CHAPTER III

GEOLOGY

1. *Evolution of the Indian Subcontinent*

THE OUTSTANDING FACT about the physical geography and geology of India, which is the result of its past geological history, is that in the making of the Indian subcontinent, three distinct crust-blocks of the earth's circumference have taken part. These are : (1) the Deccan peninsula south of the Vindhyan mountains, a solid and stable crust-block composed of some of the most ancient rocks of the earth's crust; (2) the great mountain ranges to its west, north and east composed of folded and crumpled sedimentary rocks building the extra-Peninsular portion of India; and (3) the Indo-Ganga plains separating the two former areas and extending from the Indus in Sind through the Punjab plains to the Brahmaputra in Assam. This part of India, structurally, is regarded as only the buckled, downwarped portion of the Deccan block.

Three constituent crust-blocks

In their characters and peculiarities as earth features, the two segments of India—Peninsular and extra-Peninsular—are entirely unlike each other. The first difference is stratigraphic, or that connected with the geological history of the areas. Ever since the dawn of geological history (Cambrian period), the Peninsula has been a bare land area, a continental fragment of the earth's surface; since that early period it has never been submerged beneath the sea except temporarily and locally. The extra-Peninsula, on the other hand, has been a region which had lain under the sea for the greater part of its history and has been covered by successive marine deposits characteristic of the great geological periods commencing with the Cambrian. The second difference relates to the geological structure of the two regions. The Peninsular part of India reveals a type of architecture of the earth's crust quite different from that shown by the Himālayas and the other mountain ranges of the extra-Peninsula. It is a segment of the earth's outer shell that stands upon a firm and immovable foundation, and that has for an immense interval of geologic time remained so, impassive amid all the revolutions that have again and again changed the face of the earth. Lateral thrusts and mountain-building forces, since early pre-Cambrian times, have had but little effect in folding or displacing its original horizontal structure.

The extra-Peninsula, on the contrary, is a portion of what appears to have been a comparatively weak and flexible part of the earth's crust which has undergone a great deal of crumpling, folding and deformation. It has undergone, at a very late geological epoch, an enormous amount of compression and mountain-building upheaval. The third difference is in the diversity of the physical features—physiography—of the two areas. In the Peninsula, the external or surface relief, its hills and mountains, are mostly of the "relict" type; that is, they are not mountains of uplift, but are mere outstanding portions of the old plateau of the Deccan that have escaped the weathering of ages which cut out all the surrounding part of the land. Its rivers denuding their beds for long geological ages have flat, shallow valleys with low gradients, the channels having approached the base-level of erosion. Contrasted with these, the mountains of the extra-Peninsula are all true tectonic; that is, they owe their origin to a distinct uplift of the earth's crust. The rivers of this area are rapid torrential streams which are still in a very youthful or immature stage of development; they are continuously at work in degrading or lowering their channels and cutting deep gorges, hundreds of metres in depth, through the mountain part of their track.

The third division of India, the great alluvial plains of the Indus and the Ganga, though of the greatest importance as the main theatre of Indian history, is geologically the least interesting part. These plains are only the alluvial deposits of the rivers of the Indus, Ganga and Brahmaputra systems, borne down from the Himālayas and filling up a deep depression several hundred metres deep.

How these crust-blocks came to be together to build the geographic entity we call India is one of the puzzles of geology.

Fusion of the three blocks

One school of geologists denies the Asiatic parentage of India. It suggests that the Indian and Arabian peninsulas of Asia were parts of an ancient, far-away, southern continent beyond the Equator, of which Africa and Australia are the surviving remnants. The impact of these drifting fragments of the southern continent with the southern shores of the block of Eurasia is held to have ridged up its geosynclinal sea-floor into the imposing chain of mountains which girdles India's Asiatic front.

The orthodox school of geologists finds no adequate force or agency in the earth's body to effect a congregation of continents

ARYAN GROUP	Newer alluvium of the deltas; newer raised-beaches; coral banks. Cave-deposits of Kurnool.	Modern river-deposits. Dry deltas, fans, etc.	Newer alluvium— *Khādar* of the Indus and the Ganges.			*Recent.*
	Older alluvium of the Narbada, Godāvari, etc.; *Palaeolithic* gravels; low-level *laterite*; *Porbander* sandstone; raised-beaches; sand-dunes; loess; desert sands of Rājputāna and Cutch. **Upper Cuddalore sandstone.**	**Ice Age.** Glacial moraines; perched blocks, etc.; *Upper Karewas* of Kashmīr; old high-level alluvia of the Sutlej, etc. River-terraces.	**The Indo-Ganga Alluvium—** *Bāngar.* Loess of Baluchistān.			*Pleistocene.*
			Sind and Baluchistān.	Assam.	Burma.	
	Laterite (high-level) of the Peninsula.	*Upper Siwālik.*	**Manchar** System of Sind.	*Dihing* Series.	Irrawaddy System.	*Pliocene.*
	Ossiferous conglomerate of Perim island.	*Middle Siwālik.*		*Dupi Tila* Series.		*Upper Miocene.*
	Miocene of puri and Baripāda. **Cuddalore Series** of the east coast (part); Tertiary of Quilon.	*Lower Siwālik or Nāhan.*	**Mekrān** System of Baluchistān. **Gaj Series of** Sind.	*Tipam* Series.	Pegu System.	*Middle Miocene.*
	Gaj Series of Cutch.	*Murree* Series of Punjab Himālayas; *Kasauli* and *Dagshai* Series of Simla Himālayas. *Fatehjang* beds.	*Flysch* of Baluchistān. *Bugti* beds of Baluchistān.	*Surma* Series.	*Upper Pegu.*	*Lower Miocene.*
	Nari Series of Cutch; *Dwārka* beds of kāthiāwār.	Intrusive granites, etc., in the core of the Himālayas.	**Nari Series** of Sind.		*Lower Pegu.*	*Oligocene.*
	Nummulitics of Surat and Broach; Lower Tertiaries of Cutch; nummulitic limestone of Rājputāna and Kāthiawār. *Laki* Series of Bīkaner. Eocene of Pondicherry.	*Subathu* and *Chharat* Series of Outer Himālayas; Lower Tertiaries of the Inner Himālayas, Indus Valley and Hundes. Coal-bearing beds of Jammu. *Laki* Series of Kohāt. Hill Limestone of Hazāra and Punjab.	*Barail* Series of Assam. **Kīrthar Series** (Nummulitic limestone) of Assam (*Jaintia* Series), **Burma,** Sind and **Baluchistān.** **Laki Series** of Sind and Baluchitstān.			*Upper Eocene.*
	Rānikot Series. **Deccan Trap.**	*Rānikot* Series.	**Rānikot Series** of Sind. Paunggyi conglomerate of Burma.			*Lower Eocene.*
	South-East Coast Cretaceous. *Niniyur* Stage. *Ariyalur* Stage. *Lameta* Series. *Trichinopoly* Stage. *Bāgh* beds. *Utatur* Stage.	**Cretaceous of Central Himālayas.** Plutonic and volcanic rocks of Astor and Dras. *Flysch* of Central Himālayas.	*Disāng* Series of Assam. Intrusive granite, gabbros, and serpentine of Baluchistān and Burma. *Cardita beaumonti* beds.			*Danian.*
	Himatnagar sandstone. Marine *Umia* beds.	*Chikkim* Series of North Himālayas. *Giumal* sandstone of Spiti and Hazāra. Volcanic series and *Orbitolina* limestone of Burzil and Astor.	*Pab* sandstone of Sind and Baluchistān. Cretaceous of Assam and Burma. *Parh* limestone of Baluchistān.			*Cenomanian.* *Wealden.*
	Upper Gondwāna System. *Umia* Series. *Rājmahāl* Series. *Jabalpur* Series. *Kota* Series. *Umia* Series. **Marine Jurassic of Cutch** *Katrol* Series. *Chari* Series. *Patcham* Series. Marine beds in the East Coast Gondwānas.	**Jurassic of the Himālayas.** *Spiti* shales. *Kioto* limestone { *Tagling* Stage. *Para* Stage. (*Megalodon* limestone). *Tal* Series of Garhwāl. Oolite of Hazāra. Jurassic of Banināl.	Massive limestone of Baluchistān (Oolite). Black crinoidal liemstone of Baluchistān (Lias). *Saighan* Series of Afghānistan. *Namyau* beds of Northern Shan States. *Tabbowa* beds of Ceylon. *Loi-an* coal-beds.			*Jurassic.*
	Middle Gondwāna System. *Maleri* Series. *Parsora* Stage. *Mahādev* Series. *Pānchet* Series.	**Trias of the Himālayas.** Upper Trias. Middle Trias. Lower Trias (*Otoceras* zone).	Upper Trias of Baluchistān and *Napeng* beds of Burma.			*Triassic.*
	Lower Gondwāna System. *Damuda* Series. { *Rāniganj* Stage. *Ironstone* shales. stage. *Barākar* Stage. *Productus* bed of Umaria.	**Permian of the Himālayas.** *Zewan* Series of Kashmīr and the *Productus* shales of Spiti and the Central Himālayas. *Sirban* limestone and *Krol* Series of Kashmir & Simla.	*Plateau* limestone— Upper part, of the Northern Shan States.			*Permian.*
	Talchir Series. { *Karharbari* Stage. *Talchir* Stage. (Talchir boulder-bed).	**Gondwānas of Himālayas.** *Gangamopterius* beds of Kashmīr. *Panjāl* Volcanics. *Blaini* and *Tanakki* boulder-beds.	*Subansiri* beds of Assam.			*Permo Carboniferous.* *Upper Carboniferous.*
DRAVIDIAN GROUP		**Carborniferous of Spiti and Kashmīr.** *Po* Series of Spiti and *Fenestella* shales of Kashmīr.	*Plateau* limestone— Middle part, of the Northern Shan States. *Fusulina* limestone of Baluchistān.			*Middle Carboniferous.*
		Lipak Series of Spiti. *Syringothyris* limestone of Kashmīr.	*Plateau* limestone— Lower part, of the Northern Shan States. *Sarikol* Series of Chitrāl and Pamīr.			*Lower Carboniferous.*
		Muth Series of Spiti and Kashmīr. **Devonian** of Chitrāl. *Jaunsār* and *Lower Tanāwal* Series. *Deoban* Series.	**Devonian of Burma.** Crystalline limestones of Padaukpin. *Wetwin* shales.			*Devonian.*
		Silurian of Spiti and Kashmīr. Fossiliferous Silurian beds of Spiti and Kashmīr.	*Zebingyi* Series. *Namshim* sandstone.			*Silurian.*
		Ordovician of Spiti and Kashmīr. Fossiliferous Ordovician beds in Central Himālayas and in Kashmīr.	*Naung Kangyi* Series of Northern Shan States.			*Ordovician.*
	Upper *Vindhyans* of Madhya Bharat.	**Cambrian of Spiti and Kashmīr.** *Haimanta* System of Central Himālayas. Cambrian of North-west Kashmīr.	*Chaung Magyi* Series of Northern Shan States.			*Cambrian.*
PURANA GROUP	**Vindhyan System.** Upper { *Bhander* Series. *Rewah* Series. *Kaimur* Series. Lower { *Semri* Series : *Kurnool* Series : *Malani rhyolites* and *Jalor* and *Siwana granites.*	*Attock* slates of Peshāwar and Hazāra *Dogra* slate of Kashmīr. *Baxa* Series of Eastern Himālayas. *Simla* slate and *Deoban* Series of Central Himālayas.				*Torridonian.*
	Cuddapah System : Delhi System. *Upper Cuddapah.* *Lower Cuddapah* : *Raialo* Series.		*Miju* Series of Assam.			*Algonkian.*
ARCHAEAN GROUP	**Archaean.** **Dhārwār System : Arāvalli System.** *Iron-ore* Series. *Gondite* Series. *Sausar* Series. *Kodurite* Series.	*Vaikrita* Series of Spiti; *Jutogh* and *Salkhala* Series of Punjab Himālays ; *Daling* Series of Eastern Himālayas.	*Shillong* Series. Crystalline limestones, etc. of Burma. *Mergui* Series of Burma.			*Huronian.* ARCHAEAN
	Gneisses & Granites { *Charnockite* Series of S. India. *Bundelkhand gneiss.* *Bengal gneiss* and schistose gneisses of the Peninsula.	"Central gneiss" in part. Basement gneiss, granulite and schists.	Archaean fundamental gneiss and intrusive granites of Burma, Assam, Ceylon, Baluchistān, etc.			*Lewisian.*

into one mass and their subsequent fragmentation and drifting away across the oceans. They are inclined to believe in the permanence of all the continents and ocean basins of the earth since the beginning, with only subordinate movements of elevation and depression on lateral shift. According to these geologists, the making of India has been an evolutionary process. The two component crust-blocks were integral and adjacent parts, though each pursued a distinct geological course of events; one was a stable land-mass composed of ancient crystalline rocks and never, since the end of the earliest era of geology, submerged underneath the ocean; the other was a flexible and comparatively weak belt of the earth's circumference which was again and again submerged under sea-water and covered with hundreds of metres of marine sediments. The ridging up of the sedimentary pile from the sea-bottom into the great mountain wall of India is explained as due to tangential pressures which acted on this overloaded and consequently weakened zone of the crust, lying as in a vice between High Asia and the Deccan block. In contrast with the stable rocks of the Deccan block which have remained unfolded, the Himālayan segment of India has undergone colossal flexuring, thrusting and compression. During these earth plications, masses of igneous plutonic rocks, granites from the depths of the earth, have been pushed up through the sedimentary cover and now build the central zone of highest elevation of the Himālayas, from the snow-capped peak of Everest to Nanga Parbat on the Indus.

Table of geological systems

The Table, on pp. 119-120, gives the main outlines of the succession of rock-systems in the two divisions of India, arranged in the order of date and referred to the standard divisions of the geological time-scale accepted by the world. It gives also in a systematic chronological order the succession of the geological formations found in different parts of India, commencing with the oldest. The Indian Geological Survey have classified the rock-systems of India from the earliest records into four great groups : *Archaean, Purāna, Dravidian* and *Aryan*. These do not all correspond to the four divisions of European standard geological scale—Archaean, Palaeozoic, Mesozoic and Cainozoic—but are well adapted for a comprehensive grouping of the rock-systems of the Deccan, by reason of their character and peculiarities. It is only in the Himālayan region that a classification of rock-systems in terms of the European sequence can be established beyond doubt. The respective limits of the four main divisions in terms of European and standard geological time-scale are : the *Archaean* of India practically corresponding to the European Archaean; the *Purāna* era roughly corresponding to Algonkian and representing the rock-records of several hundred million years from the end of the Archaean to the commencement of the Cambrian; the name *Dravidian* is given to the rock-systems commencing from the Cambrian to the Middle Carboniferous; and the *Aryan* era which follows corresponds with the long sequence of systems beginning with the Upper Carboniferous; through the Mesozoic and Tertiary, to the Pleistocene. In the Table, the subdivisions of these groups as developed in the various parts of the country are shown with their approximate correlations to the standard stratigraphic scale of the world.

The following pages give a brief review of the successive rock-formations representative of the various geological periods found in India; it takes into account their chief rock components, their fossil contents, the geographical revolutions that happened during the ages, and the important economic mineral resources associated with the various systems of strata.

2. *The Archaean Era*

Archaean is the name given to the oldest rock-system in the world, forming the very basement on which all the succeeding divisions of the geological column rest. To these fundamental basement rocks of India composed of gneisses, schists and crystalline metamorphosed rocks, Sir Thomas Holland gave the name, *Vedic system*. This name, however, has not found acceptance in world geological terminology.

The Archaean rocks of India, in part at least, represent the first formed crust of the earth. They are also believed to be the earliest sediments, formed under conditions of the atmosphere and the oceans quite different from those existing at later dates, and subjected to an extreme degree of thermal and regional metamorphism. A large part of the Archaeans is believed to be highly metamorphosed and deformed igneous rock-masses under great earth-movements and stresses. The Archaean rocks cover approximately 2 million sq. km. of the surface of India in Madras, Mysore, Andhra Pradesh, Orissa, Madhya Pradesh, Chota Nāgpur and Rājasthān. They extend north-westwards along the chain of the Arāvallis, one of the oldest mountain ranges in the world, while they build a considerable though yet undetermined extent of the inner snow-covered ranges of the Himālayas from Kashmīr to

Sikkim. To the north-east, they extend from Bihār to the Assam plateau.

These rocks are thoroughly azoic, devoid of any vestiges of life. They are largely a mixture of gneisses, granites and schists, all thoroughly crystalline, and permeated by injections of igneous magma from the deeper plutonic parts of the subcrust. With these once molten crystalline rocks are associated clastic sediments which have undergone an extreme degree of metamorphism due to their subjection to the heat and pressure of the earth's interior. To this part of the Archaean complex, the name of *Dhārwār system* has been given. Due to the greater interest of these sedimentary Archaeans and the mineral and ore deposits associated with them, the Dhārwārs have received much study and attention from geologists. Owing to the widely divergent conditions under which these rocks were formed and their subjection to successive orogenic periods during the whole vista of geological time, now reckoned about 3,000 million years, the Archaean basement rocks everywhere possess an extreme complexity of character, and relations which have not yet been completely resolved.

The Dhārwār system

Though of the same age, and probably in some parts older than the associated Archaean gneisses and granites, the Dhārwār system of rocks is designated under a different name because of their special interest in Indian geology. These sedimentary strata appear to rest over the gneisses at some places with unconformity, while at others they are largely interbedded and interfolded with them. Although of undoubted sedimentary origin, the Dhārwārs are altogether unfossiliferous, a circumstance to be explained as much by their extreme antiquity, when no organic creatures inhabited the earth, as by the great degree of mechanical alterations and deformations they have undergone. These circumstances have led to the sedimentary nature of the Dhārwār rocks of several areas, notably in Mysore, being doubted by some geologists; they regard the bedded schists, limestones and conglomerates as of igneous origin. Field-work in Mysore, however, has clearly established the sedimentary nature of many terrains of Dhārwār rocks without any doubt. The main areas of Dhārwār rocks in India are southern Deccan, including the type area of Dhārwār and Mysore State, Karnātaka, Chota Nāgpur, Jabalpur, Rewa, Hazāribāgh, Shillong plateau, and the Arāvalli region in Rājasthān extending as far north as Jaipur. In the Himālayas, the Dhārwār system is well represented in the central and northern ranges.

This system is very well developed in the Karnātaka region and covers a large area there. The types of rocks found are volcanic acid and basic lava-flows and tuffs, crystalline schists and granites containing kyanite, graphite, garnet and corundum, together with metamorphosed sediments with conglomerates, phyllites, limestones, and basic and ultra-basic intrusives.

Distribution of the Dhārwār system

Homotaxial series of rocks developed in Rājasthān are known under the name of the *Arāvalli system*—they build the Arāvalli range, the most ancient mountain chain of India. Since then, the Arāvalli mountains have remained one of India's principal physical features. By their meteoric denudation they have contributed sediments to many subsequent geological systems. There is evidence that this mountain chain has received renewed post-Dhārwār upheavals. It is a closely plicated synclinorium of Dhārwār schists, quartzites, phyllites and slates together with composite gneisses, aggregating over 3,000 metres in vertical extent. The degree of metamorphism shown by these rocks is highly variable and there are exposures of almost unaltered Archaean slates in one part of the outcrop and highly altered hornblende-schists and schistose conglomerates in another. The outliers of the Arāvalli system are found as far south as Baroda in Gujarāt (*Chāmpāner series*).

Dhārwār rocks cover large connected areas in Madhya Pradesh, extending over to Bihār. In these areas, the system possesses a highly characteristic metalliferous facies of deposits which have attracted much attention on account of the ores of manganese and iron associated with it. The rocks are granulites, dolomite marble with mica, sillimanite, and hornblende-schists, in the Nāgpur and adjoining Districts (*Sausar series*). An upward extension of the Sausar series containing chlorite schists, jaspilites and haematitic quartzites is known as the *Sakoli series*. The famous "marble rocks" developed in the Narmada gorge belong to this system. In some parts of Madhya Pradesh, these rocks are distinguished by a richly manganiferous facies containing workable deposits of manganese-ores (*Gondite series*). Gondite rocks are found typically in the Bālāghāt and Nāgpur Districts as well as in the extension of these rocks in the old Bombay State and in Rājasthān. A similar series of manganiferous rocks found in the Vishākhapatnam area of Andhra, consisting mostly of Manganiferous sediments, metamorphosed by plutonic intrusives into hybrid crystalline rocks, is known as the *Kodurite series*.

The next important development is seen in Singhbhūm and Orissa. This area contains the well known mica fields of North India, in the Rānchi, Hazāibārgh and Gaya Disrticts. A geologically interesting development of the system is seen in South Bihār, Singhbhūm, Gāngpur and Mayūrbhanj areas in enclosing thick masses of richly ferruginous sediments (*Iron-ore series*). The Iron-ore series carries interbedded iron-ores of large dimensions, estimated to yield 8,000 million tonnes of high grade haematitic iron-ores. The question of the ultimate source of the iron-oxides and the exact processes which segregated them here on such a scale have been discussed by Indian geologists and they ascribe it variously to marine chemical precipitation, sedimentary deposition and metasomatic replacement of pre-existing sediments in a period of marked volcanic activity. The *Khondalite series*, a group of sillimanitegraphite schists, is of wide prevalence in Dhārwār areas.

Dharwar rocks of the Himālayas are found in Kashmīr, Garhwāl and in the Nepāl-Sikkim areas, where they are recognized by the name of *Salkhala series*, *Vaikrita series*, *Jutogh series* and *Daling series* respectively.

Economic importance of the Dhārwār system

The Dhārwār system, containing many of the principal mineral and ore deposits of the country, is of great economic importance. It carries the principal ore deposits of gold, manganese, iron, chromium, copper, beryllium, uranium, thorium and titanium. The Kolar gold-reefs produce over 7,100 kg. of gold annually; about 6 million tonnes of high quality iron-ore, over a million tonnes of manganese-ore, 100,000 tonnes of chromite and smaller quantities of copper are also produced every year. Lead and zinc are other minor products of this rock-system. The strategic atomic metal, thorium, occurs in the widely distributed mineral monazite. To the same system belong such industrial minerals as mica, corundum, graphite, precious and semi-precious stones, ilmenite, kyanite and columbite, which bring an annual revenue of several crores of rupees. The system is also rich in resources of monumental building stones--granites and marbles, for instance. These were the materials for the finest specimens of ancient Indian architecture, such as the South Indian temples and the Tāj Mahal at Āgra. Extensive spreads of heavy mineral sands on the Malabār and Coromandel Coasts—the source of valuable, rare compounds, monazite, ilmenite, rutile, zircon—are derived from the weathering of Dhārwār rocks.

3. *The Purāna Era*

After the termination of the Archaean era of geology, a long interval of unrecorded ages followed. In that period, earth-movements on a very extensive scale folded the Dhārwār sediments into complicated mountain ranges, which were subsequently worn down to the base-level. It is over the deeply denuded edges of the Dhārwār rocks that the basement of succeeding rock-formations rests.

The Ep-Archaean interval

These formations, known in Indian geology as the Purāna group, succeeded the Archaean-Dhārwār after an immense lapse of geological time, representative of many cycles of mountain-uplift and their complete weathering and erosion to the roots. The Purāna division is of great thickness, over 9,000 metres, consisting of wholly unfossiliferous slates, quartzites, sandstones and limestones, found developed in Rājasthān, the Cuddapah area of Madras, Andhra Pradesh and some Districts in Central India. Being of pre-Cambrian age, these rocks are still devoid of any identifiable forms of life preserved in them. The older subdivision of this group of rocks, the *Cuddapah system*, shows a much greater amount of structural deformation and metamorphism than the younger subdivision, the overlying Vindhyan group, which shows hardly any disturbance from its original horizontal stratification. As stated before, the Deccan plateau of India since the Dhārwār period has not undergone any orogenic mountain-building movement, or submergence under the sea.

Cuddapah system

Rocks of the Cuddapah group occupy large areas in the Cuddapah District of Andhra Pradesh and Chhattīsgarh in Madhya Pradesh. They are recognized in different parts of the country under the names *Bijawar series*, *Gwalior series*, *Cheyair series* and others. Some dykes of basic lavas penetrating the Bijawar series are believed to be the parent rocks of the famous "Golconda" diamonds. The *Kaladgi series* occurs in the country between Belgaum and Bijāpur, carrying some workable ores of iron. Other representatives of the Cuddapah are the *Kistna series* in the Krishna valley, *Pakhal series* in the Godāvari valley, and the *Raipur series* of Chhattīsgarh.

Delhi system

Rocks belonging to the *Delhi group* are of the same age as the Cuddapahs, though much more severely disturbed and folded, because of their involvement in Arāvalli orogeny. They occupy, besides the type area, wide areas in North-east Rājasthān, extending upto Delhi and forming prominent ridges there—hence they are known by this name. From Idar to Delhi they form narrow, constricted, eroded bands known as *Alwar* quartzites. These rocks have acquired a higher metamorphism also because of the intrusion of two phases of granite bosses (*Erinpura* and *Idar* granite). The constituent rocks of the Delhi system comprise 5,100 metres of slates, schists and hornstones, with massive development of limestones and quartzites. Over the whole of its extent, the Delhi system exhibits violent unconformity to the Arāvallis, while towards its overlying the *Vindhyan system* to the east, it shows a steeply faulted contact.

The main economic interest of the Cuddapah system is in its store of building stones, some workable deposits of barytes and asbestos, steatite, and bright-coloured jaspers.

Vindhyan system

The next succeeding system of strata, consisting of 4,200 metres of almost undisturbed or horizontally-bedded sediments, rests over the denuded surface of the Cuddapah rocks. It covers large tracts in Madhya Pradesh, where two well marked divisions of the system are observed—the Lower Vindhyans, composed of slates and shales with limestones and the Upper, composed exclusively of sandstones and some shales. Contemporaneous volcanic action is evident in the Lower Vindhyans of Rājasthān, which has a large development of lavas and volcanic matter (*Malani rhyolite*). The Lower Vindhyans in the Son valley are known as the *Semri series* and in the Bhīma valley they are known as the *Bhīma series*. South of the Narmada, in the Cuddapah basin, the same rocks are known as the *Kurnool series*, resting unconformably on the Cuddapah system.

The Upper Vindhyans, in their type area north of the Narmada, occupy a large part of the country and constitute three well marked divisions—the *Kaimur series*, the *Rewa series*, and the *Bhander series*.

Except for a few obscure traces of animal and vegetable life occasionally found in the Vindhyan sandstones, this system is devoid of any recognizable fossil remains. From the evidence of some primitive, obscure molluscoid and algal remains, the upper limit of the Vindhyan system is believed to extend to the Lower Cambrian period.

The Vindhyan system, though devoid of any metalliferous deposits, is of considerable economic importance because of its unlimited store of building stones of great beauty and durability. It has yielded building stones for some of the finest specimens of Indian architecture, such as the famous stupas of Sānchi and Sārnāth and the Mughal palaces of Delhi and Āgra. The modern Government edifices of Delhi are built of Upper Vindhyan sandstones. The famous "Golconda" diamonds, for which India was once a much-sought market, were derived from some conglomeratic bands interstratified with the Upper Vindhyans.

The Himālayan Purānas

The Himālayan representatives of the Purāna system are recognizable by their lithological resemblance with their Peninsular congeners, occurring in wide bands of metamorphosed sedimentary complex, separating the central axial ranges from the lesser Himālayan ranges. It is believed that formations such as the *Dogra slates*, *Simla slates* and a part of the *Dalings* of the Eastern Himālayas are extensions of the Peninsular Purānas, caught up in the Himālayan system of flexures. It was during the Vindhyan period that the Arāvalli mountains received their major uplift. Since then, the Peninsula of India has experienced no orogenic movement of the crust of any significant nature.

4. *The Dravidian Era*

The Dravidian era covers the largest section of the Palaeozoic time, from the Cambrian to Middle Carboniferous. But unlike in the rest of the world, this era is unrepresented in the Deccan almost in its entirety. In the Himālayan zone and its extensions in the surrounding regions, on the other hand, the whole group is found developed in a more or less continuous sequence of marine strata. These, by reason of their well preserved fossil remains, can be correlated with their European parallels with sufficient accuracy to warrant their designation by standard stratigraphic names such as Cambrian, Silurian, Devonian, and Lower and Middle Carboniferous.

Palaeozoic record missing in the Deccan

In the Deccan, these geological periods are completely missing; for, succeeding the Vindhyans there is a total blank in the geological sequence. In other words, a number of geological ages passed away without leaving any record of rocks and signifying that no sedimentation took place in these vast intervals of time; but the surface of the Deccan land-mass remained exposed to denudation and the wear and tear of meteoric forces. We might compare the geological record as preserved in the Deccan to a manuscript of history out of which entire sections dealing with groups of dynasties have been torn out, several others mutilated or damaged, and only a few chapters left decipherable.

The materials for the geological history of India during the Dravidian era are to be sought in the extra-Peninsular mountain zone and outlying terrains such as the Salt Range of West Punjab, Chitrāl and Hazāra in Pākistān, and Burma. The representatives of the Cambrian system are to be found in Kashmīr and in Spiti, where a complete and conformable sequence of marine fossiliferous strata, many thousands of metres thick, is found. The characteristic Cambrian fossils at these localities are trilobites and brachiopods, *Agnostus*, *Olenus* and *Lingulella*, which fully establish the homotaxy of the Himālayan Cambrian with the Cambrian of the rest of the world.

The Cambrian Period of the Himālayas

Massive beds of pure crystalline salt aggregating 170 metres in thickness, associated with gypsum, underlie the Cambrian succession in the Salt Range mountains at Khewra in Pākistān. The exact structural relations of the salt with the overlying *Neobolus*-bearing Cambrian beds is not clear and some geologists believe that the salt is of Tertiary age and its present position is the result of an underthrust.

Overlying the Cambrian in both Kashmīr and Spiti areas, there come variable thicknesses (600-900 metres) of Ordovician, Silurian and Devonian rocks, characterized by their typical fossil remains, trilobites, brachiopods, corals and crinoids bearing close affinities with the Palaeozoics of Europe and North America. The Kashmīr sequence is fuller and more widely distributed than the Spiti sequence, though its fossil remains are not so diversified or abundant as in Spiti.

Ordovician, Silurian, Devonian & Carboniferous strata

Overlying the Devonian in both these localities are 900 metres of Lower and Middle Carboniferous strata designated under the names of the *Syringothyris limestone* and *Fenestella shales*. These contain a succession of marine faunas of molluscs, trilobites and corals, which enable a more or less precise classification of the record into series and stages. In the rest of the Himālayas there are vast tracts which are yet geologically unexplored; in these, representatives of the marine Palaeozoic systems are yet unknown. The only other area where marine fossiliferous Palaeozoics occur is Chitrāl, beyond Hazāra, in Pākistān. But here also large gaps occur and several of the Palaeozoic systems are missing. These facts suggest that the enormous land period of the south prevailed also in this part, and that the shores of the northern sea in which the Himālayan Palaeozoics were laid down barely touched North-west Punjab at long intervals. Altogether, the Dravidian era of geology for the greater part of India has left but a sketchy and interrupted record of the life and events of the time and at only a few localities.

5. *The Aryan Era—Upper Carboniferous to Pleistocene*

We may now turn to the next, the *Aryan era,* commencing from the Upper Carboniferous, for a connected story of India's past geography and geological history, which is preserved in some degree of fullness in the Peninsula and in a long and perfectly legible sequence of events in the Himālayan range along its entire northern (Tibetan) border.

Physiographical changes

With the end of the Middle Carboniferous, the second era of geological time-scale in India ended. Before proceeding to the description of the succeeding era, we have to consider a great revolution in the physical geography of India at this epoch, by which profound changes were brought about in the relative distribution of land and sea. The readjustments that followed these crust-movements brought under sedimentation large areas of India which hitherto had been exposed land-masses. An immense tract of India now forming the northern zone of the Himālayas was submerged under the waters of a sea which invaded it from the west and overspread North India, Tibet and a part of China. This sea, the great *Tethys* of geologists, was the ancient central mediterranean ocean which encircled almost the whole of the earth equatorially at this period of its history, and divided the continents of the northern hemisphere from the southern hemisphere. It retained its hold over the Himālayas for the whole length of the Mesozoic era and gave rise, in the geosynclinal trough that was forming at its floor, to a system of deposits which recorded a continuous history of the ages between the Permian and the Eocene. This long cycle of sedimentation constitutes the second and last marine period of the Himālayas.

During this interval, the Peninsula of India underwent a different cycle of geological events. The Upper Carboniferous movements interrupted its long unbroken quiescence since the Vindhyan. Although the circumstance of its being a horst-like segment of the crust gave it immunity from deformation of a compressional or orogenic nature, yet it was susceptible to another kind of crust-movements characteristic of such land-masses. These manifested themselves in tensional cracks and in the subsidence of large linear tracts in various parts of the country between more or less vertical fissures of dislocation in the earth (block type of earth-movement), which eventually resulted in the formation of chains of basin-shaped depressions on the old gneissic land. These basins received the drainage of the surrounding country and began to be filled by its fluviatile and lacustrine debris. As the sediments accumulated, the loaded basins subsided more and more. Subsidence and sedimentation going on *pari passu*, there resulted thick deposits of freshwater and subaerial sediments, thousands of metres thick, entombing among them many relics of the terrestrial plants and animals of the times. These records, therefore, have preserved the history of the land surface of the Indian continent, as the zone of marine sediments, accumulated in the geosynclinal of the Northern Himālayas, have preserved that of the oceans. Thus, a double facies is recognizable in the two deposition areas of India in the systems that followed—a marine type in the extra-Peninsula and a freshwater and subaerial type in the Peninsula.

The commencement of the Aryan era (Upper Carboniferous of the standard stratigraphical scale) as stated above ushered in an epoch of powerful earth-movements and of profound geographical changes. These changes were initiated by an Ice Age, which has left its characteristic marks at a number of centres over India, from the Outer Himālayas to Orissa, in glacial till, boulder-beds and conglomerates. The extra-Peninsula from Hazāra in Pākistān to the extreme east of Assam now enters upon a long marine period receiving a vast pile of marine sediments, encompassing the whole of the Mesozoic and a part of the Cainozoic era. These deposits today form the bulk of the Inner Himālayas.

In the Deccan, as stated before, the end of the Dravidian and the beginning of the Aryan era brought in a different kind of earth disturbances and a new chain of events. The drainage of a vast continental land-area, discharging its sediments into a chain of inland depressions and basins, has preserved in them countless remains of land-inhabiting plants and animals, which today are valuable documents of past life and geographic conditions prevailing during the middle ages of earth history.

Henceforth, the succeeding Palaeozoic and Mesozoic systems exhibit a marine facies in the extra-Peninsula and a freshwater and terrestrial type of deposits in the rest of India. This latter system of Mesozoic land deposits is known in Indian geology as the *Gondwāna system*—from the typical basins of these rocks in the Gondwāna country to the south of the Narmada valley, where they were first studied and brought to the notice of the world.

Table of correlation of the series and stages of the Gondwāna System in different parts of Peninsular India

System. Series. Stages.	Dāmodar Valley	Rājmahāl	Son & Mahānadi Valleys	Sātpura	Godāvari Valley	East Coast	Cutch	Age
Upper Gondwāna { **Umia..**	—	—	—	—	—	*Tripetty, Pavalur,* etc.	*Umia.*[3]	*Lower Cretaceous.*
Jabalpur. **Rājmahāl.**	*Rājmahāl.*	*Rājmahāl.*	*Jabalpur.* (*Athgarh* Sandstone).	*Jabalpur.* *Chaugan.*	*Chikiala.*	*Raghavapuram,*[2] *Sripermatur*, etc.	*Jabalpur.*	*Upper Jurassic.*
Kota.[1]	—	*Dubrājpur* Sandstone.	*Chicharia.*	—	*Kota.*	*Golapilli* and *Budavada*[2] stages.		*Lias.*
Middle Gondwāna { **Maleri and. Parsora.**	—	—	*Tiki.* *Parsora.*	*Bagra.* *Denwa.*	*Maleri.*	—		*Keuper* and *Rhaetic.*
Mahādev (or Pachmarhi)	*Durgāpur.*	—	—	*Pachmarhi.*	—	—		*Muschelkalk.*
Pānchet.	*Pānchet..*	—	—	*Pānchet.*	*Pānchet* or *Mangli.*	—		*Bunter.*
Lower Gondwāna { **Damuda.**	*Rānīganj.* *Ironstone shales* (Barren measures).	—	*Himgir.*	*Bijori.*	*Kāmthī.*	*Chintalpudi* Sandstone.		*Upper Permian.*
	Barākar.	*Barākar.*	*Barākar.*	*Motur.* *Barākar.* *Umaria* marine beds.	*Barākar..*	—		*Middle Permian.*
Talchir.	*Karharbari.* *Talchir.*	— *Talchir.*	*Karharbari.* *Talchir.*	*Karharbari.* *Talchir.*	— *Talchir.*	— —		*Upper Carboniferous.*

1 The relationship of the *Kota* and *Rājmahāl* stages is uncertain; possibly the Kota beds are younger than the Rājmahāl..
2 These beds are now assigned to the Lower Cretaceous.
3 The lower Umia beds are uppermost Jurassic.

The Gondwāna System

Upper Carboniferous to Jurassic

The enormous system of continental deposits known as the *Gondwāna system* forms one conformable and connected sequence of strata, aggregating over 6,000 metres in thickness, divided into a number of series and stages (Table p. 132). Investigations in other parts of the world—South Africa, Madagascar, Australia and South America—have brought to light a more or less parallel group of continental formations exhibiting much the same physical as well as stratigraphic and palaeontological characters. From this firmly established evidence, it is argued by geologists that land connection existed between these distant regions across what is now the Indian and South Atlantic Oceans, forming one continuous southern continent, which united within its borders South America, South Africa, India and Australia. It is now believed from further evidence that large parts of the Antarctica also formed a unit of Gondwānaland. The northern frontier of the Gondwāna continent was approximately coextensive with the central chain of high peaks of the Himālayas and was washed by the waters of the Tethys sea.

The Gondwāna system is in many respects a unique formation which has preserved the history of land surface of a large segment of the earth for a vast measure of time. It is entirely composed of fluviatile and lacustrine land deposits, in which are preserved numerous terrestrial plants, insects, fishes, amphibians and reptiles, as in the alluvial deposits of modern river valleys. Climatic vicissitudes, from arctic cold of the Glacial Age to tropical and desert conditions, are readable in the occurrence of characteristic strata enclosed in this thick pile of sediments. Its mode of origin is also unique. The rivers deposited their detritus into faulted depressions; these, through the continually increasing load of sediments poured into them, kept on sinking relatively to the surrounding Archaean and Vindhyan country from which the sediments were derived.

This system is of wide distribution in Eastern and Central India in the valleys of the Dāmodar, Mahānadi and Godāvari rivers; in Madhya Pradesh; in the Sātpura mountains; and in small patches in the Salt Range mountains of West Punjab in Pākistān, Kashmīr and Sikkim. The accumulated drift of the dense forest vegetation covering Central India in those times has given rise to thick buried seams of coal interbedded with the lower part of the Gondwānas, which thus constitutes one of the most productive rock-formations of India.

The Talchir Ice Age

At the base of the Gondwāna is a group of strata known as the *Talchir series*, widespread from Hazāra to Orissa, composed of boulder-beds, containing an assortment of ice-scratched pebbles, and boulders of all sizes up to several cubic metres embedded in a fine-grained matrix such as is typical of glacial deposits of the Ice Age. These beds testify to the prevalence of glaciers and ice-sheets covering the land surface of India from as far north as lat. 33° to lat. 20°N. A parallel series of glacial boulder-beds at the same horizon occurs in the Upper Carboniferous of South Africa, Australia and parts of South America. The glacial series is overlain by a thick succession of strata with interbedded coal measures aggregating 2,400 metres in thickness, which is recognized in Indian geology as the *Damuda series*. The Damuda series carries the most important coal deposits of India, supplying 55 million tonnes of coal per year. A wealth of fossil plants, chiefly cryptogamic, occurs in the Damudas, of which *Gangamopteris* and *Glossopteris* are the most important and typical. Other plants are of the order of ginkgos, cordaites, ferns, equisetums and lycopods.

Vegetation and animal life

The Damuda series is succeeded by a thick group of Middle Gondwāna beds belonging to the three series, *Pānchet*, *Mahādev* and *Maleri*, which in geological age are coeval with the Triassic system of Europe. These strata bear witness to a climatic revolution in which the luxuriant forest vegetation of the previous age had disappeared and desert conditions supervened, throughout its 3,000 metres of barren sandstones and red clays, carrying few plant remains but entombing many fossil fish, amphibians and reptiles. Among these are the labyrinthodonts, *Mastodonsaurus* and *Gondwanosaurus*, from the Maleri beds of Sātpura. This group is well displayed in the Sātpura range, forming important constituents of the Mahādev and Pachmarhi hills of Madhya Pradesh and over a long stretch of country in the erstwhile Hyderābād State.

Upper Gondwāna—flora and fauna

The upper division of the Gondwāna system, from the evidence of the few fossil reptiles and preponderance of ferns, conifers and cycads, is determined to extend in geological age from the Jurassic to Lower Cretaceous. Outcrops of Upper Gondwāna are seen at a number of localities from the Rājmahāl hills in Bihār to the neighbourhood of Madras. The Upper Gondwāna flora, consisting of preponderant cycads belonging to the genera *Ptilophyllum*, *Williamsonia*, etc., marks a distinct advance in modernity over the *Glossopteris* flora of the Damuda age of Lower Gondwāna. These strata, grouped into the *Kota, Rājmahāl, Jabalpur* and *Umia series*, are typically seen in the gigantic escarpments of the Sātpura range and in a large outcrop in the Godāvari basin. There are also solitary outcrops along the Coromandel Coast. In the Rājmahāl hills of Bihār, a more massive development of the Upper Gondwānas is observed, resting unconformably on the Damuda series. Here the Upper Gondwānas are associated with 600 metres of volcanic eruptions, basalts and dolerites. The Rājmahāl series is distinguished by its rich, classical assemblage of cycads, ferns and conifers. The Rājmahāl cycad flora is believed to be the direct ancestor of modern angiosperms. For Kutch and Kāthiāwār, the Upper Gondwānas have a special interest, since they are intercalated with marine Upper Jurassic strata containing cephalopods and lamellibranches. The full sequence, 900 metres thick, is seen at Umia in Kutch. Near Wadhwān in Kāthiāwār is seen another outcrop of the Umia series.

Parallelism with Australia and South Africa

The fossil flora and fauna found in Brazil, Australia, Madagascar and South Africa from parallel groups of deposits resting upon basal glacial conglomerates, possess striking affinities with the Indian Gondwāna flora and fauna. From this fact the conclusion is drawn that this old-world Gondwāna continent persisted as a prominent feature of the southern hemisphere from the end of the Palaeozoic to the beginning of the Cretaceous. It then disappeared as a geographic entity by fragmentation into constituent units, some of which foundered under the waters of the ocean, forming parts of the Indian Ocean, the Arabian Sea and the Bay of Bengal. Another theory ascribes the dismemberment of the once compact Gondwāna continent to its breaking up through fissures and the drifting away of the constituent blocks of Australia, India, Arabia, South Africa and South America across the oceans in various directions to their present positions. (See Table of *series* and *stages* of the Gondwāna system at p. 132).

Gondwāna coal reserves

India's estimated reserves of Gondwāna coal are of the order of 50,000 million tonnes, of which about 95 per cent are contained in the coal measures of the Lower Gondwānas. In general, Gondwāna coals are bituminous, good quality steam and gas coals, with 11 to 28 per cent ash, and of 6,000 to 7,500 calorific value. Anthracite coal is rare and deposits of coking coal are confined to 3 or 4 Bihār coal-fields. But good quality metallurgical coke is being produced by washing and blending semi-cooking varieties with Jharia coal.

A totally different succession of geological events was taking place in the north during the Gondwāna era, resulting in the formation of quite different set of rock-records. Commencing from the Upper Carboniferous, these rock deposits were laid down on the broad basin of the Tethys, the mediterranean sea which extended from the south-west extremity of China to the Atlantic end of the present Mediterranean (the small remnant left after the disappearance of the Tethys). In this pile of marine sediments, more than 9,000 metres thick, representatives of the Upper Carboniferous, Permian Trias, Jurassic, Cretaceous and Eocene periods are found, containing well preserved suites of characteristic fossils. The wealth of fossil life preserved in the Himālayan Mesozoic is described in a series of voluminous Geological Survey of India publications, the *Palaeontologia Indica* series, by a number of distinguished European scientists. The rock-systems are clearly exposed in magnificent escarpments to the north of the Central Himālayan axis in Kashmīr, Spiti, Garhwāl, Nepāl and further east in Sikkim, where the Tibetan plateau ends in gigantic cliffs. In their lithologic constitution as also in their contained fossils, these systems show kinship with the Alpine and other European Mesozoic areas rather than with the marine Mesozoic of South India. The North Himālayan profile sections are known as some of the most perfect and legible expositions of the stratified crust of the earth. There are no unconformities or lost intervals in them.

Aryan era in the Himālayas

Portions of the sea-floor subsiding in the form of immense troughs concurrently with the deposition of great thicknesses of sediments are called geosynclines and the Himālayan rock-sequence furnishes one of the best illustrations of geosynclinal formations. The immense and continuous accumulation of deposits in one belt, by overloading it, disturbs the gravitative equilibrium of the crust in course of time; consequently, the overloaded and weakened belts come to be wrinkled up by tangential, compressive earth forces to form the mountain chains of the world.

In Kashmīr, the Permo-Carboniferous system attains a thickness of some 6,000 metres composed of a varied assemblage of rock types, sedimentary and volcanic, marine as well as freshwater. A well marked unit among them is the *Productus limestone*, bearing the brachiopod genera *Productus* and *Spirifer*, indubitable index fossils of the Permian age, succeeded by slates and a great thickness of volcanic eruptives, both lava and pyroclastic (*Panjāl* trap). This is in turn succeeded by a well developed sequence of Triassic strata,

Marine Mesozoic of Kashmīr

mostly composed of fossiliferous limestones, in which the preponderant fossils are numerous genera of *Ammonites*, *Otoceras*, *Ophiceras* and *Meekoceras*, well displayed in the cliffs of the Sind and Liddār valleys and in Gurais. The fully developed Triassic system is succeeded by a series of calcareous and argillaceous strata showing a less perfect, patchy and fragmentary development of the Jurassic and Cretaceous, both in respect of the area they cover and in their fossil remains.

Sequence in Spiti

In the Spiti area, at the back of the crystalline axis of the Kāngra Himālayas, is witnessed a fuller and more perfect sequence containing all the series and stages of the Permian, and the Triassic, Jurassic and Cretaceous, encompassing the whole range of the Mesozoic. This contains a succession of varied fossil faunas of Alpine and European affinities, mostly composed of cephalopods and lamellibranchs. From the testimony of its fossils, the Spiti sequence is divided into systems, series and stages correlated to the homotaxial divisions in the rest of the world. Notable among these for its faunal wealth is the *Spiti shales* (Jurassic) which forms a well marked horizon of Jurassic strata stretching almost uninterruptedly from the Pamīrs and Hazāra to Nepāl and Bhutān. At the top of the Mesozoic of Spiti are the *Giumal* and *Chikkim* series of the Cretaceous, which are equally well recognized in the Hazāra, Kashmīr and Garhwāl Himālayas by their characteristic lithology and fossils. These formations are well displayed in the complete sequences in the Tibetan cliffs north of the Himālayas. The eastern part of the Himālayas has, however, not received the same attention from geologists as the mountains of Hazāra, Kashmīr and Simla, and the Karakoram.

The summit of Mount Everest is formed of a Permo-Carboniferous limestone, succeeded on its northern flank by a continuous conformable succession of Permian, Trias, Jurassic and Cretaceous formations, sloping away towards the Tibetan plateau.

Representatives of the Himālayan Mesozoics are seen in different degrees of completeness in the trans-Indus mountains, in the Sind-Baluchistān ranges and in the Salt Range in Pākistān on the west, and in the Arakan Yoma and the Shan plateau of Burma on the east.

Mesozoics of the rest of India

As stated earlier, during this long succession of geological ages, there were no marine deposits laid down in Peninsular India. But in an extensive fringe area of Kutch-Kāthiāwār and in Jaisalmer (Rājasthān), representatives of marine, Jurassic and Cretaceous, do occur. They are, however, deposits of an arm of the Southern Sea peopled by a fauna different from that of the Alpine-Himālayan province, having more affinities with Jurassic-Cretaceous of Madagascar, Transvaal and Brazil. During the Jurassic and Cretaceous, these few interludes of marine periods in the Deccan are of importance and much interest. These took place during minor inroads of the Southern Sea, on the coastal fringes of the Peninsula, which was by then partly severed from its African and Australian connections. In the most important of these, the Upper Jurassic in Kutch, there was laid down 1,800 metres of limestones, sandstones and shales containing an extraordinarily diversified assemblage of ammonite genera with thousands of species. This is divided into four series—*Patcham, Chari, Katrol* and *Umia*. The marine transgression of Kutch extended north-west as far as Jaisalmer in Rājasthān and southwards to Kāthiāwār. In another of these transgressions of the sea during the Middle and Upper Cretaceous over the Tiruchchirāppalli coast in Madras, a larger area was submerged and covered with 900 metres of richly fossiliferous marine limestones, regularly bedded sands, argillaceous and calcareous beds, resting upon the much-worn ancient land surface of Archaean gneisses.

The Cretaceous of the Madras coast is divided into three series : *Utatur, Trichinopoly* (Tiruchchirāppalli) and *Ariyalur series*. The highly diversified life of the period is preserved in numerous fossil brachiopods, corals, gastropods, cephalopods and lamellibranchs, together with a few reptilian remains. In a third invasion of the sea, in a narrow inlet along the Narmada valley penetrating as far as Jabalpur, a small thickness of Cretaceous coralline limestones and marls were laid down, which are today seen in a number of small detached outcrops near Baroda and Gwalior and in Kāthiāwār; these are known as the *Bāgh* beds.

Assam had a similar temporary invasion of the Southern Sea during the Lower Cretaceous, vestiges of which are seen in patches of marine fossiliferous limestones, overlying the ancient crystalline foundations of gneisses. The geological records left by these marine incursions throw much light upon the palaeogeography of India during the successive Mesozoic periods and at the end of that era. India was then still separated by a sea from the mainland of Asia, but its severance from Australia and Africa through disruption of Gondwānaland had begun and advanced to a certain stage, the complete severance being accomplished subsequent to the Trichinopoly Cretaceous.

It is interesting to note that the fauna of the Bāgh beds, though of the same age, differs materially from the fauna contained in the Assam and Trichinopoly Cretaceous, the two belonging to diverse marine zoological provinces. Assam and Madras then formed with South Africa one common and continuous coastline of the Southern Sea, while the two arms of the sea were separated by an impassable barrier—the whole width of the Gondwāna continent.

The Deccan Traps

The end of the Cretaceous and the beginning of the Eocene was a period of intense volcanic activity in the Deccan of a type that has no parallel in the volcanic phenomena of the modern world. Several hundred thousand square kilometres of Mahārāshtra was flooded by quiet outflows of lava from fissures in the earth's surface which was eventually converted into a volcanic plateau over 1,800 metres in height and more than 1,000,000 sq. km. in area. The denudation of ages has carved out this plateau into numerous isolated flat-topped hill-masses which are today such a characteristic feature of the picturesque landscapes of the Western Ghāts. In the dissected sides of these peculiar Ghāt-shaped hills are seen today the piles of interbedded lava-flows, 6 to 24 metres thick in horizontal attitudes, separated occasionally by thin partings of lake or river-sediments. These *intertrappean* beds are fossiliferous and are thus valuable in preserving the relics of plant and animal life that inhabited the surrounding area during quiescent intervals of volcanism. The petrified vegetation obtained from these beds bears witness to the advanced, and more evolved forms of life of the Gondwāna period. The era of modern vegetation and plant life had already set in.

Much interest also attaches to the old much-worn land surface on which the perfectly stratified thousands-metres-high lava pile rests. In Mālwa, Madhya Pradesh and many other parts is observed, at the base of the Deccan Traps, a thin variable group of lacustrine limestones, cherts and grits—*Lameta series*. From the Lametas of Jabalpur, remains of 12 genera of fossil dinosaur reptiles have been discovered, including *Titanosaurus* and *Megalosaurus*, closely allied to the fossil giant dinosaurians of Brazil and Madagascar together with remains of crocodiles, iguanodons and lizards.

A very remarkable character of the lavas of the Deccan Traps, having a bearing on their mode of origin, is their persistent horizontality of bedding throughout the wide area covered by them from Bombay to Nāgpur and from Indore to Dhārwār. It is only in the neighbourhood of Bombay that a gentle dip is perceptible in the trap strata, of about 5° to 10° towards the sea.

In petrological composition, the Deccan basalts are monotonously uniform. The most common rock is an olivine-free augite-basalt, which persists undifferentiated in composition from one extremity of the trap area to the other. The rock is often vesicular and scoriaceous, the amygdules being filled by chalcedony, quartz and varieties of zeolites. Porphyritic varieties often occur with phenocrysts of felspars. Over an enormous extent, there is no evidence at all of any magmatic differentiation. A few notable exceptions, however, have been observed in Kutch and in the Girnār hills of Kāthiāwār, where rocks of more acid or ultra-basic composition have been found associated with the basalts. In these localities are found varieties of rhyolites, monzonites, andesite, limburgite and gabbro, which are believed to be post-trappean intrusions of differentiated types, proceeding from the same magma reservoirs.

Mode of eruption

The actual mode of eruption of these enormous lava floods (originally spreading over more than 1,030,000 sq. km. and at present reduced through denudation to 515,000 sq. km.) is believed to have been discharged through long linear fissures from which a highly liquid magma welled out and spread in wide horizontal sheets. That the eruptions were not of violent volcanic nature is easily borne out by the absence of any coarse agglomerates or any vestiges of cones and craters of the usual type. Similar gigantic outpourings of lava have been observed in other parts of the world, e. g., in the plateau of Idaho in the U.S.A. and the Abyssinian plateau in East Africa.

There are many proofs of the existence of original fissures from which the lava welled out in extensive, wide fissure-dykes; these have been mapped along the periphery of the trap area. Massive dykes, several kilometres in length and of great width have been observed. Contemporaneous igneous action both in its volcanic and plutonic phases took place on a wide scale in the inner ranges of the Himālayas, particularly in the Kumaun-Johar region, where masses of acid and basic lavas have flooded large areas, alternating with bosses of gabbro, peridotite and granite.

Age of the Deccan Traps

There is no conclusive internal evidence in the Deccan Traps themselves regarding their exact age. But the external evidence furnished by the underlying and overlying marine and estuarine strata is adequate. The eruptions were certainly subsequent to the Bāgh beds (Cenomanian), which they overlie at some places. Another indication is provided by the interstratification of some basal flows of the traps with *Cardita beaumonti* beds, whose horizon is indicated as uppermost Cretaceous. At one or two places on the West Coast, the traps are seemingly unconformably overlain by outliers of Eocene Nummulitic limestones, as at Surat and Broach.

In the Godāvari delta, a distant outlier of the traps occurs on the top of marine Cretaceous sandstones of Ariyalur age. Further evidence of a rich fossil flora occurring in intertrappean beds in the Nāgpur-Chhindwāra area and containing fossil *Nipadites* and *Azolla* is also indicative of the Eocene age. The stratigraphic horizon of the Deccan Traps is now regarded as covering the period from Upper Cretaceous to Lower Eocene.

Save for an unlimited store of road metal and the less attractive kinds of building material, the lavas of the Deccan volcanic series possess no mineral resources of any value. The ornamental stones, agates, carnelian, etc., for which Cambay was once a noted market, are derived from the filled-up cavities and steam-holes of the lava-flows. The black "cotton" soils of many Deccan Districts are believed to be the subaerial decomposition products of the surface flows of the lavas of the Deccan Traps.

Tertiary systems (Cainozoic era)

In Europe, the end of the Cretaceous and the beginning of the Eocene is marked by an abrupt hiatus. A sudden and striking change in the fauna and flora takes place and new and more advanced types of creatures make their appearance. The class of reptiles, the pre-eminent vertebrates in the later part of the Mesozoic, undergo a decline and the less developed types of mammals begin to take precedence with the commencement of the Eocene. Amongst the invertebrates, the cephalopods suffer widespread extinction and their place is taken by the gastropods, which enter on the period of their maximum development. In India, although these changes in the history of life are well marked, no sharp stratigraphic unconformity between the Cretaceous and the Eocene, as in the rest of the world, is observed.

The Tertiary era is highly important in the physical history of the Deccan as well as the Himālayas. The most important surface features of India were acquired during this period and the present configuration of the country outlined. With the middle of the Eocene, secular (slow and continuous) earth-movements began, and that materially altered the geography of the Indian region.

Breaking up of the Gondwāna continent

The great events of geodynamics stand out prominently in these readjustments: one was the final break-up of the Gondwāna continent by the submergence of large segments of it under the sea; the other was the uplift of the Tethyan geosynclinal tract of sea-deposits to the north into the lofty chain of the Himālayas. These two events were coeval with the prodigious outbursts of igneous volcanic and plutonic action that took place at the end of the Cretaceous. The transfer of over two hundred thousand cubic kilometres of magmatic matter from the inner subcrust layers to the outer crust of the earth could not but be accompanied by profound disturbances of the isostatic equilibrium of the earth's outer shell.

Elevation of the Himālayas

The pile of marine sediments that was accumulating in the Tethys since the Upper Carboniferous began to be upheaved by periods of orogenic movement of great magnitude, alternating with quiet intervals. From the Middle Eocene to the end of the Tertiary, this upheaval continued in three intermittent phases. The first of these was post-Nummulitic, towards the end of the Eocene. The second took place about the middle of the Miocene. The third uplift, the most important phase, was in the post-Pliocene age, which elevated the axial part of the range together with the outer Siwālik foot-hills, to form the present Himālayan chain. This phase did not cease till after the middle of the pleistocene.

After the breaking up of the Gondwānaland, the Peninsula of India began to acquire its present restricted triangular form.

Distribution of Tertiary system

A most unequal distribution of the Tertiary rocks is observed in Peninsular and in extra-Peninsular India. In the Deccan, a few outcrops of small lateral as well as vertical extent are exposed in the vicinity of the coasts of Kerala and Gujarāt. In Kutch, the Tertiary rocks are seen in a more connected sequence overlying a large area of the Deccan Traps. A somewhat larger area is covered on the East Coast by marine coastal deposits of the Eocene, Miocene and Pliocene ages of which the most important is known as the *Cuddalore sandstones*. The Cuddalore sandstone stage (Mio-Pliocene) is of interest. At Neyveli, it encloses thick seams of brown coal (lignite), estimated to contain 2,000 million tonnes of much needed fuel in South India.

An enormous superficial extent of the extra-Peninsular country is covered by Tertiary rocks in a belt running along the foot of the mountainous region. It starts from the southernmost limits of Sind and Baluchistān and runs along the North-West Frontier Province of Pākistān, through the trans-Indus ranges, to the North-western Himālaya border, where it retains a great width; from there the Tertiary band continues eastwards, with a diminished width of outcrop, flanking the foot of Punjab, Kumaun, Nepāl and Assam Himālayas, up to the gorge of the Brahmaputra. Thence the outcrop continues southwards with the acute syntaxial bend of the Himālayan tectonic strike. It is here that the Tertiary system attains its greatest and widest superficial extent passing over Eastern Assam, building the core of the Assam-Burma frontier ranges

Correlation of Tertiary formations

	Kashmīr and Punjab	Kumaun Himālayas	Sind and Gujarāt	Peninsula (South)	Assam	Burma
Recent	*U. Karewas*	Sutlej alluvium	Indus alluvium	Newer river deposits; deltas	Brahmaputra alluvium	Irrawaddy alluvium laterite
	III & IV Glacial					
Pleistocene	*3rd Himālayan Upheaval*		Rann of Kutch	Older human artifacts;		
	II Glacial I Glacial			Older alluvium		
	L. *Karewas* and U. Siwālik	U. Siwālik				
Pliocene	M. Siwālik	M. Siwālik	Dwārka Manchar	Kārikāl (?) Cuddalore and Warkalli	Dihing Dupi Tila Tipam	Irrawaddy
Miocene U.						
Miocene M.	L. Siwālik	L. Siwālik		Quilon		U. Pegu
	2nd Himālayan Upheaval		Gaj			
Miocene L.	Murree	Kasauli Dagshai	U. Nari	Baripāda	Surma	
				Widespread Unconformity		
Oligocene	Absent	Absent	L. Nari		Barail	L. Pegu
	1st Himālayan Upheaval (Intrusive Granite)					
Eocene U.	Kīrthar (Chharat)		Tāpti Kīrthar	Eocene of Pondicherry	Jaintia and Disāng	Eocene
Eocene M.	Laki Rānīkot	Subathu	Laki	Deccan Trap (top part)		
Eocene L.			Rānīkot			

Note : U. stands for Upper, M. for Middle and L. for Lower.

and spreading out in Upper and Lower Burma, to the extreme south of Burma. In all these areas, the Tertiary rocks enter largely into the architecture of the outer flank of mountain ranges.

All through this extent of country, the Tertiary strata exhibit a dual facies of deposits a lower marine facies characterizes the Eocene and Oligocene from Sind to Burma, and an upper fluviatile and subaerial, the Miocene and Pliocene. This is due to the fact that the sea in which the early Tertiary strata from Eocene to Lower Miocene were laid down was gradually filling up and was being driven back by an uprise of the bottom. It steadily retreated southwards from the two extremities of the Himālayas, the eastern end towards the Bay of Bengal and the other towards Sind and the Rann of Kutch. River and estuarine deposits continued after the Middle Miocene to be laid down on the site of the obliterated sea-bed.

The last remaining chapter of the Aryan era in the Himālayas is contained in deposits referable to the Eocene system, marking the commencement of the Tertiary era (the Cainozoic). These occur in two isolated outcrops in the Inner Himālayas, one in the Ladākh District of Kashmīr, the other in the area of Kumaun. In Ladākh, north of the central crystalline axis of the mountains, there is a narrow elongated band of Nummulitic limestone with associated beds of sediments, intercalated with basic lavas. The Nummulitic limestone is a landmark of the closing marine period of the Himālayas, deposited in gulfs left behind by the retreating Tethys before its final disappearance. For, with the end of the Eocene, the first phase of upheaval of these mountains was due to commence.

The Eocene system

Nummulitic limestone, the indubitable index-mark of Eocene age in most parts of the world, is developed on a far larger scale in the Outer Himālayan ranges and their extensions, the extra-Peninsular hill ranges of Sind-Wazīristān in Pākistān on the west and of Assam-Burma on the east.

The Eocene is divided into three series, *Rānīkot*, *Laki* and *Kīrthar*, in the order of superposition, it is highly fossiliferous, containing a varied fauna of foraminifers, gastropods, coral and echinoids. The upper part of the Eocene with the Oligocene carries the main petroliferous horizon of India. In Assam and Gujarāt, recent explorations in these series have revealed the possibility of obtaining an annual yield of 4 to 5 million tonnes of petroleum.

The Eocene is well developed in Baluchistān and Sind (which is taken as the type area); in the north and south margins of the

Potwar plateau in Pākistān; and in a narrow interrupted band in the Outer Himālayas from the Jhelum to Naini Tāl. In Assam, it covers hundreds of square kilometres, where its main constituents are the *Jaintia* and the lower part of the *Barail series*; the latter is of considerable economic importance, since it carries thick seams of lignitic coal and some oil-measures. The coal of Jammu and lignite of Bīkaner are also deposits of this age.

The Eocene and the early Tertiaries possess considerable mineral resources. Besides the petroleum and brown coal (lignite) already referred to, they carry important rock-salt deposits at Kohāt (N.W.F.P. in Pākistān) and Mandi (Himāchal Pradesh), and gypsum beds in the Bīkaner area of Rājasthān. An unlimited store of good limestone fit for cement manufacture is contained in the Nummulitic limestone beds of this period.

Oligocene and Lower Miocene

Whether marine conditions persisted throughout the Oligocene in most of the deposition centres is doubtful, for there is a considerable hiatus between the Eocene and the next succeeding Lower Miocene in most parts ofthe Outer Himālayas. The upper part of the 4,500 metres thick Barail series of Assam is believed to be of Oligocene horizon, though convincing fossil evidence is lacking. It is, however notable for enclosing many productive oil-sands. With the end of the Oligocene, marine conditions mostly disappeared from North India, the next succeeding formation being a thick series of fluviatile red and purple sandstones and shales (*Murree series*) occupying a wide outcrop in the Punjab Himālayas. The parallel of the Murree series in the Kumaun Outer Himālayas are the *Dāgshai* and *Kasauli series*. In Assam, it is known as the *Surma series*. These rocks are poorly fossiliferous, containing some badly preserved plants and vertebrate remains. The retreat of the sea from North India by the end of this period was complete and final.

The Siwālik system (Middle Miocene to Lower Pleistocene)

The newer Tertiary system of rocks, designated the *Siwālik system*, attains much greater lateral as well as vertical dimension, being over 6,100 metres thick and covering long stretches of the extra-Peninsula. The name is derived from the Siwālik hills near Dehra Dūn. Here rich deposits of fossil mammals were obtained, and these have enriched many museums of the world. They are wholly composed of freshwater and subaerial deposits laid down in river basins and estuaries. Along the Himālayas, they form a continuous range of low foot-hills, fringing the mountains over a width of 16 to 48 km. from the Indus to Sikkim, and also extending on both its flanks to Sind-Baluchistān and to Assam and Burma. Lithologically, the Siwāliks are composed of alluvial detrital matter derived from the subaerial waste of the Himālayas, swept down by the numerous rivers and deposited at their foot. The Siwālik system has been involved in the last phase of upheaval of the Himālayas and in the severe compression to which they have been subjected. They are separated from the older rocks of the Middle Himālayas by a prominent line of faults and overthrusts.

Exuberance of mammals

From a palaeontological point of view, the Siwālik system is of the highest importance, noted for the wealth of fossil genera and species of extinct elephants, rhinoceroses, horses, giraffes, pigs, hippos, deer, bovids, antelopes, carnivores and anthropoid apes. These animals are the immediate ancestors of existing higher mammals and are not far distant in age from our own times. There are over 20 genera and species of fossil elephants in place of the one single living species, and an equally large number of equids, bovines and pigs and nearly 15 genera of anthropoid apes, the highest mammals in the then existing world, some of which are believed to be links in the line of human ancestry. Many factors must have helped in the development and differentiation of this fauna; among these favourable conditions, the abundance of food supplies and the presence of a suitable environment under a genial climate in a land watered by many rivers and lakes must have been most important. This large assemblage of mammals is, however, believed to be not of wholly Indian origin. According to Dr. Pilgrim, India received large migrations of herds of quadrupeds from such areas as North-east Africa, Arabia, Central Asia, and even North America, by way of land-bridges across Alaska, Siberia and Mongolia. On the testimony of the enclosed fossil remains the Siwāliks are divided into Lower, Middle and Upper series, all composed of a monotonous succession of coarse sandstones, highly coloured red and brown shales and conglomerates. Amongst the more noteworthy fossils entombed in the Siwāliks are *Dinotherium*, *Mastodon*, *Elephas*, *Stegodon*, *Hippopotamus*, *Indratherium*, *Sivatherium*, *Pal-hyaena*, *Giraffa*, *Hipparion* and the apes, *Sivapithecus* and *Dryopithecus*.

The Pleistocene system

A very full and comprehensive account of the Pleistocene is preserved in India. In comparison with it, the rest of the geological record appears sketchy and fragmentary. It is of great value as linking up prehistory with the geological history of India and of a large section of South Asia. The following phases of the Pleistocene of India deserve notice :

The Ice Age of India.

The Indo-Ganga alluvium of the plains of India.

The Rājputāna (Rājasthān) desert and the Rann of Kutch.
The laterite cap of the Peninsula : loess, the *regur* soils.
The older alluvia and high-level terraces of the Peninsular and Himālayan rivers and the old lake deposits of Kashmīr.
Cave deposits : human cave-dwellers and their animal contemporaries.
The Human Epoch.

The last stage of the Siwāliks was in force when the Tertiary era came to an end with the commencing of the Pleistocene (the Quaternary era of earth history). In all parts of the northern world, this period is distinguished by the onset of the Ice Age, which culminated in the establishment of arctic conditions up to the latitude of 49° N. The northern parts of all the continents (except Africa) were covered under vast glaciers and ice-sheets, radiating from the higher ground. The evidence of this great refrigeration of climate is well preserved both in the physical records, as for example in the characteristics glacial topography buried under morain deposits, as well as in the organic records i.e., the effect of this extreme climatic vicissitudes on the living plants and animals of the period, and in the migration or extinction of species. Except the elevated ground of the Himālayas, the rest of India did not experience the full force of the Ice Age. In the Himālayas, everywhere, there is evidence of extensive glaciation of the mountains up to the altitude of 1,800 metres, while glacial drift and terminal moraines extend down even to altitudes of 1,400 metres, covering hill-sides and valley-floors. In the rest of India, the incidence of the Ice Age was felt in a great lowering of temperature, increased rainfall and humidity, and, more strikingly, in the sudden extinction of the population of Siwālik mammals which had flourished in such profusion in the immediately preceding age. Their widespread extinction is attributed to the intense cold of the Ice Age, a change in their physical environments, which the more highly specialized mammals could not withstand. The less organized comparatively simpler creatures could survive it by adapting themselves to the altered surroundings, or by migration to less severe environments. Interesting glaciological investigations have been made in the Kashmīr Himālayas and the Karakoram region. Some of the largest glaciers outside the Polar circles are still found in this region. The Central and Eastern Himālayas have not received the same attention. On the north flank of the Pir Panjāl and on the ranges bordering the Kasmīr

The Ice Age

valley to the north, four distinct Glacial stages, separated by three Inter-Glacial stages, have been worked out by Dr. de Terra.

Indo-Ganga alluvium

The most important and widespread Pleistocene geological formation of the country is the *Indo-Ganga alluvium* filling the great depression between the foot of the Himālayas and the edge of the Vindhya-Kaimur range, created as a concomitant of the Himālayan uplifts of the Tertiary times. The alluvial deposits, mostly sand and silt, brought down by the hundreds of tributaries of the Indus-Ganga drainage system, form the great plains of North India occupying an area of 770,000 sq. km. of the country from Rājasthān, through Punjab, U.P., Bihār and Bengal, to Assam. The exact depth of the alluvium has not been ascertained but recent geophysical exploration shows that it is variable from less than 1,300 to over 1,800 metres. Underlying the alluvium are unconsolidated Siwālik Sediments and older Tertiaries and below these are more consolidated older formations, such as the Upper Gondwānas, or the Cretaceous, the presence of which is indicated by good reflections of the seismic wave and also by borings. The depth is not even—it is greater in the northern than in the southern sector. The northern rim of the basin, where it adjoins the foot-hill zone of the mountains, is one of considerable faulting and structural strain. It is also probable that the alluvium conceals 2 or 3 transverse ridges due to crumpling and dislocation of the basement floor. This structural weakness of the Ganga trough has made it tectonically weak, the seismic belt of India passing alongside it and the Himālayan border. The alluvial plains have no mineral deposits but they are the greatest agricultural asset of India. There are large reservoirs of underground fresh water stored in the more porous beds, supporting thousands of tube-wells for irrigation.

An area of 102,400 sq. km. on the west flank of the Indo-Ganga plains, stretching from the west of the Arāvallis to the Indus basin, is an arid waste land covered under wind-blown sands. The Thar, the desert tract of Rājasthān, is not one flat level expanse of sands, but is diversified by rock projections, and the heaping up of sands in well marked ridges, dunes and mounds through the action of strong prevailing winds. The origin of the Rājputāna desert is attributed to long continued aridity of the region combined with the sand drifting action of the south-west monsoon winds which sweep through the area for several months of the year, without precipitating any part of their contained moisture. The true desert area is surrounded by a belt of mesi-arid country, which supports a thin scrubby vegetation, but large areas of irrigated cultivation occur here and there. The Rājasthān desert is of comparatively recent geological age, for there is historical evidence that 5,000 years ago it was a well-watered and forested tract of the country.

The Rājasthān desert tract terminates in the south-west in the broad depression of the Rann of Kutch, another tract of the Indo-Ganga depression that owes its present condition to geological processes of Recent age. It is a saline marshy plain today, dry for part of the year and otherwise covered by a shallow sea. Its sands include deep pockets and lenses of pure salt, aggregating several million tonnes in quantity. It was once inlet of the Arabian Sea which has now been silted up by the enormous volume of detritus discharged into it by several small seasonal streams draining the arid country to the east and north-east.

Laterite

An important Pleistocene or late Tertiary formation of Peninsular India is laterite. This is a residual, vesicular or pisolitic clayey rock of deep red colour, composed of a mixture of hydrated oxides of aluminium and iron, derived from the alteration of subjacent parent rocks, passage into which is clearly observed. According to the preponderance of either of the oxides, laterite is at times an usable ore of iron or aluminium. It occurs as a cap, 15 to 60 metres thick, on the summits of basaltic and other rocky hills and plateaus of the Deccan, Bihār, Bengal, Assam and Madhya Pradesh, at altitudes varying from 600 to 1,500 metres. Laterite as a cap-rock extends to adjacent tropical countries, Pākistān, Burma and Ceylon, covering stretches of long exposed surfaces of ancient rock-formations. The origin of laterite is connected with the physical, climatic and denudational processes at work in humid countries with a tropical climate, subject to alternations of monsoon weather. Under such conditions of climate, the decomposition of rock-silicates goes a step further, and instead of kaolin being the final product of decay, the rock is further broken up into oxide of aluminium. The laterite of many areas, notably of Rānchi, Madhya Pradesh, Salem, Bombay and Bhopāl, is rich in concentration of hydrated alumina (bauxite), the chief ore of aluminium. The quantity of bauxite of lateritic origin is over 200 million tonnes; of this, about 50 million tonnes have a high alumina content.

Older alluvia

Extensive alluvial plains exist in the valleys of the Narmada and Tāpti and to a less extent in the Godāvari, Krishna and Cauvery valleys. A system of clearly defined terraces, on four or five levels and separated by hundreds of metres, is a well marked phenomenon in some Himālayan rivers too, notably the Sutlej, Jhelum, Chenāb, the

Yamuna and Ganga. The latter contain material for the study of glaciation periods and early human culture. The alluvial plains of the Narmada and Tāpti are remarkable as they lie in deep rock-basins, probably faulted, rising 156 metres above the present beds of these rivers; they too contain numerous relics of contemporary animals and human artifacts.

The valley of Kashmīr is a broad synclinal basin largely filled with an old lake alluvium, which dates back to early Pleistocene and late Pliocene. Weathered remnants of this alluvium form flat mounds or platforms (*Karewas*), sloping away from the mountains bordering the Kashmīr valley on all sides. They bear numerous relics of *elephas*, *cervus*, *rhinoceros*, human artifacts and fossil plants belonging to hundreds of species of semi-tropical vegetation.

Cave deposits

Only a few caves of palaeontological interest exist in India; of these, one occurrence has received systematic exploration—a group of small caves in the Kurnool District of Andhra Pradesh. From a 9-m. thick stalagmitic deposit on its floor, a large assemblage of fossil bones have been excavated, belonging to a mixture of recent and extinct species of monkeys, hyaena, bear, several rodents, an extinct rhinoceros and tiger. A few bone implements of Middle and Upper Palaeolithic culture are also associated.

Loess

In the drier parts of North-west India there are thick sub-aerially deposited wind-blown accumulations of loess—loose unstratified earth and sand. They form wide mounds or platforms capping the country-side over elevations. The loess mounds form the characteristic "bad land" topography of some parts of Punjab.

Sand-dunes

Dunes of great linear extent, and height up to 60 metres, are common in the desert of Rājasthān and in the semi-arid belt surrounding it. Small dunes are also met with on the dry coastal areas of Malabār and Coromandel Coasts of the Deccan.

Black cotton soil

Among the residual soils of India, one variety is of great geological and agronomic interest. This is the black soil or *regur* of many parts of Gujarāt, Madhya Pradesh, Berār area and other "Cotton Districts" of the Deccan. *Regur* is a highly argillaceous, fine-grained soil, extremely plastic and retentive of moisture. The black colour as well as the exact origin of the soil itself are obscure. Black cotton soil is of variable fertility. At places it is known to have supported agriculture for centuries without manuring or being left fallow, and with no apparent sign of exhaustion or impoverishment.

The Pleistocene of India, especially in its Middle and Upper divisions, as in other parts of the world, is marked by the presence of Man. Early Man's existence in India is revealed by his stone tools and implements preserved among the gravels of some Himālayan rivers and of the Narmada, Godāvari and Son. Varied collections of Palaeolithic implements of late Chellean and Acheulian horizons are preserved in many museums. Lately, good collections have been made from Kashmīr, Potwar in Pākistān, the Sābarmati valley, Nellore, and other areas. The earliest Palaeoliths, probably pre-Chellean, have been found in the

The Human epoch

Stone implements of early man

Table of approximate correlations of Pleistocene deposits of India with fossil remains

Age	Deposits	Fossil man	Contemporary fossil animals
Sub-Recent	Modern alluvia ; delta deposits ; spring deposits; blown sand.	Modern man; Neolithic man.	Living species of mammals and domestic animals.
Upper Pleistocene.	Loess ; Uppermost *Karewas; Khadar* alluvium; 4th Glacial ; low-level laterite.	Upper Soan & South Indian river industries ; Middle & Upper Palaeolithic fossil *Homo sapiens.*	Kurnool cave fauna a few extinct species; many living species.
Middle Pleistocene.	River-terraces & older alluvium ; Upper *Karewas*; 3rd Glacial; *Bangar* of Yamuna & Ganga.	Middle Soan & Narmada industry, Neanderthal man.	*Elephas antiquus;* *Manis gigantea, Rhinoceros Hippopotamus, Equus namadicus.*
Lower Pleistocene.	*Boulder-conglomerate* stage of Upper Siwālik; Oldest river terraces; 2nd Glacial ; Lower *Karewas.*	Oldest flake industry of Narmada, Godāvari & Soan; Chellean & Acheulian palaeoliths; Heidelberg man.	*Elephas namadicus*, extinct species of *Hippopotamus, Equus and Bubalus.*
Upper Pliocene	Pinjor stage of Upper Siwālik.		*Sivatherium, Stegodon,* many extinct elephants species *Equus; Bos Equus; sivalensis;* mostly extinct;

Narmada and Godāvari valleys. Somewhat later proto-historic relics of Man's industry occur in the *Karewa* deposits and in Potwar, correlated to the Boulder-conglomerate stage of the Uppermost Siwāliks. No organic vestiges of Pleistocene Man in the form of his skeletal fossil remains have so far been obtained in India.

In the foregoing account of the later geological deposits of India there is everywhere a gradual passage from Pleistocene to sub-Recent and thence to the prehistoric Recent. These periods overlap each other, as do the periods of human history, and there is no general agreement among geologists as to the exact limits of each.

Here we reach the limits of geological history; further study lies in the domain of archaeology, anthropology and prehistory. When India emerged at the end of the Cainozoic era into the age of Man, it was a land-area eminently fitted in its physical setting and biological environments for the spread and development of the new and most highly developed mammal, Man.

6. *Late Geodynamic Forces affecting the Indian Land-Mass*

In the preceding section, the salient features of the main periods of India's geological history up to the Pleistocene, the last chapter of earth history, have been summarized. This age saw the completion of the broad outlines and relief of the earth, and the configuration of its seas and continents, mountains, plateaus and plains. In the present section we shall examine the operation of some geological agencies that have affected in a material degree the physiography of the country, but which have not been dealt with in the preceding pages. The geography of the land is still being constantly modified by these geodynamic forces. Their effect may be assessed under the following heads : definition of the coastline of India, and the submerged mountain chains and valleys of the Arabian Sea; the seismic zone of India in relation to the earthquake belt of the world and earthquakes ; volcanoes; local alterations of level of land and sea; sub-Recent changes in the hydrography and drainage-pattern of North India: India's Position in the desert belt of Central Asia ; and the meteorological influence of the Himālayan chain in arresting continental desiccation.

Coastline of India

The seas that surround the coastline of India are not of any great geological antiquity. They originated in the earth-movements of early Cretaceous or Tertiary times, as bays or arms of the Indian Ocean. The Coromandel Coast is certainly as old as the earliest Cretaceous. The Malabār Coast is fronted by a broad submerged continental shelf which stretches in a straight line from Karāchi in Pākistān to Cape Comorin at depths of less than 180 metres. It suddenly plunges to 2,000 metres, to a deep submarine valley separating the shelf from a broad irregular submarine ridge that stretches intermittently from the latitude of Bombay to the Laccadive and Maldive Islands; this line of elevations is believed to be the continuation of the axis of the Arāvallis southwards. The smooth Malabār coastline from Cambay to Comorin is the result of faulting; the escarpments of the Western Ghāts, parallel with the coast, are ascribed to this scarp-fault of late Pliocene time. The whole of the northern border of the Arabian Sea, from Karāchi through Arabia to the Somaliland coast, is likewise believed to be the result of tensional faults of the same period. Strata of late Pliocene age are exposed in the fault-scarps of the Malabār Coast and the Persian Gulf. The Coromandel Coast from the Mahānadi has a simpler structure, having emerged from the sea at a comparatively late date, fronted with low submarine plains. This coast of India has been invaded by the sea repeatedly during sub-Recent times. The island of Ceylon is a part of the Madras mainland, severed only in recent geological, even prehistoric times. Outside the Indo-Ceylon platform, the common coastal shelf plunges down to 3,000 metres. The islands of the Bay of Bengal are all volcanic, and not coral-fringed continental islands, as is the case with the Arabian Sea islands.

Earthquakes

The late Tertiary and Pleistocene earth-movements of the extra-Peninsula have greatly affected the seismic stability of this part of India, which forms a close unit of the great seismic belt traversing the earth from the mid-Atlantic coast, through Southern Europe, the Alps, Īrān and the Indian extra-Peninsular ranges, to the extreme end of Malayan arc, where it meets the circum-Pacific earthquake zone. This girdle corresponds broadly with the prominent zone of mountain-building tectonic earth-movements of the Tertiary age, but has no close correspondence with the line of living volcanoes of the world.

The majority of Indian earthquakes have originated either from the mountain barrier on its west, north and north-east, or from the plains of India lying immediately at its foot. All the

74 disastrous Indian earthquakes recorded in the last 200 years had their epicentres in this zone. Some of the more destructive earthquakes of recent times are the Kutch quake of 1819 and the Assam earthquake of 1897, which affected no less than 4,100,000 sq. km. and was one of the most disastrous earthquakes of the world on record. The Kāngra earthquake of 1905 was felt over the whole of India north of the Tāpti. The epifocal tract was between Kāngra and Kulu. The Bihār earthquake of January 1934 shook North Bihār and Nepāl area and laid in part ruin many cities from Kātmāndu through Patna to Darjeeling. The main epicentres were Motīhāri, Kātmāndu and Monghyr, lying in the fractured zone of the crust underneath the Ganga alluvial basin. The Quetta (Pākistān) earthquake of 1935 turned that city in a few minutes into a graveyard entombing 20,000 people. The area, however, enclosing isoseist of high intensity was comparatively small. That was the case also with the Makrān Coast (Pākistān) earthquake of 1945, where the tidal wave caused by the quake reached a height of 12 metres. The North-east Assam earthquake of 1950 was again one of high intensity, comparable with the 1897 disaster. The Isoseist VIII encompassed an area of 192,000 sq. km. in an unpopulated mountain terrain; the damage was confined to landslips of great size and consequent damming of river valleys, materially altering the drainage of the country. We thus see that the catalogue of seismic disasters is confined to the extra-Peninsula and few or no earthquakes have shaken the Deccan part of India in historic times; there is no authentic record of a seismic convulsion in the Deccan area in recorded history.

Volcanoes

There are no living or active volcanoes in the Indian region. The Malay branch of the most active living volcanoes, if prolonged to the north-west, would connect a few dormant or extinct volcanoes in this region. Of these, the most important is the volcano of Barren Island in the Bay of Bengal. This volcano has been dormant in the last 165 years. Narcondam and Popa are other extinct volcanoes of this region. The extinct volcano of Koh-i-Sultān in the Nushki desert of Western Baluchistān is another example.

The so-called Mud-volcanoes of the Arakan (Burma) and Makrān (Pākistān) coasts are due to eruptions of natural gas in petroliferous terrain and have no connection with vulcanicity.

Few hypogene disturbances have interfered with the stability of the Peninsula, but there have been some minor secular upheavals and depressions along the coasts and in the interior of the Deccan plateau, within sub-Recent times. The most important of these is an appreciable elevation of some parts of the

Deccan mainland and exposing of portions of the plain of marine denudation in front of the present coastline. Raised beaches are found at elevations from 30-45 metres at many places along the coasts of India. The scarp face of the Sahyādri mountains and their parallelism to the coast are ascribed to their recent elevation after the faulting movement already referred to. The existence of beds of lignite and peat in the Ganga delta, and near Pondicherry, and the submerged forest of Bombay coast are proofs of slow movement of depression. The submerged forest of Bombay is 3·6 metres below low water and 9·2 metres below high water level. On the Tirunelveli coast, a similar submerged forest has been observed. The recent subsidence in 1819, during an earthquake on the western border of the Rann of Kutch, is the most striking event of its kind recorded in India. Here an area of nearly 5,100 sq. km. was suddenly depressed to depth of 3·6 to 4·6 metres below the sea, while an adjacent area of 5,180 sq. km. was simultaneously elevated several metres above the plains, into a mound which has been appropriately named by the people *Allah Bund.* The branching *fjords* of the Andaman and Nicobar Islands point to a submergence of these islands within late geological times, by which their inland valleys were drowned.

Local alterations of level

An important question in the investigation of the past hydrography of Northern India is the date of disappearance of the last remnant of the sea from the plains tract. Whether, if ever, the Deccan was an island, subsequent to the Eocene, with a coastline represented by the rocky islands and promontories of Kutch, Rājasthān, Delhi, Bundelkhand, Rewa and Rājmahāl is impossible to decide, because the desert sands and river alluvia have completely buried thousands of square kilometres of rocks along this border since that age. The Cretaceous sea of Western India (Bāgh epoch), south-west of Rājasthān, was only a narrow inlet and probably did not extend beyond Jabalpur, while the Eocene sea, though spread over a wide expanse of Rājasthān, did not go further east than longitude 74°E.

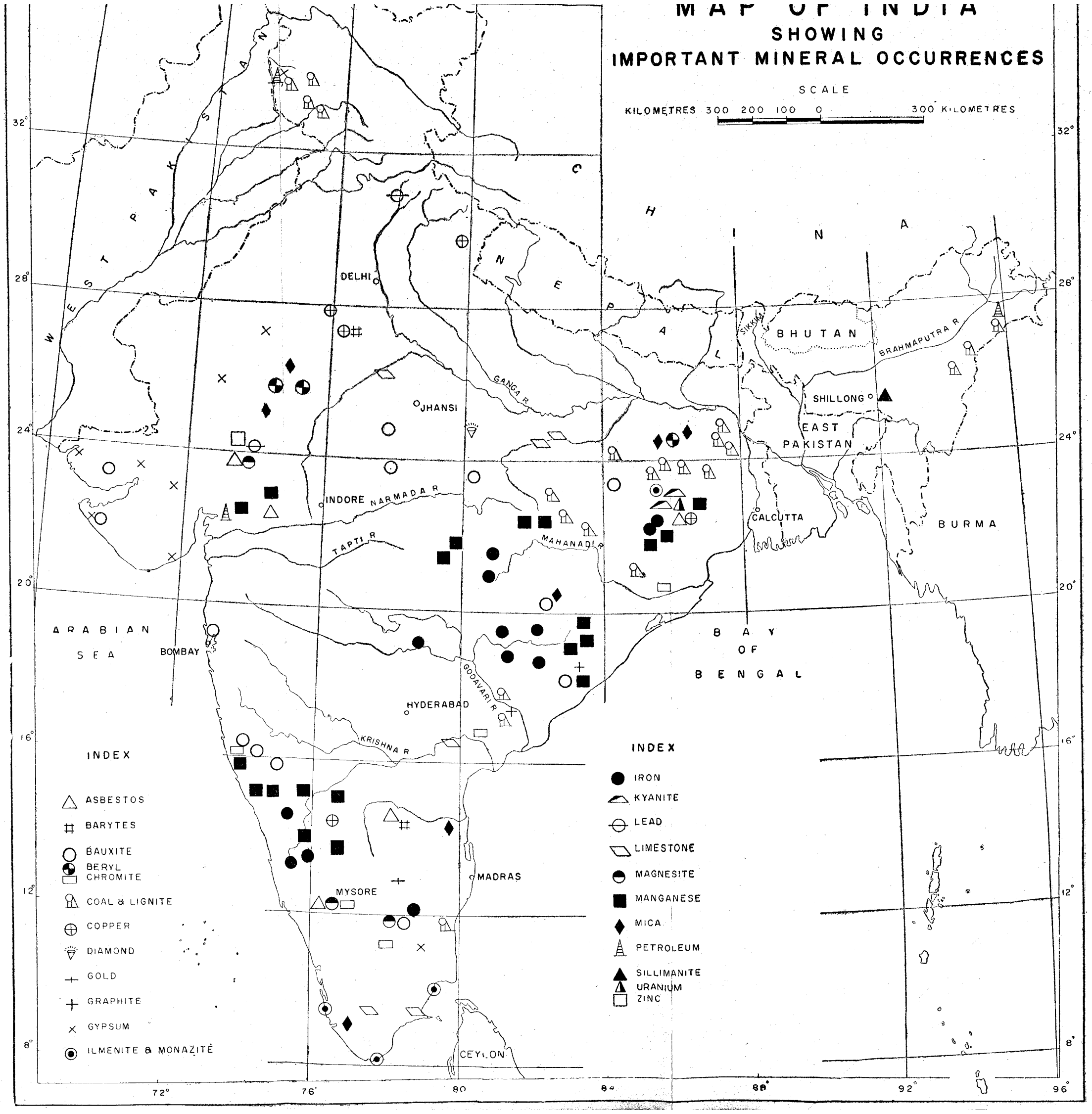
Many profound changes in the hydrography and the chief drainage lines of North India since late Tertiary and Pleistocen times have taken place. Changes, which have produced a complete reversal of the flow direction of the chief rivers of North India have been postulated by some eminent geologists. They ascribe the Siwālik deposits to the work of a great north-west flowing river, lying south of and parallel to the Himālayan chain, from Assam to North-west Punjab, and thence flowing south-west to Sind, it carried

Changes in hydrography and drainage pattern the combined discharge of the Brahmaputra, Ganga and Indus at one time—the *Indo-Brahm* river of Pascoe. This old river is believed to be the successor of the narrow strip of the sea left after the main uplift of these mountains. The final extinction of this gulf, which once stretched from Assam to Sind, left behind it a wide river basin. Post-Siwālik minor uplift movements of the ground in the Punjab brought about a dismemberment of this river system and its severance into three subsidiary systems—(1) the present Indus flowing southwards from Hazāra; (2) the five Punjab tributaries of the Indus; and (3) the river systems tributary to the Ganga, which after its severance from the Indus was deflected from its former course and finally took a south-easterly course.

Less important changes in still later times have taken place. The river Yamuna, the sacred Sarasvatī river of Hindu traditions in Vedic times, flowed to the sea through a separate channel now deserted (the modern Ghaggar and the Nara). In course of time, the Sarasvatī took a more and more easterly course and ultimately merged into the Ganga at Prayāg. It then received the name of Yamuna. Great changes have likewise taken place in Bengal and in the Ganga delta in the last 200 years, and hundreds of square kilometres of the delta have become habitable since then. The Tīsta, originally flowing into the Ganga, now discharges into the Brahmaputra; only 150 years ago, the Brahmaputra which now flows to the west of Dacca and Madhupur jungle in Pākistān, then flowed to the east of these localities.

The drainage pattern of Peninsular India is of very high antiquity and has persisted more or less unchanged since early Gondwāna era. On the other hand, northerly drainage of the Deccan, flowing to the shores of the Himālayan Sea (the *Tethys*) in Gondwāna times, was completely disorganized in the beginning of the Tertiary; and subsequently, during the late Tertiary and post-Tertiary; all its main lines were buried under the 320-km. wide belt of alluvial plains of the north from Sind to Manipur. The present valley-system of Northern India, one of the youngest hydrographic systems of the world, has inherited nothing from the old; it is an entirely superimposed drainage with no relations whatever to the old river-courses.

The Himālayan system of drainage is not a *consequent* drainage, but is of the *antecedent* type, the main channels of flow being of greater antiquity than the mountains they traverse. Hence, the main rivers flow right across the axis of the range through deep transverse gorges which they have themselves eroded. The erosion of the river-bed has kept pace with the slow uplift of the mountains.


MAP OF INDIA
SHOWING
IMPORTANT MINERAL OCCURRENCES
SCALE
KILOMETRES 300 200 100 0 300 KILOMETRES
WEST PAKISTAN
CHINA
NEPAL
BHUTAN
EAST PAKISTAN
BURMA
DELHI
JHANSI
INDORE
CALCUTTA
SHILLONG
BOMBAY
HYDERABAD
MYSORE
MADRAS
CEYLON
ARABIAN SEA
BAY OF BENGAL
GANGA R
NARMADA R
TAPTI R
MAHANADI R
GODAVARI R
KRISHNA R
BRAHMAPUTRA R
INDEX
ASBESTOS
BARYTES
BAUXITE
BERYL
CHROMITE
COAL & LIGNITE
COPPER
DIAMOND
GOLD
GRAPHITE
GYPSUM
ILMENITE & MONAZITE
INDEX
IRON
KYANITE
LEAD
LIMESTONE
MAGNESITE
MANGANESE
MICA
PETROLEUM
SILLIMANITE
URANIUM
ZINC
72°
76°
80
88°
92°
96°
32°
28°
24°
20°
16°
12°
8°

A very well marked phenomenon of late Pleistocene, post-Glacial times is the conversion of a large part of Central Asia into a desert belt continuous with the Sahara. The Thar desert of Rājasthān to the south of the Himālayan chain and the vast Taklamakān desert to the north are a part of this great Asian desert. This belt is largely the creation of geological agencies of sub-Recent times extending down to prehistoric and even historic. All along this vast extent there are marks of flourishing human settlements, with irrigation works, forests and other evidences of much more moist climate. The continental desiccation has arisen through increasing aridity caused by the deflection of moisture-bearing winds from the Indian Ocean and disruption of the drainage lines of the country.

Desert belt of Asia

The Thar area of Rājasthān has not felt the full impact of this desiccation because of the meteorological influence of the Himālayas on the atmospheric circulation of India and the adjoining countries of Asia. On account of its altitude and its situation directly in the path of the monsoons, this mountain system is favourably placed for the precipitation of much of their moisture, either as rain or snow. Glaciers of enormous magnitude are nourished in its highest ranges. These, together with the abundant rainfall of the lower ranges, feed a number of rivers coursing down to the southern plains in hundreds of fertilizing streams. In this manner the Himālayas have protected the heart of India from the gradual desiccation which has overspread the Central Asian continent. To the same cause is ascribed the desiccation of parts of Tibet and the Tarim basin to its north-west, some of the most desolate regions of the earth today. Their desiccation is connected in a large measure with the interposition of the Himālayan chain, which has shut out the monsoonic wind circulation from the ocean. This has had its full toll on the river systems which have withered away in the growing volume of sands.

Meteorological influence of the Himālayas

7. *Economic Mineral Resources of India*

In the preceding pages we have dealt with the broad features of the stratigraphical and structural geology of India, with only brief references to the economic mineral deposits contained in the successive rock-systems. It is necessary to review here the general picture of mineral products associated with the various rock-system of India and the economic resources they possess.

An appraisal of the total mineral resources of India so far known to geologists brings home the fact that the mineral wealth of India is not inconsiderable for a country of her size and population. The resources include a sufficient range of useful products that are necessary to make a modern civilized country more or less industrially self-contained. Except in the case of minerals such as iron-ore, aluminium-ore, titanium-ore, manganese and rare metals, mica and a few other minerals, the resources in economic minerals and the non-ferrous metals are, however, limited. New mineral deposits of any extent and richness are not likely to be discovered by ordinary geological methods. But the new geophysical methods of locating underground minerals by electrical, magnetic, gravimetric and seismic methods seem to offer possibilities of bringing to light hitherto undiscovered deposits of petroleum, coal, natural gas, underground water and metallic lodes.

Distribution of minerals

Barring coal and petroleum, and the somewhat disputed position of salt and gypsum due to their undecided age, the bulk of the valuable minerals and metals obtained in India are products of rocks of pre-Palaeozoic age, confined to metamorphic rock-systems of either the Archaean or pre-Cambrian period. The principal ore and metal deposits, the precious and semi-precious stones, mica and a large number of industrially valuable minerals are derived from the Dhārwār system. Ninety-eight per cent of the coal is of Lower Gondwāna age, the remainder being Tertiary. The main petroleum horizons in India are Tertiary.

Nature has made a very unequal territorial distribution of minerals in the Indian region. The vast tract of alluvial plains of Northern India is devoid of economic minerals. The terrain of Bihār and Orissa possesses the largest concentration of ore-deposits, such as iron, manganese, copper, aluminium, chromium and the atomic metals thorium and uranium; valuable industrial minerals like mica, sillimanite and phosphates; and over three-fourths of India's reserves of coal, including coking coal. The iron-ore reserves lying in one or two Districts of Bihār and in the adjoining territories of Orissa are calculated at over 8,000 million tonnes, surpassing in richness and extent those of any other known region. There are large reserves of manganese-ores. Over 50 per cent of the world's best mica, block, splittings and sheet, is supplied by the mica mines of Kodarma and Gaya in Bihār. The second minerally rich province is Madhya Pradesh, carrying good reserves of iron and manganese, coal, limestone and bauxite. Madras and Andhra Pradesh have workable deposits of iron, manganese, magnesite, mica, limestone and lignite. Mysore

Economic minerals of India

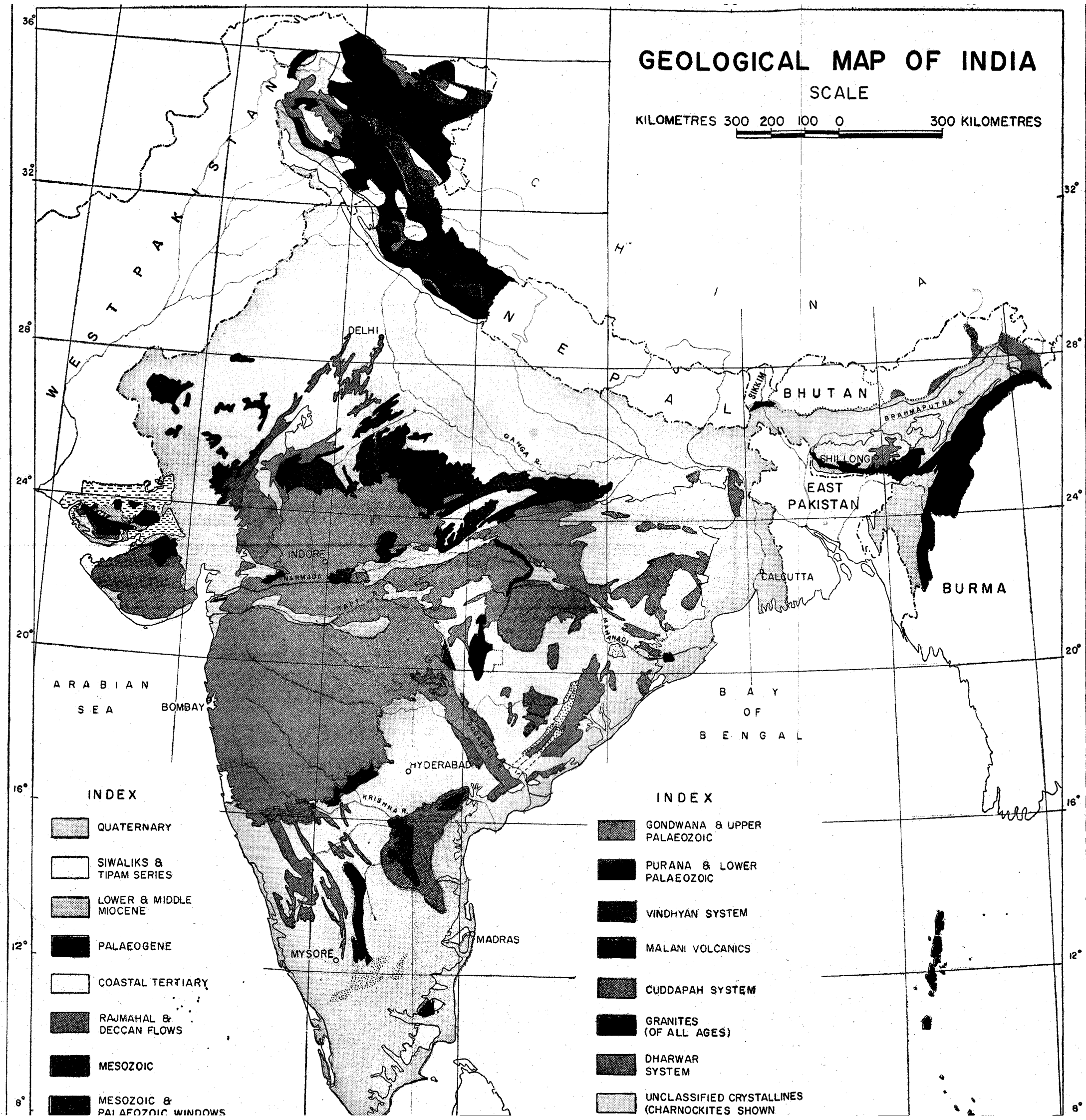
Mineral	Quantity		Value (Rs.)
Asbestos	1,700	tonnes	2,01,000
Barytes	13,600	,,	3,44,000
Bauxite (aluminium-ore) . . .	383,000	,,	41,50,000
Beryl	1,100	,,	7,42,000
Building stone	..		14,00,00,000
Chromite	100,000	,,	57,33,000
Clays (industrial)	510,000	,,	70,00,000
Coal	62,600,000	,,	148,93,46,000
Copper-ore	442,000	,,	2,27,25,000
Corundum	400	,,	1,65,000
Diamonds	2,200	carats	5,60,000
Glass sand	16,000	tonnes	3,62,000
Gold	239,168	oz.	5,22,00,000
Graphite	1,500	tonnes	1,50,000
Gypsum	950,000	,,	58,60,000
Ilmenite	314,000	,,	1,80,50,000
Iron-ore	10,600,000	,,	7,70,35,000
Pig-Iron	4,000,000	,,	16,00,00,000
Steel	2,500,000	,,	1,00,00,00,000
Kyanite	42,000	,,	87,50,000
Lead-concentrate	8,500	,,	39,10,000
Limestone	11,000,000	,,	4,84,00,000
Magnesite	162,000	,,	28,25,000
Manganese-ore	1,102,000	,,	8,18,00,000
Mica	7,200	,,	10,50,00,000
Ochre	75,000	,,	5,50,000
Petroleum	3,700,000	,,	23,00,00,000
Salt	4,550,000	,,	9,80,00,000
Saltpetre	3,000	,,	16,50,000
Steatite	90,800	,,	31,23,000
Zinc-concentrate	9,000	,,	25,00,000

State has yielded all the gold of India, besides producing appreciable quantities of iron, porcelain clays and chrome-ores. Andhra Pradesh has good reserves of second-grade coal, besides being a potential source of several industrial minerals. Kerala, at the southern tip of the Peninsula, possesses enormous concentrations of heavy-mineral sands of high strategic importance, calculated to contain some 150 million tonnes of ilmenite, as also monazite, zircon, rutile and sillimanite in workable quantities. Punjab and Uttar Pradesh have been far less productive and have scarcely as yet figured in India's mineral statistics. The new States of Mahārāshtra and Gujarāt are fast developing their mineral resources. Gujarāt produces bauxite, salt and manganese-ore and has newly discovered oilfields of considerable potential. Mahārāshtra has resources in coal, iron, manganese, titanium, bauxite and salt. Rājasthān is gradually becoming a productive centre, holding promise for the future in non-ferrous metals (copper, lead and zinc), mica, steatite, beryllium, and precious stones (acquamarine and emerald). Assam supplies about 700,000 tonnes of much needed petroleum, besides carrying important reserves of this fuel and of Tertiary coal. West Bengal's mineral resources are confined to coal (annual production capacity about 15 million tonnes) and iron-ore. Of the vast extent of the Himālayan region, the only proved mineralized area of importance is the territory of Kashmīr south of the Great Himālayan Axis, with its lignite, coal (some of it anthracitic), gypsum, aluminium-ore, sapphires and some minor industrial minerals. The next mineralized terrain is Nepāl, from where occurrences of cobalt, nickel and copper ores are reported, but which has scarcely yet been geologically fully explored. But for the partly-known copper deposits of Sikkim and Kumaun and some fairly widespread iron-ore bodies in these areas, the rest of the Himālayan region is a *terra incognita* with regard to economic minerals.

The Table on p. 159 gives the quantity and value of the annual production of 31 leading economic minerals mined in India during recent years.

Geological map of India

Map No. 3 in the folder is reproduced on a small scale from the map published by the Geological Survey of India on the scale of 32 miles=one inch. It depicts the disposition of the main rock-formations, with their principal divisions of the Union of India together with their natural extensions to the adjoining countries of Pākistān, part of Afghānistān and Burma, which together form the Indian sub-continent, a well-knit geological unit of the Eurasian mainland.



GEOLOGICAL MAP OF INDIA
SCALE
KILOMETRES 300 200 100 0 300 KILOMETRES
WEST PAKISTAN
CHINA
NEPAL
SIKKIM
BHUTAN
EAST PAKISTAN
BURMA
DELHI
SHILLONG
INDORE
NARMADA
CALCUTTA
ARABIAN SEA
BOMBAY
BAY OF BENGAL
HYDERABAD
KRISHNA R.
MADRAS
MYSORE
BRAHMAPUTRA R.
GANGA R.
INDEX
QUATERNARY
SIWALIKS & TIPAM SERIES
LOWER & MIDDLE MIOCENE
PALAEOGENE
COASTAL TERTIARY
RAJMAHAL & DECCAN FLOWS
MESOZOIC
MESOZOIC & PALAEOZOIC WINDOWS
INDEX
GONDWANA & UPPER PALAEOZOIC
PURANA & LOWER PALAEOZOIC
VINDHYAN SYSTEM
MALANI VOLCANICS
CUDDAPAH SYSTEM
GRANITES (OF ALL AGES)
DHARWAR SYSTEM
UNCLASSIFIED CRYSTALLINES (CHARNOCKITES SHOWN

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