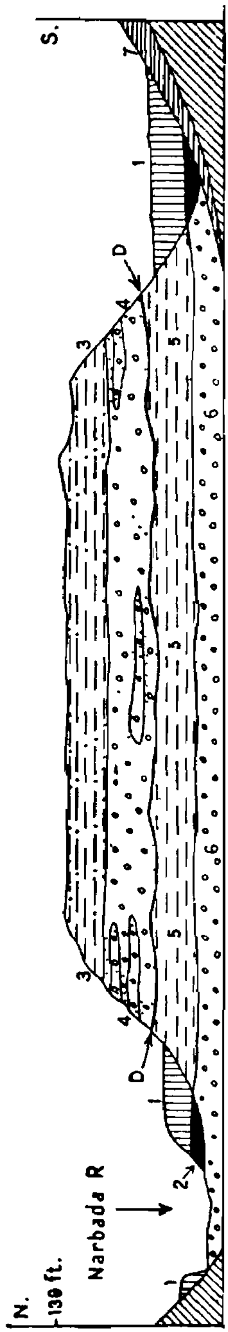


FIG. 14.—SECTION THROUGH THE NARBADA PLEISTOCENE (AFTER H. DE TERRA AND TEILHARD DE CHARDIN. *Proc. Amer Phil Soc.* 1936.)
1. Black cotton soil 2. Gravel at base of cotton soil. 3. Upper pink concretionary clay. 4. Upper gravel and sand.
5. Lower red concretionary clay. 6. Basal conglomerate. 7. Laterite. D Disconformable break.

Burhanpur westward for 150 miles and is 30 miles broad at its maximum. To the south-east is the valley of the Purna river in Berar, also containing Pleistocene deposits.

The Narbada deposits, amongst these, have received the best attention. The deposits in the Harda plain are composed of reddish and brownish clays, with intercalations of gravel and with *Kankar* (calcareous concretions). 'Hard pans' of calcareous conglomerate are often found. The plains are about 100 feet above the bed of the Narbada, this representing the thickness of the deposits. Near Gadarwada, north of Mohpani in the Central Provinces, the alluvium attains a thickness of over 500 feet and contains a lateritic gravel at the bottom.

Between Hoshangabad and Narasinghpur the river terrace is about 120 feet above the bed of the river. Two stages are recognised here each with a basal gravel overlain by orange clays and silts. The gravel and conglomerate of the lower stage are harder and better cemented than those of the upper. Fossils are found especially at the junction of the two stages, being sometimes accompanied by human implements. The lower zone contains Acheulian axes and flakes while the higher zone contains flakes, chips and cores of quartzite and trap resembling the Soan implements of the Potwar area.

In some places, at the sides of the valley, a basal laterite underlies the alluvium. This is more than 30 feet thick and represents, according to De Terra, a stratigraphical break. The laterite may possibly be older than the Pleistocene or may be Lower Pleistocene. The lower stage is correlated with the Boulder conglomerate zone of the Siwaliks on the evidence of lithology, fossils and implements. The upper zone may therefore be the equivalent of the extensive silt deposits of the Potwar area since both contain implements of the Soan type. The black cotton soil of this area is probably the equivalent of the re-deposited Potwar silts and the second Loess of Northwestern India. Table 50 shows the correlation suggested by De Terra.

The following are the chief fossils of the Narbada alluvium :

Reptilia .. *Pangshura flaviventris*, *Batagur* sp., *Trionyx gangeticus*.

Mammalia .. *Ursus namadicus*, *Hippopotamus* (*Hexaprotodon*) *palindicus*, *H. namadicus*, *Rhinoceros unicornis*, *Equus namadicus*, *Elephas namadicus*, *E. insignis*, *Stegodon ganesa*, *Bubalus palaeindicus*, *Leptobos fraasi*, *Bos namadicus*.

TABLE 50.—CORRELATION OF THE NARBADA AND N.W. INDIA PLEISTOCENE.

(*After* DE TERRA AND P. TEILHARD DE CHARDIN).

Age.		N.W. Punjab.	Kashmir Valley.	Narbada Valley.
PLEISTOCENE.	Upper	Redeposited Potwar and Second loess.	IV Glacial.	Black Cotton soil.
	Upper	*Erosion interval.*	III Inter-glacial.	*Erosion interval.*
	Upper	Potwar Silt.	III Glacial.	Upper zone.
	Middle	*Long Erosion interval.*	II Inter-glacial.	*Erosion interval.*
	Middle	Boulder conglomerate.	Upper Karewa. II Glacial. Karewa gravels.	Lower zone.
	Lower	Pinjor stage.	I Inter-glacial.	?
	Lower	Tatrot stage.	I Glacial.	Narbada laterite.
Pliocene		Dhok Pathan stage.	—	—

Godavari alluvium.—There are thick deposits of alluvium along the upper Godavari in the Central Provinces and Hyderabad State. They are composed mainly of brown clay and sandy silts with nodules of *kankar* and beds of gravel. In some places west of Chanda they are saline. The gravels are composed of pebbles of Deccan trap, agate and chalcedony. Fossil wood trunks have been found in them between Wardha and Enchapalli and between the latter and Albaka. Animal remains including *Elephas namadicus* and *Bos*. sp. have been found near Mungi, Paitan, Hingoli and a few other places.

Kistna (Krishna) alluvium.—Gravels, sandy silts and calcareous conglomerates of Pleistocene age occur in the Upper Kistna valley 60 to 80 feet above the present river bed. Parts of the cranium of *Rhinoceros deccanensis* have been found near Gokak and also remains of *Bos.* The alluvia of the tributaries of this river in South Mahratta country have yielded stone implements.

Madras.—Overlying the conglomerates of the Satyavedu (Upper Gondwana) beds, in the valley of the Kortalayar river there is a series of four terraces, respectively 100 feet, 60 feet, 20 feet, and 8 feet above the river bed. These contain implements which are referable to Abbevillian-Acheulian (first terrace), Acheulian (second terrace) Late Acheulian and Levalloisian (third terrace) and Upper Palaeolithic (fourth terrace).

In the Vadamadurai area southwest of Madras, Pleistocene boulder-conglomerates containing Abbevillian tools overlie the upper Gondwanas. Above this is detrital laterite and alluvium, the former containing Acheulian type of tools.

Irrawaddy alluvium.—Four terraces have been recognised in the Irrawaddy valley overlying the Irrawaddy system. The oldest terrace is seen in a group of hills 300 feet above the present river bed near the Chauk oil-field. This contains gravel and boulder-beds and sandstones which are tilted. The fossils found in them are *Elephas namadicus*, *Bos*. cf. *namadicus* and *Hippopotamas.* The second and third terraces lie 180 and 100 feet respectively above the river and contain Middle Pleistocene fauna and Palaeolithic tools near Mandalay. The fourth terrace, of sandy gravel and sand, contains a late type of Palaeolithic implements. The fifth terrace grades into recent river deposits. The whole of the terrace system is assigned a Middle to Upper Pleistocene age by De Terra, the uppermost Irrawaddys being regarded as Lower Pleistocene by the same authority.

THE INDO-GANGETIC ALLUVIUM.

General.—The great alluvial tract of the Ganges, Brahmaputra and the Indus forms one of three main physiographic divisions of India, separating the Peninsular from the Extra-Peninsular region, and covering an area estimated at over 250,000 square miles. The deposits of this tract belong, so to say, to the last chapter of earth's history and conceal beneath them the northern fringes of the Peninsular formations and the southern fringes of the Extra-Peninsular formations. The area is geologically uninteresting but, being a rich agricultural tract, is of great interest and importance in human history.

It consists of two units separated by a narrow low ridge passing through Delhi and Ambala which is but a continuation of a part of the Aravalli ranges. This ridge is not particularly noticeable as it is covered by thin deposits of geologically recent date. Geodetic observations indicate the presence, underneath the Indus alluvium, of a ridge parallel to the Himalayas from Delhi to the Salt Range, on which lie the Kirana and Sangla Hills.

Origin of the depression.—The alluvial tract is of the nature of a synclinal basin formed concomitantly with the elevation of the Himalaya to its north. One view, due to Eduard Suess, the great Austrian geologist, holds that it is a 'fore deep' formed in front of the resistant mass of the Peninsula when the Tethyan sediments were thrust southward and compressed against the former. The Peninsula is regarded as a stable unmoving mass and Central Asia as the moving segment of the crust. According to a second view, due to Sir Sydney Burrard (formerly

Surveyor-General of India) the plains represent a rift-valley bounded by parallel faults on either side. A third and more recent view regards this region as a sag in the crust formed between the northward drifting Indian continent and the comparatively soft sediments accumulated in the Tethyan and connected basins on the north when the latter were crumpled up and lifted up into a mountain system.

Whether the first or third interpretation is accepted, the dynamical effect would appear to be the same, but accumulating evidence tends to support the third view. The depression perhaps began to form in the Upper Eocene and attained its greatest development during the second Himalayan upheaval in Middle Miocene. Since then it has been gradually filled up by sediments to form a level plain with a very gentle seaward slope.

Depth.—The shape of the depression is known in a general way, though not with any accuracy. It is deepest within a few miles of the mountains and gradually shelves up towards the Peninsula. The borings that have put down in the alluvium in search of artesian water, show that the depth is well in excess of 2,000 feet. Recent geodetic data would indicate that the maximum thickness of the alluvial deposits in the Ganges basin is of the order of 6,000 feet and probably not so much as 10,000 feet. The Bihar earthquake of 1934 showed that there are some zones of disturbance underneath the alluvium, parallel to the Himalayan trend, which may be faults. Near the northern margin the floor is undoubtedly greatly disturbed and is underlain for some distance by the Siwalik strata.

The alluvium is shallow between the Rajmahal and the Garo hills, these being connected by a ridge. Some authorities opine that this depression was formed at as late a period as the Pleistocene, but it may well have been formed by faulting during the Middle Miocene uplift, for it is surmised that about the same period a series of N.-S. block faults were formed in Assam as a result of the compression of the northeastern part of the Peninsula against Burma.

Nature of the deposits.—The sediments are sands, silts and clays with occasional gravel beds and lenses of peaty organic matter. The older alluvium (called *Bhangar* in the Ganges valley) is rather dark coloured and generally rich in concretions and nodules of impure calcium carbonate known as *kankar* in Northern India. The *kankar* concretions are of all shapes and sizes from small grains to lumps as large as a man's head. The older alluvium forms slightly elevated terraces, generally above the flood level, the river having cut through it to a lower level. It is of Middle to Upper Pleistocene age.

The Newer alluvium (called *Khadar* in the Punjab) is light coloured and poor in calcareous matter. It contains lenticular beds of sand and gravel and peat beds. It merges by insensible gradations into the recent or deltaic alluvia and should be assigned an upper Pleistocene age.

The older alluvium contains the remains of extinct species of animals including *Rhinoceros*, *Hippopotamus*, *Palaeoloxodon*, *Elephas* and *Equus*. The fossils in the Newer Alluvium are mostly those of animals still living.

COASTAL DEPOSITS.

Eastern Coast.—Raised beaches, some of them elevated as much as 50 to 100 feet above the present sea level, occur at several places along the coast. They contain molluscan shells of recent or present day species. Such deposits are common along the Orissa, Nellore, Madras, Madura and Tinnevelly coasts.

The Chilka Lake.—The Chilka lake on the Ganjam coast dates back to the Pleistocene. It has been rendered shallow by the deposits from the mouths of the Mahanadi, while a sand spit has been thrown across its mouth by the monsoon winds. Near the southwestern end of the spit there is a deposit of estuarine shells 20 to 30 feet above the high tide level. The shells include *Cytherea costa* and *Arca* *granosa*, neither of which live in Chilka Lake at present, but the former is known in the estuary connecting the lake with the sea. The Chilka lake appears to be gradually diminishing in size.

South-western Coast.—Along the Travancore and Malabar coasts, mud banks have been formed which separate lake-like expanses of water (backwaters or *Kayals*) from the sea. The backwaters are used for coastal communication by small boats. The mud banks are Pleistocene to Recent in age.

Gujarat.—The lowlying tract connecting the Kathiawar Peninsula with the mainland near Ahmedabad shows recent deposits with *Cerithium*, *Potamides*, etc., indicating that this was an estuarine area in Pleistocene times.

Kathiawar.—On the coast of Kathiawar is found a marine limestone composed of the remains of the foraminifer *Miliolite*, around which oolite grains have been formed. It is usually sandy in the vicinity of the coast, and attains a thickness of 100 feet in western Kathiawar, but is thinner and less extensive in eastern Kathiawar. This Miliolite limestone, also called *Porbandar Stone*, is found on the top of Chotila hill (1,173 feet altitude) which provides clear proof of the elevation of the coast in recent times. This is locally used as a building stone in Kathiawar.

There are also raised beaches, oyster beds and coral reefs on the Kathiawar coast which have been elevated a few hundred feet since the Pleistocene.

Rann of Cutch.—During the Pleistocene the Rann was a shallow arm of the sea. Even in historic times it was so, as the Indus and the Sarasvati of Vedic times flowed into it. It is now silted up and forms an extensive and desolete salt marsh during the dry part of the year and a tidal flat covered wih a few feet of sea water during the monsoons.

Mekran coast.—Raised beaches containing shells of living species are found about 100 feet above the sea level in the Mekran coast of Baluchistan. The commonest shells are *Ostrea hyotis*, *Anomya archaeus*, *Pecten crassicostatus*, *Arca antiquata*, *A. nivea*, etc.

AEOLIAN AND OTHER DEPOSITS.

Loess.—Large stretches of wind-blown dust of sandy to clayey constitution are found in Punjab, Kashmir, Sind and Baluchistan. This material, called loess, is of fine grain, buff or grey coloured and with little signs of stratification. It covers the land surface irrespective of barriers and altitude, and deposits are particularly well seen in the Potwar plateau, Salt Range, and Thal Chotiali in Baluchistan. It is essentially a deposit of arid regions liable to strong winds carrying much dust. The irregular distribution of loess has in some measure been responsible for the formation of shallow lakes at the top of the Salt Range.

Desert sands.—A vast tract of western and south-western Rajputana and adjoining parts of Sind, occupying an area 400 miles long and 100 miles wide, constitutes the Thar desert. It is covered for a depth of several feet, and a few scores of feet in places, by sands which are at the mercy of the winds blowing from the south-west for several months in the year. The sands lie over and cover an irregular rocky floor but rocky ridges and prominences sometimes raise their heads above the level of the sand. Over the greater part of the area the sands are piled up into *dunes*. The longitudinal ridge-like dunes are common in the south where the winds are stronger, while the crescentic type or 'barchane' is common in the interior.

The desert conditions seem to have been established during and after the Pleistocene when the monsoons became operative. Winds blowing from the Arabian sea meet with no obstacles until they encounter the Himalaya. The Aravallis are aligned parallel to the course of the winds, so that they are unable to prevent the winds from traversing the whole length of Rajputana. Hence Rajputana has only a very scanty rainfall—5 to 8 inches in a year—and most of this is precipitated during the few sudden cloud-bursts. The increasing aridity and the large diurnal range of temperature are instrumental in disintegrating the rocks and this is helped further by the sand-blasting action of the winds.

A large part of the desert is, however, not a perfect sandy waste, for it supports a scrubby, stunted, xerophytic vegetation. It is studded with cities and villages which indicate that the arid conditions are of a recent date and still in course of development. When the sand cover is thin or is kept off by human endeavour, the underlying soil is found to be rich and is cultivated by means of water drawn from below. In many places the subsoil water from some depth is of quite good quality.

The growth of desert conditions has of course been aided by man by his habit of destroying forests. The Rajput kingdoms must originally have been established in a fertile region well clothed with forests. But now the desert is slowly and relentlessly marching northward. A feature of this advance is the transport by winds of large amounts of comminuted saline matter from the Rann of Cutch and the Arabian Sea Coast. This is deposited with the sand, and the scanty rainfall helps to concentrate it in the inland lakes. This wind-borne salt is, in the opinion of Sir T.H. Holland and Dr. W.A.K. Christie, responsible for the salt content of the Sambhar and other lakes in Rajputana.

Daman Slopes.—Pleistocene gravel and talus deposits are a conspicuous feature of the lower slopes of the hills in Baluchistan and neighbouring areas. The loose rocky material is highly porous and often stores up large quantities of water which can be drawn by driving tunnels and wells through it. In proper locations water rises up in wells under artesian pressure. The long, nearly horizontal, tunnels driven into these deposits for obtaining water are called *Karezes*.

Bhabar and Terai.—In the foot-hill region of the Himalaya, the hills are fringed on the side of the plains by talus fans. The upper portion of the talus fans is composed of rock fragments, gravel and soil and supports good forests. This zone, known as the *Bhabar*, has a vertical extent of less than 1,000 feet between its upper and lower limits.

The *Terai* tract lies immediately below the *Bhabar*. It is composed of gravel and soil often forming a marshy tract overgrown with grass and thick jungle. It is an unhealthy zone, uninhabitable unless well drained.

Cave Deposits.—Though a number of caves exist in various parts of the country, especially in limestones, few of them have been investigated in detail. Some are in unfrequented areas and even the more easily accessible ones have not received the attention they deserve from the scientists.

A group of caves (Billa Surgam) near Betamcherla in the Kurnool district, Madras, was examined by Bruce Foote and his son who found a rich Pleistocene fauna well preserved in the red marl of the floor of the caves. The majority of the fossils belong to species still living, but a few which are extinct in India are still found in Africa, such as *Papio* sp., *Equus asinus*, *Hyaena crocuta*, *Manis* cf. *gigantea*. Amongst the others are :

Mammalia	..	*Presbytis, Macacus, Cheiroptera, Sorex, Felis tigris Viverra karnulensis, Canis, Herpestes, Hystrix crassidens, Mus, Nesokia, Sus karnulensis, Lepus, Rhinoceros karnulensis, Rusa, Memimma, Gazella, Portax, Capra, Ovis, Bos.*
Reptiles	..	*Crocodilus, Varanus, Lacerta, Ophidia, Emys, Phelona.*
Amphibia	..	*Rana, Bufo.*

RECENT DEPOSITS.

Coastal Dunes.—The recent deposits are sand dunes in the coastal and desert areas, the various types of soil covering the surface of the country and river alluvia of the present day.

Several parts of the eastern coast of India are covered by sand which is massed into small sized dunes by winds, rarely attaining a height of 30 feet. Such are seen on the coasts of Ganjam, Vizagapatam, Nellore, Ramnad and Tinnevelly. The sand dunes slowly march inward and are a menace to cultivation. Their progress can be controlled by plantations of trees.

River alluvia.—All the important rivers have an erosive action in their upper courses and deposit their sediments in the delta region. The deposits consist of lenticular beds of sand and clay.

Along the upper courses of North Indian rivers there are deposits of blown sand and fine dust. These are laid down where there are obstacles to wind movement such as clumps of trees or shrubs. In course of time these deposits near river banks become consolidated into mounds and form good sites for villages above the flood level. They are called *bhur lands*.

In the drier portions of the Indus and Ganges valleys, where there is no good outward drainage, the soil becomes water-logged and the accumulated salts in the ground water are drawn up to the surface to appear as efflorescences. Such efflorescences are called *reh* in the United Provinces and *kallar* in the Punjab. The term *usar* is applied to alkali-laden land unfit for cultivation. The salts in these are mainly sodium chloride, sodium sulphate and sodium carbonate. Water-logging and concentration of salts is also a feature in parts of the canal-irrigated areas wherefrom there is no adequate outward drainage.

The salts become concentrated comparatively near the ground level, especially within a depth of some 30 feet from the surface. The water from this part is unpalatable and often injurious to the health of plants and animals. Further down, however, sweet potable water is usually met with.

SOILS.

Soils are of two types, residual and transported. The first group is derived *in situ* from the rocks and the second is brought by flowing water or wind from elsewhere. The soils of the river valleys, deltas and valleys in mountainous country belong to the second type while those of other areas are practically all residual.

Large parts of the Peninsula, particularly the regions occupied by granites and gneisses, give rise to 'red soil.' The red soil is not always necessarily red in colour though it is frequently so. The colour is due to the oxidation and wide diffusion of the iron content. It is moderately fertile and varies considerably in composition because of the variation in characters of the original rock.

Regur or 'black cotton soil' (the equivalent of the Russian *chernozem*) is a black clayey soil containing high alumina, lime and magnesia, a rather variable but small amount of potash, and low nitrogen, phosphorus and humus. It is highly porous and swells enormously when wetted and dries up with conspicuous cracks on drying. Though sticky when wet and impassable in the rainy season, it does not become compact or 'heavy' clay. It forms on basic rocks like the Deccan traps and also on some gneisses, Cretaceous rocks, etc. It is prevalent in areas with low rainfall (20 to 30 inches).

Lateritic soils are those in which there is a concentration of the hydroxide of alumina and iron, with loss of silica, lime, magnesia and alkalies. They are associated with laterite in various parts of India.

The soils on sedimentary rocks are variable in nature, those derived from shales and slates being usually richer in plant food than those from arenaceous and calcareous rocks. Impure calcareous rocks can however give rise to good soils.

The soils of the Peninsula have, in general, attained a high degree of maturity as they have been under cultivation for many centuries and represent products of weathering over long ages.

The alluvial soils are of comparatively recent origin and do not show the maturity characteristic of the soils inland. They are however very rich and support a vast agricultural population and livestock. They are clay-loams and do not show much difference in composition over large areas.

The arid tracts of India such as Rajputana, parts of Sind and Baluchistan have no soil cap, the surface being covered by sand or loess. Though loess can support agriculture, there is generally much difficulty in obtaining water in the areas covered by it.

Soils (and wind-blown materials) are deposits which are forming at the present day. Their study is now specialised and belongs to the province of the science of Agriculture, though their mineralogical characters are best elucidated by geologists.

RECENT CHANGES IN THE COASTAL TRACTS.

Many changes have happened at numerous places in the coastal region during the Recent and historic periods. The evidences are much more noticeable on the eastern coast than on the western. Both submergence and emergence of the coast are known.

In the Princes Dock at Bombay, tree stems were found standing *in situ* at a depth of 30 feet below high water level. On the Tinnevelly coast also, in the Valinokkam bay, a similar submerged forest has been noticed, in which numerous tree stumps of about 2 feet diameter at the base were seen at low tide sticking out of a bed of dark clay containing oyster and other marine shells. The peat beds of Pondicherry give evidence of submergence in Pleistocene and Recent times. Several places which were on the sea a few centuries ago are now some miles inland. For instance, Coringa at the mouth of the Godavari, Kaveripatnam in the Cauvery delta and Korka on the Tinnevelly coast were all flourishing sea ports 1,000 to 2,000 years ago but are now some distance inland, mainly because of the outward march of river deltas. The Rann of Cutch has also gradually emerged into dry land during Recent times.

The Arakan coast and the Andaman and Nicobar islands have undergone submergence in Pleistocene and Recent times. The presence of deep creeks and inlets in the Arakan and Tennasserim coasts is clear evidence of such submergence. The Gulf of Cambay region is also being encroached upon by the sea.

The sea has advanced on land at Tranquebar on the Tanjore coast and the remains of a pagoda could be seen above water level at low tide even in the last century. The town of San Thome (now part of Madras City) is said to have been some distance inland formerly but is now on the sea shore. The sea is also vigorously invading the northern part of the city of Madras, expensive protective works being necessary to check the incursion. This is at least partly attributable to the construction of the Madras harbour, for the coastal current sweeps past the pier and whirls in towards the land on the north side of the harbour works, the prevailing direction of the current being more or less parallel to the Coast from the south to north.

Changes of level have also occurred as a result of earthquakes. A large area bordering the Rann of Cutch was suddenly submerged some 15 feet and an adjoining area inland was elevated after the great earthquake of 1819. The Madhupur jungle in Eastern Bengal is known to have been elevated by as much as 50 feet to 100 feet in very recent times, producing thereby a westward shift of the course of the Brahmaputra. Several cases of change of level have been recorded by R. D. Oldham as having been produced by the Assam earthquake of 1897.

Changes in the course of Rivers.—Some of the important changes noticed in the river courses of the Indus and Ganges-Brahmaputra systems have already been referred to. The most notable of these is the drying up of the rivers that once flowed through Rajputana, and the shift in the course of the Brahmaputra. Further details will be found in Chapter I.

LATERITE.

No account of the stratigraphy of India is complete without a reference to the peculiar ferruginous material called *laterite* which is a product of tropical alteration suffered by some rocks. It is typically developed in tropical lands such as India, Malaya, East Indies, West Indies, and Tropical America, though similar formations of warm climates in some past ages are known in the temperate regions of the present day also.

Characters.—Laterite is a porous, pitted, clay-like rock with red, yellow, brown, grey and mottled colours, depending in some measure on the compsoition. It has a hard protective limonitic crust on the exposed surface, which is generally irregular and rough. When dug up, the fresh material is comparatively soft and easily cut by a spade or a saw. In this state it has often variegated colours and shows vermicular cavities which are irregular and tortuous. Laterite is often pisolitic, the pisolites having a concentric structure and being cemented together by ferruginous or aluminous material. When the fresh soft rock is exposed to air, it is quickly dehydrated and becomes quite hard.

The term was first used for material from Malabar in South India by Francis Buchanan in 1800. The following extracts* from his diary are of interest in this connection:—

" The ore is found forming beds, veins, or detached masses in the stratum of indurated clay that is to be afterwards described, and of which the greater part of the hills of Malabar consist. This ore is

*Francis Buchanan: A journey from Madras through the countries of Mysore, Canara, Malabar, etc. (London, 1807, 3 volumes). Vol. 2, pp 436-437, dated Angadipuram 20-21st December, 1800.

composed of clay, quartz in the form of sand, and of the common black iron sand. This mixture forms small, angular nodules closely compacted together and very friable. It is dug out with a pick-axe"

Continuing, he wrote on a later page (p. 440) :—

"It is diffused in immense masses without any appearance of stratification and is placed over the granite that forms the basis of Malayala†. It is full of cavities and pores and contains a very large quantity of iron in the form of red and yellow ochres. In the mass, while excluded from the air, it is so soft that any iron instrument readily cuts it and is dug up in square masses with a pick-axe and immediately cut into the shape wanted with a trowel or a large knife. It very soon after becomes as hard as a brick and resists the air and water much better than any bricks that I have seen in India . . . . As it is usually cut into the form of bricks for building, in several of the native dialects it is called the brick-stone (*itica-cullu*). Where however by the washing away of the soil, part of it has been exposed to air and has hardened into rock, its colour becomes black, and its pores and inequalities give it a kind of resemblance to the skin of a person affected with cutaneous disorder; hence in the Tamil language it is called *shuri cull* or itch stone. The most proper English name would be laterite, from *laterites*, the appellation that may be given to it in science."

Composition.—Laterite may form from a variety of rocks, the end product containing mainly the hydroxides of iron, alumina and manganese. The original alkalies, lime, magnesia and silica are removed in solution, silica being present until a late stage. Titania remains in the residual material so that, in some Indian laterites derived from the traps, as much as 8 to 16 per cent. of this constituent may be present. Analyses of gneisses and khondalites in various stages of lateritisation will be found in the papers by C. S. Fox and M. S. Krishnan cited in the bibliography.

In accordance with the relative amounts of ferric oxide, alumina and manganese present, the material is called ferruginous laterite (laterite), aluminous laterite (bauxite) and manganiferous laterite (lateritoid manganese ore). In general, the highly ferruginous material is red to red-

†Malayalam is the local name of the Malabar Country and also of the language of Malabar, Cochin and Travancore.

brown, the aluminous one creamy or greyish, and the manganiferous one dark brown to black.

Types related to parent rock.—Large areas of Deccan trap are covered with a laterite cap having a thickness up to 100 or 150 feet. In these the lateritisation has gone to completion, with little or no combined silica, and the material may vary from ferruginous to highly aluminous laterite.

In the case of khondalites, lateritisation is generally not so well developed as in Deccan traps, for there is often much kaolinic or lithomargic material. In certain areas as on tops of hills, the process has been carried to completion. The study of the laterite of Malabar by C. S. Fox has shown that it is generally lithomargic and derived from granite and granite-gneiss. There is still much combined silica in the rock. Though this is the type originally described by Buchanan, the term laterite is now restricted by usage to the product which is free from combined silica, so that the Malabar laterite will now be called lithomargic laterite.

In typical sections in Malabar, the surface material is highly ferruginous and pellety in structure, underlain by vermicular mottled laterite containing some clay and free silica. Below this comes the soft, pale coloured, highly lithomargic material which preserves to some extent the gneissic structure of the underlying rock. This is really kaolinised gneiss gradually changing to laterite. Almost the whole section shows the presence of free quartz and kaolinic material except a small thickness exposed at the surface.

Sir John Harrison's observations are interesting in this connection :—

"Under tropical conditions, acid rocks, such as aplites, pegmatites or granites or granitic gneiss, do not undergo primary lateritisation but gradually change through katamorphism into pipe or pot-clays, or more or less quartziferous impure kaolins."

"Under tropical conditions, the katamorphism of basic and intermediate rocks, at or close to the water-table, under conditions of more or less perfect drainage, is accompanied by the almost complete removal of silica and of calcium, magnesium, potassium and sodium oxides, leaving an earthy residuum of aluminium trihydrate (in its crystalline form of gibbsite), limonite, a few unaltered fragments of felspars, and in some cases, secondary quartz, and the various resistant minerals originally present in the rock. This residuum is termed primary laterite."

The observations of Fox on Malabar laterite show that when free silica is present in the parent rock, the tendency is to form kaolinic and lithomargic products; when free silica is absent, as in basic rocks, true laterite is formed.

Another type of lateritic product is known, particularly in the Mediterranean region. It is the 'terra rosa' type, a red clay derived, according to Fox, from the accumulation of the insoluble matter of limestones and dolomites, and typical of the bauxite deposits of France. It is characterised by a comparatively low content of combined water (which may be due to the preponderance of the monohydrate of aluminium), and by a low percentage of silica. The terra rosa type is present in India over some areas of calcareous rocks, but is insignificant in quantity in comparison with the other types.

High-level and low-level laterite.—Most of the laterite occurring as massive beds is found generally capping hills at altitudes of 2,000 to 5,000 feet. The laterite cap in the Deccan trap country varies considerably in thickness and may be up to 200 feet. Laterite also occurs at lower levels, but in many cases this is secondary, being derived from the high level laterite and recemented in the valleys or plains. There is also laterite which is formed on rocks exposed at low levels. This classification according to altitude is now known to be untenable. A genetic classification can differentiate between only primary and detrital laterite, the first referring to material formed *in situ* while the second is primary laterite transported to other places and there recemented. Primary laterite can be formed at all altitudes if the conditions are favourable. On the whole, however, the primary material is compact and fairly uniform in composition while the detrital laterite is heterogeneous and far from compact.

Distribution.—Laterite is extensively distributed in Peninsular India. The best known occurrences are on the Deccan traps and on khondalites. It is commonly seen in the Western Ghats. Less important occurrences are found in almost every district covering gneisses, schists, slates, impure limestones and ferruginous rocks.

Age.—There are no definite criteria for determining the age of the laterite. Much of the laterite on hills in Bombay, Central India, Central Provinces and Orissa is probably of Upper Tertiary age extending into the Pleistocene. It is forming at the present day in Western Ghats and probably in other regions, the necessary condition, according to Norbert Krebs, being a rainfall of over 65 inches per year and an average monthly temperature of over 20° C. It is known, however, that laterite was formed in Cretaceous times, for the Eocene of Northwestern India is underlain by a conspicuous bed of laterite. A thin zone of this material is seen also at the junction of the Upper Gondwana and Cretaceous beds in the Trichinopoly district. It indicates a period of subaerial weathering in tropical regions with fairly flat topography.

Origin.—Several hypotheses have been proposed to account for the formation of laterite. Among the earlier ones are volcanic agencies, ascending thermal waters, solution of alumina and iron by acidic waters and subsequent precipitation or deposition in lakes or lagoons through the agency of running water.

It is, however, now generally agreed that laterite is a product of subaerial weathering in a monsoon climate having alternate dry and wet seasons. Good drainage conditions also seem to have an important influence. Dr. C. S. Fox has suggested that acid waters percolating down through a porous rock might set up a potential gradient and that the passage of silica downwards and ferric oxide upwards might be allied to the phenomenon of cataphoresis, the alumina set free from the rock as a gel acting as a diaphragm. Capillary action may also help the migration of ferric hydroxide to the surface. Sir T. H. Holland has suggested that bacteria may help in the disintegration of the original rock and in the concentration of the sesqui-oxides. This seems to be supported by the work of G. A. Thiel, Ellis and others.

Fox has given a section of a typical laterite-capped plateau in the Deccan trap country. At the top occurs ferruginous laterite passing down into vermicular or pisolitic material, having a thickness of some 7 or 8 feet. Further down comes a layer of grey, creamy or reddish bauxite (aluminous laterite) whose thickness is variable. Underlying this is a porous soft laterite which grades down into lithomarge, this being highly siliceous at about the ground water level. Below the lithomarge is partially altered rock and then the unaltered parent rock.

Uses.—Ferruginous laterite is used extensively in some parts of India for building houses, culverts, bridges and other structures. It is easily dressed when freshly quarried but hardens on exposure and is a fairly good and durable building stone.

Aluminous laterite (or bauxite) is used as an ore of aluminium, *i.e.*, for the preparation of high grade alumina which is electrolysed for the preparation of the metal. It is also used in oil refining as its colloidal constituents have the property of decolourising oils. It can be employed for the manufacture of salts of aluminium and for making high-alumina cement. There is, in the ferruginous laterites of India and other countries, a vast store of iron which it should be possible to smelt cheaply at some future date when the high grade hæmatite deposits become scarce or costly to mine and concentrate.

SELECTED BIBLIOGRAPHY.

(PLEISTOCENE AND RECENT.)

Auden, J.B. Report on the *reh* soils in the U. P. *Rec.* 76, paper 1, 1942.

Foote, R. B. Billa Surgam and other caves in Kurnool. *Rec.* 17, 27-34, 1884.

Foote, R. B. Results of excavation in Billa Surgam caves. *Rec.* 18, 227-235, 1885.

La Touche, T. D. Submerged forests at Bombay. *Rec.* 49, 214-219, 1918.

Vredenburg, E. Pleistocene movement in the Indian Peninsula. *Rec.* 33, 33-45, 1906.

Wadia, D. N. *et al.* Geological foundations of the soils of India. *Rec.* 68, 363-391, 1935. (Extensive bibliography).

LATERITE.

————————Laterite and laterite soils. *Tech. Comm.* 24, *Imp. Bur. Soil Sci.*, London, 1932.

Bauer, Max. Beitrage zur Geologie der Seychellen, insbesondere zur Kenntnis des Laterits. *N JB. Min. II*, 163-219, 1898.

Fermor, L. L. What is laterite? *Geol. Mag.* 48, 454-462. 507-516, 559-566, 1911.

Fox, C. S. Bauxite and aluminous laterite occurrences of India. *Mem.* 49, Pt. 1, 1923.

Fox, C.S. Bauxite and aluminous laterite. London, 1932.

Fox, C.S. Buchanan's laterite of Malabar and Kanara. *Rec.* 69, 389-422, 1936.

Harrison, J. The katamorphism of igneous rocks under humid tropical conditions. *Imp. Bur. Soil Sci.*, London, 1934.

Holland, T.H. On the constitution, origin and dehydration of laterite. *Geol. Mag* 40, 59-66, 1903.

Krishnan, M.S. Lateritisation of khondalite. *Rec.* 68, 392-399, 1934.

Lake, P. Geology of Malabar. *Mem.* 24, 217-233, 1890.

Middlemiss, C.S. Bauxite deposits of Jammu. *Kashmir Mineral Survey Report*, 1928.

Rumbold, W.G. Bauxite and aluminium. *Imp. Inst.* London, *Monograph series*, 1925.

Smeeth, W.F. Laterite in Mysore. *M. G. D. Rec.* 11, 1910.

Thiel, G.A. Enrichment of Bauxite deposits through the activity of micro-organisms. *Econ. Geol.* 22, 480-493, 1927.

Wetherell, E.W. The nature of Laterite, the Bangalore-Kolar laterite. *M.G.D., Mem.* III.

INDEX.

N

O

P

T