

## Chapter 2

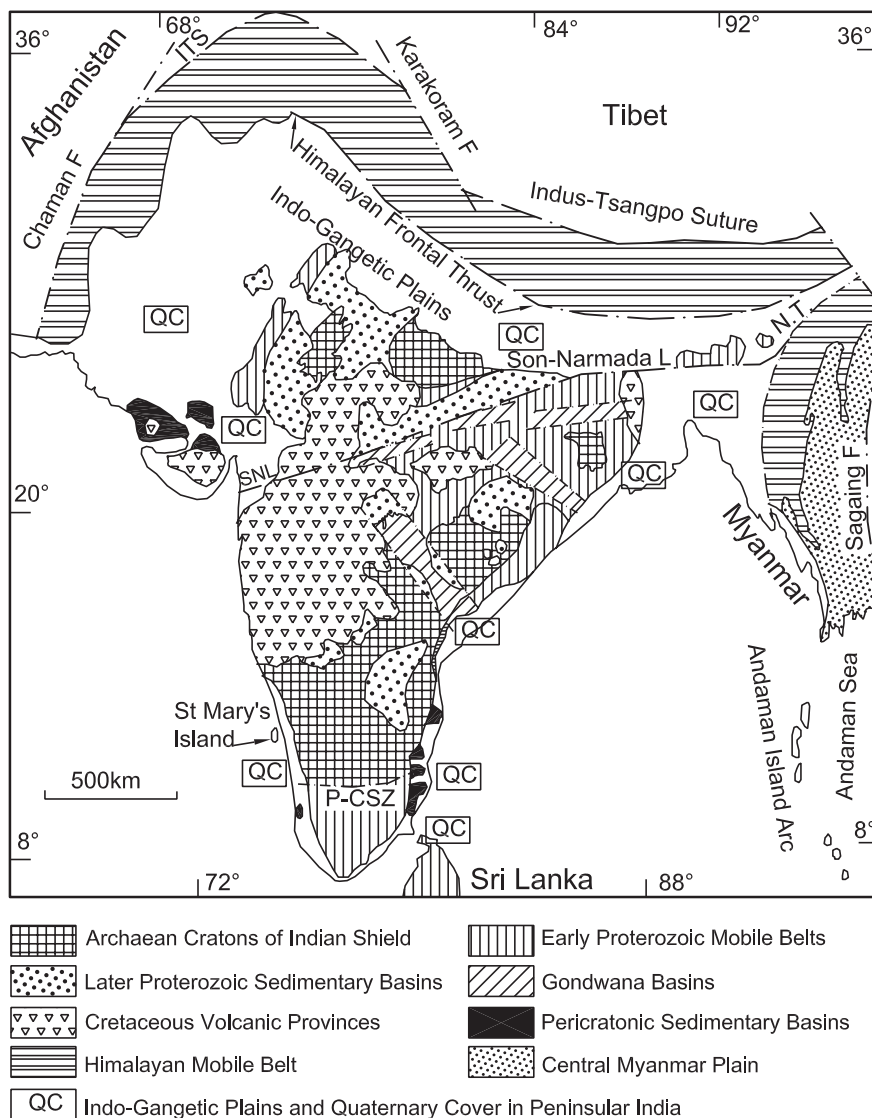
# Geological Terranes of Indian Continent

In literature and in speaking, India is described as a subcontinent forming the southern part of Asia. Before breaking and drifting away in the Early Permian time, Tibet was a part of Gondwanic India. The microplate of Myanmar separated and moved east towards the Thailand–Malaysia part of the Asian plate sometime later. The geological layouts of Pakistan, Nepal, Bhutan, Bangladesh, Myanmar and Sri Lanka are inseparably linked with the geological framework of India. Forming the periphery of India, the landmasses of these countries have gone through the same evolutionary history as India has. Larger India is, indeed, a continent. This continent comprises as many as nine geological terranes, each having its own lithological–petrochemical characteristics, structural layout and evolutionary history.

### 2.1 Indian Shield with Archaean Cratons

Peninsular India is a shield embodying four composite, consolidated and rigid blocks evolved during the Archaean era. Remaining practically underformed by compressional tectonism for very long geological periods, these blocks form the cratons—the Dharwar Craton in southern India, the Bastar Craton in central India, the Singhbhum Craton in eastern India and the Bundelkhand Craton in northern India. The cratons have Palaeoarchaeoan nuclei, 3310–3560 Ma in age, comprising granitic gneisses and basic–ultrabasic rock complexes. Experiencing widespread cratonization or stabilization at about 3000 Ma due to large-scale granite emplacement, the cratons were affected by sagging and rifting along planes of weakness, resulting in the formation of intracratonic elongate basins of sedimentation and basic volcanism. The sedimentation was dominantly ferruginous and siliceous, leading to the making of sedimentary successions that contain very rich deposits

of iron. The emplacement of granite at about 2550 Ma gave rise to large plutonic bodies in all the four cratonic blocks. In many areas, this phenomenon was attended by transformation of high-grade metamorphic rocks into charnockites.



## 2.2 Early Proterozoic Mobile Belts

The cratons are separated from one another by geodynamically mobile belts of the Early Proterozoic evolution. Shear zones and detachment planes demarcate their boundaries. The Eastern Ghat Mobile Belt borders the Dharwar and

Bastar cratons. The Satpura–Aravali Mobile Belt parabolically embraces the Bundelkhand Craton. And the Chhotanagpur–Singhbhum Mobile Belt forms the northern fringe of the Singhbhum Craton. Made up of metamorphic rocks of grades varying from very high to moderate or even low and comprising voluminous volcanics, and implanted with ultrabasic and alkaline bodies in and near the bordering shear zones, these mobile belts represent Early Proterozoic intracontinental rift basins. The sedimentary successions of these rift basins consist of greywackes and turbidities in the lower part, and quartzarenites with penecontemporaneous basic volcanics in the upper part. Emplacement of granites in some mobile belts marked the end of the Proterozoic era in the Indian Shield.

In common with the Eastern Ghat Mobile Belt that borders the Bastar Craton, the Southern Granulite Terrane in the southern part of Peninsular India is made up of very high-grade metamorphic rocks, including charnockites, khondalites and granulites, intimately associated with granite gneisses. Some of these metamorphic rocks had evolved under very high temperatures and pressures. The Southern Granulite Terrane is separated from the Dharwar Craton by a system of deep shear zones, exhibiting both dip-slip and strike-slip movements, particularly in the time interval  $500 \pm 25$  Ma, when the Pan-African orogeny overwhelmed the continent. It was around this time that there was widespread emplacement of granitic, alkaline and ultrabasic magmas within or in the proximity of shear zones. Simultaneously, there was transformation of high-grade metamorphic rocks into charnockites.

The Southern Granulite Terrane in Tamil Nadu and Kerala is, indeed, a petrochemically reconstituted and tectonically rejuvenated Early Proterozoic Mobile Belt.

## 2.3 Continent-Interior Later Proterozoic Sedimentary Basins

In front of early Proterozoic Mobile Belts, there are large basins of later Proterozoic sedimentary rocks that have escaped metamorphism, although they are structurally deformed in the proximity of the mobile belts. These basins came into existence in the aftermath of the Eastern Ghat Orogeny in the interval  $1600 \pm 100$  Ma. The Cuddapah and Godavari basins lie to the west of the Eastern Ghat Mobile Belt, and the Vindhyan Basin lies within the arm of the parabolic Satpura–Aravali Mobile Belt.

In all these basins, the thick sedimentary successions are divided into two major groups by unconformities, commonly of the nature of a disconformity. The unconformities date to an event around  $1000 \pm 50$  Ma. The lower part, including the Cuddapah in Andhra Pradesh, the Kaladgi in northern Karnataka, the Pakhal–Penganga in the Godavari Basin and the Semri in the Vindhyan Basin, consists of marine sediments associated with penecontemporaneous volcanics—lavas, agglomerates, tuffs and local ignimbrites. The carbonates at different stratigraphic levels are characterized by stromatolites that indicate their age between

1650 and 1350 Ma. The upper group, comprising the Kurnool (Cuddapah Basin), the Badami–Bhima (northern Karnataka), the Chhattisgarh (central India) and the Upper Vindhyan (Madhya Pradesh and Rajasthan) is made of sediments laid down by rivers and streams. The  $1067 \pm 31$  Ma-old kimberlite pipe intruding the Upper Vindhyan sediments implies that the terrestrial sedimentation commenced well before 1100 Ma. The spectacularly developed stromatolites in the carbonate rocks in the top horizon place it in the time range of 680–570 Ma.

Across the Aravali Ranges in western Rajasthan, the widespread occurrence of granites (Erinpura Granite) and the acid volcanics (Malani Rhyolite) represent strong magmatic activities in the period 900–750 Ma.

## 2.4 Gondwana Basins

The valleys of the Damodar River in Jharkhand and Bengal, the Mahanadi in Odisha and Chhattisgarh, the Son in southern Uttar Pradesh, the Narmada in Madhya Pradesh and the Pranhita–Godavari in Andhra Pradesh occupy elongate sedimentary basins that evolved as a consequence of formations and eventual filling up with sediments of the grabens and half-grabens. Trending roughly E–W and NNW–SSE, these grabens were formed as a result of rifting of the Gondwanic landmass in the beginning of the Permian. The Gondwana Supergroup of the Gondwana basins comprises glaciogene diamictites, in some places associated with marine sediments at the base, the terrestrial coal-bearing fluvial sediments in the middle and the fluvial–aeolian sediments in the upper part. In the southern part of the Pranhita–Godavari domain, there was intercalation of fluvial–deltaic with the marine sediments.

The sagging of the Gondwanaland, which was under cover of continental glaciers, invited marine incursion in the beginning of the Permian. Later, the burial of the forests and plant debris deposited by rivers gave rise to very rich deposits of coal. As the climate grew hot and arid, rivers deposited very ferruginous sediments that were locally reworked by winds into aeolian formations.

## 2.5 Cretaceous Volcanic Provinces

There are three major volcanic provinces in the Indian Shield which evolved as a result of large-scale volcanic eruptions and explosions during the Cretaceous period. Covering parts of Jharkhand, southern Meghalaya and the Sylhet region of Bangladesh, the Rajmahal Volcanics make the Rajmahal Hills in north-eastern Jharkhand. The lavas and tuffs are intercalated with sediments containing remains of plants of the Upper Gondwana time. The eruption took place in the interval 114–118 Ma.

Offshore north-western Karnataka in southern India, the Saint Mary's Islands are formed of nearly 86-million-year-old acidic lavas. These islands represent a centre of volcanism that preceded the gigantic outpouring of lavas in the land in the later Cretaceous time.

Forming flat-topped stepped plateaus—the Deccan Traps—the stupendous volumes of lavas with tuffs cover practically the whole of Maharashtra, the bordering areas of Karnataka and Telangana, the Malwa division of Madhya Pradesh and the Kachchh–Saurashtra region of Gujarat. The volcanic eruption commenced around 69 Ma and lasted until about 61 Ma, the bulk being emplaced at 65.5 Ma. The dykes, occurring in swarms in the Konkan Coast and in the valleys of the Tapi and Narmada rivers, are believed to have served as feeders of the lavas that flowed 100–300 km from their sources. Reactivation of ancient rift valleys was responsible for the emplacement of these dykes.

The flowing lavas dammed rivers and streams, giving rise to a multitude of lakes and swamps, which became the sanctuaries of animals (including dinosaurs) and plants. The lakes and swamps were eventually filled up with sediments. The sedimentary successions below the lava piles and interbedded with the flows are known as infratrappean beds and intertrappean beds, respectively. These beds contain rich assemblages of remains of the plants and animals that witnessed the tumultuous changes that the Deccan volcanism had brought about.

## 2.6 Pericratonic Sedimentary Basins of Peninsular India

Sedimentary formations ranging in age from the Upper Jurassic to the Quaternary occur in large discontinuous patches along the periphery of Peninsular India, from Kachchh in the west, through the Malabar and Coromandal coasts in the south, to Odisha in the east. The sedimentary successions represent the pericratonic basins that evolved following subsidence due to faulting of the coastal belts in the Mahanadi, Godavari–Krishna, Palar–Kaveri, Khambhat–Sabarmati and Kachchh sectors of the continental margin. The sedimentation in the fault-basins started in the Middle Jurassic in Kachchh and in the Upper Jurassic in the Coromandal belt. Northern Bangladesh and adjoining southern Meghalaya in the east and the Jaisalmer basins in western Rajasthan also come under the sway of marine transgression, of course at different times. An arm of the sea extended along the Narmada rift valley up to the historical Bagh Caves. The sedimentary deposits of all these basins provide accounts of the history of evolution of the land and life in the India continent.

In all these pericratonic basins, the lower parts of the sedimentary successions are made up of Mesozoic marine sediments intercalated with sediments of deltas of the rivers that brought terrestrial material, including the debris of the plants covering the Gondwanaland. The upper parts of the sedimentary piles are constituted of the Tertiary sediments, which cover much larger areas and form the continental

shelves and continental slopes in eastern and western seabords. The lower part of the Tertiary successions consists of Palaeogene marine sediments, and the upper part is made up of deltaic sediments grading imperceptibly into fluvial sediments of the Neogene period.

The pericratonic sedimentary formations are of great economic importance as they host commercially productive petroleum fields.

## 2.7 Himalaya Mobile Belt

The arcuate Himalaya province, forming the wide northern fringe of the Indian continent, is a product of docking of India with Asia—which happened sometime in the time interval 65–55 Ma. In the north, its frontier is defined by the zone of Asia-India welding characterized by squeezed up, strongly deformed, broken fragments of seafloor with sediments of an oceanic trench. The southern boundary is demarcated by a series of reverse faults against the vast plains of northern India.

Between the two tectonic boundaries, the Himalaya Mobile Belt comprises five lithotectonically distinctive and geomorphologically contrasted terranes, each one separated from the other by boundary thrust faults of regional dimension. The northern part, known as the Tethys Himalaya, embodies a thick pile of sedimentary rocks ranging in age from the beginning of the Palaeozoic era to the end of Mesozoic, or locally early Tertiary. There are many long and short gaps in sedimentations, the most important being the one when there was widespread volcanic eruptions in lower Permian on a grand scale, as witnessed in the Pir Panjal in Kashmir and the Abor in eastern Arunachal Pradesh. An arm of the Tethys Sea had also transgressed into the southern border of the Himalaya, leaving behind marine sediments intimately associated with volcanic materials and fluvial sediments containing Gondwana coal with plant fossils.

The Phanerozoic pile of the Tethyan sediments rests (locally discordantly) on the foundation of high-grade metamorphic rocks intruded pervasively by Early Miocene ( $21 \pm 2$  Ma) granites. The crystalline rock complexes from the lofty, rugged Great Himalaya or the Himadri terrane. Across a boundary thrust to the south of the Himadri lies the Lesser Himalaya terrane of comparatively milder topography. This subprovince is made up of two parts, the Lower Proterozoic sedimentary pile and the upper imbricating succession of thrust sheets, or nappes, of metamorphic rocks. The sedimentary pile in the lower part comprises Early Proterozoic argilloarenaceous sedimentary rocks, beginning in some places with turbidites and diamictites. The upper part consists of dominant carbonate rocks and argillo-calcareous shales. The carbonate rocks are Later Proterozoic in age, characterized by  $1000 \pm 50$  to 570 Ma-old stromatolites, and locally with rich lenticular deposits of magnesite and talc.

The lower thrust sheet or nappe is made up of low-grade metamorphics invariably associated with mylonitized porphyritic granites and quartz porphyries

belonging to the time interval  $1900 \pm 100$  Ma. In some sectors, a facies variant consisting of quartzarenites interbedded with penecontemporaneous lavas and tuffs with agglomerates forms a disparate independent sheet. The upper nappe is constituted of medium-grade metamorphics penetrated on extensive scale by  $500 \pm 25$  Ma-old Cambro-Ordovician granites.

South of the Lesser Himalaya is a narrow belt of Tertiary sedimentary rocks evolved in the foreland basin that came into existence in front of newly formed mountain as the Lesser Himalaya was thrust southwards and broke along a regional fault. These sediments in Pakistan and Assam hold reserves of petroleum oil and gas. Further southward thrusting of the Himalaya in the Middle Miocene time led to the formation of yet another foreland basin. It was rapidly filled up by great volumes of sediments brought down from the fast rising Himalaya by rivers and streams. The sedimentary pile eventually evolved into the Siwalik terrane.

Further tectonic deformation caused not only the faulting along transverse faults of the Himalaya Mobile Belt, but also the formation of a series of reverse faults parallel to the trend of the mountain which demarcate its southern boundary against the vast plains of northern India.

## **2.8 Indo-Gangetic Plains and Quaternary Cover of Peninsular India**

South of the mountainous Himalaya Mobile Belt, stretching from the Sindhu delta in Pakistan to the Sundarban region in Bengal, are the vast plains of Quaternary sediments known as the Indo-Gangetic Plains. The plains are the outcome of rapid filling up of the foreland basin that was formed in front of the rising Siwalik Ranges. Presently, at the general altitude of 30–100 m above the mean sea level, the Quaternary sediments vary in thickness from less than 10 m in the southern margin to as much as 1500–2500 m in the northern part, in the Bihar–Uttar Pradesh sector. The Indo-Gangetic Plains comprise four major units. The Pleistocene Varanasi terrain, with ferruginous concretions in gravelly coarse sediments from the fringe of the Vindhya Ranges in the south, and the Holocene gravel fans make the Bhabhar apron along the foothills of the Siwalik. In between, the fluvial sediments deposited in the channels, flood plains, lakes and marshes form the Bhangar terraces. The wide, flat valley cuts that the meandering rivers made have been covered thickly with sediments, making the Khadar flats.

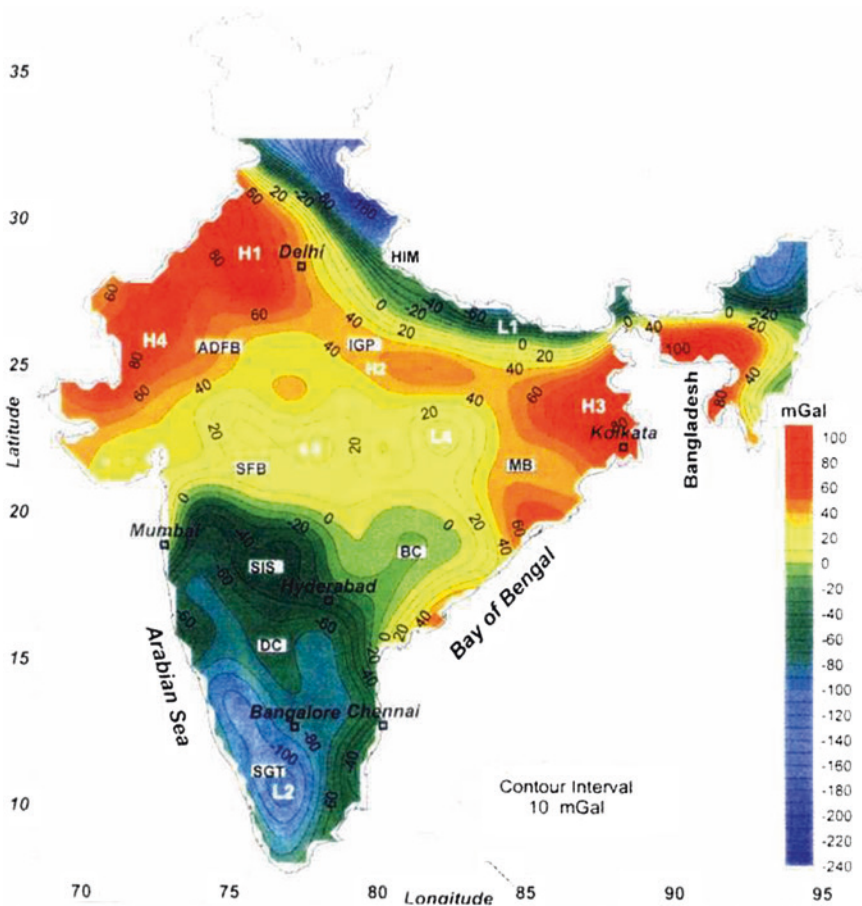
The southerly extension of the Sindhu Plains in the western Rajasthan is converted into a desert—the Thar—by the winds that have been blowing ever since aridity set in the later Pleistocene time. The desert domain extends south into Gujarat up to the valley of the Narmada Rivers.

Large parts of the deltaic regions in the riverine regimes of the eastern and western coastal belts have Quaternary covers.



## 2.9 Andaman Island Arc and Central Myanmar Plain

Constituting the central part of the Indonesia–Myanmar Mobile Belt, the 850-km-long chain of islands between the Bay of Bengal and the Andaman Sea makes the Andaman Island Arc. It comprises two nearly parallel arcuate belts. The western arc is represented by more than 300 islands of the Mentawai, Nicobar and Andaman groups. These islands are made up of successions of Cretaceous to Tertiary sedimentary rocks implanted at various levels with broken-up ocean floor and split up into a multiplicity of steeply dipping rocks of imbricating sheets. The evolutions of these islands are related to the continued underthrusting eastwards of the Indian



**Plate 2.1** Bouguer anomaly (low pass-filtered) map of India with wave number <0.02 corresponding to wavelength of 300 km. L-1 and L-2 gravity lines; H-1 to H-4 gravity highs; *IGP* Indo-Gangetic Plains; *SGT* Southern Granulite Terrane; *DC* Dharwar Craton; *BC* Bastar Craton; *MB*; *SFB* Satpur Belt; *ADFB* Aravali Belt; *HIM* Himalayan Belt (Photo courtesy D.C Mishra NGRI, Hyderabad)



Ocean floor along the Java–Andaman Trench. This trench demarcates the boundary of the Andaman Island Arc. The chain of islands extends north into the land where it is represented by the Indo-Myanmar Border Range, with almost identical structural architecture and lithological setting (Plate 2.1).

The eastern arc embodies seamounts and volcanoes (dormant and active). The volcanoes are related to the actively spreading floor of the Andaman Sea, a back-arc basin. The volcanic island arc extends northwards into the Central Myanmar Plain, characterized by Miocene to Quaternary volcanoes in the alluvial expanse of the Irrawaddy River system.

On the inner (east) side of the volcanic island arc lies the Andaman Sea, the floor of which continues to spread out laterally. The northern part of this back-arc basin is being filled up with terrestrial sediments brought by the Salween, the Sittang and the Irrawaddy rivers. The northern extension into the land of the Andaman Sea basin has been completely filled with sediments delivered by the rivers of the Irrawaddy system and converted into a large alluvial plain—the Central Myanmar Plain.

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