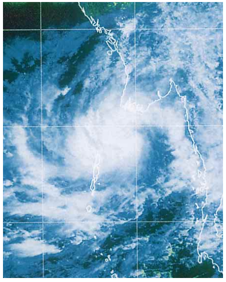


CHAPTER XI

EARTH SCIENCES

The earth scientists of India, working in academic and research institutions, have endeavoured for an understanding of the geological architecture of varied terranes of the Indian subcontinent and their geodynamic development. On the other hand, the scientists of the government agencies like the Geological Survey of India, Oil and Natural Gas Corporation, Atomic Minerals Department, National Mineral Development Corporation, Central Groundwater Board and others pursued their primary agenda of exploring and seeking intelligent guidance for the search of mineral resources, including oil, gas and water. In the recent years, problems of environmental integrity and the security of ecologically sensitive and fragile terrains are being addressed with keen interest.

The founding of discipline-specific research institutions, like Birbal Sahni Institute of Palaeobotany, National Geophysical Research Institute, National Institute of Oceanography, Physical Research Laboratory, Wadia Institute of Himalayan Geology, and Centre for Earth Science Studies, have provided a great impetus for intensive research on diverse aspects of earth sciences. One of the good things that has happened in the post-Independence India is the coming into being of the Geological Society of India and its continuing efforts to project to the world the developments in India in the fields of geology, geophysics and geomorphology.

THE TERRANE-BOUNDING FAULTS OF INDIAN SUBCONTINENT

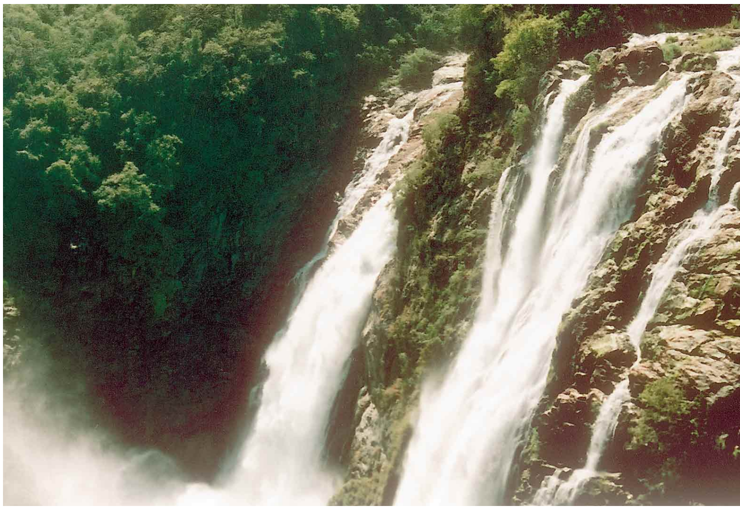
The Indian subcontinent comprises several geological provinces including cratonic blocks, each characterized by its distinctive structural setting, rock sequences and evolutionary history. These contrasted lithotectonic provinces or terranes are separated by fault zones of great length and depth. The identification and characterization of the zone of collision of India with mainland Asia, along what is today occupied by the rivers Sindhu (Indus) and Tsangpo (Brahmaputra), is one of the most important developments in the history of regional earth science

The ocean-floor basic-ultrabasic rocks along with seafloor sediments were forcibly squeezed up when India collided with mainland Asia. The junction of the collided continents is now occupied by the Sindhu river (Indus) in Ladakh.

studies. Known as the Indus-Tsangpo Suture (I-TS), the India-Asia collision zone embodies ancient ocean-floor and mid-oceanic basic and ultrabasic rocks, including sea mounts and island arcs, and deep-sea and oceanic-trench sediments of the Cretaceous age. Caught as they were between the vice-like grip of the collided and still converging continents, the lithological assemblages of the collision zone experienced severe deformation and high pressures of 9 to 11 kilobars (kb), as indicated by the presence of blueschists in Ladakh. The gravity anomaly pattern indicates that the northward-sliding Indian plate has bent down 10-15° in the zone 50 km south of the I-TS, with attendant detachment of the crust from the mantle, the latter sliding under Tibet and the former buckling up. The Main Boundary Thrust (MBT), sharply separating the Himalayan province from the Peninsular Indian Shield, is recognized as the plane along which the Indian Shield--along with its frontal sedimentary prisms of the Indo-Gangetic Plains and the Siwalik -- is sliding under the Himalaya. The faults of the MBT zone have been proven to be very active and the cause of the great earthquakes in the Himalayan region.

Characterized by the horst-and-graben structure, the Aravali mountain is delimited by NNE-SSW trending *en echelon* faults, including the 800 km long eastern Great Boundary Fault that in the north disappears under sediments of the Indo-Gangetic Plains, and the western boundary recognized as a subduction-related thrust characterized by ophiolites and plutons of granites, alkali rocks and ultrabasic-basic bodies. Movements along these faults account for the high seismicity of the Aravali domain. The basement complex, known as the Banded Gneissic Complex, includes metamorphic rocks that evolved at temperatures of 800-850° C and 650-850° C and pressures of 11-7 kb and 6.7 kb, in different parts. Related to the tectonics of the Aravali are the series of E-W trending arcuate faults in Kachchh that are locales of moderate to great earthquakes, including the one (Mw7.7) that occurred near Bhuj on January 26, 2001.

Another most significant finding was the identification of the great tectonic divide between northern and southern India along the margin of the Satpura horst mountain. Occupied by the rivers Narmada and Son, the Narmada-Son Lineament has been linked in the west with a transform fault in the Arabian Sea and in the east with the strike-slip Dauki Fault. The Dauki Fault, in turn, merges with the Naga Thrust that represents the subduction of the Indian Plate under the Myanmar-Malaysia Plate. This fundamental fault of ancient origin reaches the mantle as revealed by deep seismic sounding, and has influenced the deposition and deformation of Proterozoic Vindhyan and Early



The Karnataka Craton in the Southern Indian Sheild, made up of rocks as old as 3,000 million years and 2,500 million years, and thickly covered with laterite soil, has long been a stable land mass. The Kaveri river drops as water falls across the faults that are found to be active.

Phanerozoic Gondwana sediments.

In the Karnataka Plateau, the Dharwar Craton, subdivided into eastern and western blocks by the NNW-SSE trending Chitradurga Shear Zone, is characterized by horizontal shortening and thrusting of ductile shearing during the Late Archaean period. This was followed by Dharwar sedimentation on a stable platform earlier and in an unstable mobile belt later. The green-schist belts in the Shield are recognized as suture zones related to plate tectonics of the Archaean period.

The Bhavani-Moyar Shear Zone sharply separates the Dharwar Craton from the Southern Granulite Terrane in the south. It is responsible for the uplift and attendant exhumation of deep-seated rocks of the 2,500 m high Nilgiri massif, and continues to be active as evident from river ponding, recent sediment deformation and mild seismicity in the belt. The constituent rocks charnockites and granulites were formed as a result of intermittent influx of CO_2 in the lower crust where the temperatures were as high as 700-900° C and pressures 5 to 6 kb or even 7-9 kb. This is evident from thermodynamic phase-equilibrium and fluid-rock interaction studies. Further south, the Palghat-Kaveri Shear Zone divides the Southern Granulite Terrane into two blocks, the southern one being an Archaean-Palaeoproterozoic mobile belt characterized by widespread formation at 550 Ma (million years or Mega annum) of charnockites and coeval emplacement of alkali granites and syenites related to Pan-African events. The NNW-SSE trending Achankovil Shear Zone is an active fault zone responsible for the seismicity in Kerala.

Timing of the Evolution of Cratons

The U-Pb ages of detrital zircons in metapelites in the Indian Shield have been interpreted as marking the beginning of crustal development about 3,400 Ma years ago. In the Karnataka Craton the Pb-Pb 3,204 ± 30; 3,121 ± 63 and 3,400 ± 140 Ma gneisses are closely associated with samarium-neodymium (Sm-Nd) 3,191 ± 40 Ma Holenarsipur ultrabasic rock of an ancient suture zone. The Peninsular Gneiss is recognized as a composite and migmatized body covering a very large part of Peninsular India, including Bihar and Assam, and having the whole-rock ages between 3,100 and 3,200 Ma years. This includes the Pb-Pb 3,018 ± 61 Ma Bastar Gneiss in Chhattisgarh, the Pb-Pb 3,292 ± 51 Ma Singhbhum Granite, the 3,163 ± 126 Ma Bonai Granite in Jharkhand-Orissa, and the Sm-Nd 3310 ± 70 Ma Udaipur Granite, the last one associated with the 2,830 ± 59 Ma volcanigenic amphibolite within the Banded Gneissic Complex in Rajasthan. The rubidium-strontium (Rb-Sr) 2,500 Ma old acid volcanics occurring within the greywackes constrain the time-span of the Dharwar Supergroup from 2,800 to 2,600 Ma. The U-Pb 2,513 ± 5 Ma Closepet Granite in Karnataka and the 2,550 + 50 Ma old Bundelkhand Granite in Rajasthan represent a strong 2,500 Ma old geodynamic event of continental dimension. The Sittampundi anorthosite is regarded as a layered ultrabasic-basic complex or a mixed composite body that domed up as a result of alaskite intrusion during the Closepet period. The kimberlite plutons dated Rb-Sr 1,067 ± 31 Ma at Majhgawan, MP, and 1,090 ± 20 Ma at Wajrakaur, AP, the 850 to 1,250 Ma old alkaline plutons and carbonatites, and the 800-200 Ma old dyke swarms that straddle across the Palghat-Kaveri Shear Zone represent tectonomagmatic events of significance.

Reconstructing the Stratigraphic History

The lower Cuddapah Pulivendla unit is dated Pb-Sr 1,817 ± 24 Ma, the Pb-Pb age of the Vempalle dolomite is 1,756 ± 29 Ma, and the Kaladgi base is dated 1,800-1,900 Ma. These data constrain the lower temporal boundary of the Purana (Proterozoic) sedimentary succession in South India -- the beginning of the Purana Sedimentation. Rift-basin sedimentation in the Godavari-Pranhita domain is characterized by tectonogenic and volcanogenic emplacement in the earlier phase and carbonate-formation in the later part. The carbonates show considerable diagenetic modification, including cannibalistic dolomitization. The lower limit of the Vindhyan is placed at 1,400 Ma, as the 1,009 Ma old kimberlite pipe penetrating the lower Vindhyan tends to bear out. Recognition of aeolian sand dunes in the Upper Vindhyan has a considerable bearing for the understanding of palaeoclimatic condition in the Late Proterozoic. The cyanobacteria-built stromatolites developed spectacularly in the dolomites overlying the terrigenous sedimentary rock in Himachal and Uttaranchal place the very crucial carbonate horizon of the Lesser

Himalaya in the neoproterozoic (<1,000 Ma) period.

Palaeoflow directional studies in the Lesser Himalayan sedimentary succession in Himachal and Uttaranchal demonstrated that in the mesoproterozoic and neoproterozoic times the sediments of the Lesser Himalayan basin were deposited by the north-flowing rivers that drained the mountainous terranes of northern Peninsular India. The abrupt end of sedimentary succession throughout the Lesser Himalaya and Purana basins in the Peninsular India and the pronounced interruption in the parts of Tethyan Himalayan domain in the north, is taken as implying the end of sedimentation throughout the Indian subcontinent. The Lower Cambrian fossil assemblage in the sediments coupled with Rhenium-Osmium (Re-Os) age of black shale of the terminal Tal Formation, indicate the time of cessation of sediments a little after 552 ± 22 Ma as a consequence of the Pan-African Orogeny.

Interpretation of isopach maps indicating progressive northward thickening (to ~2,000 m) and palaeocurrent directions of the coal-bearing Gondwana sediments in the basins of the Godavari, Mahanadi and Damodar rivers have been interpreted as indicating a northward slope of the land which these rivers drained in the Permian-to-Triassic period. There was a northward reversal of drainage during the Later Triassic period.

The passage over convection plumes of the northward-moving Indian Plate generated hotspots in the subcontinent. While the 115 ± 2 Ma Sung Valley carbonatite and coeval Rajmahal Volcanics in the Sylhet-Rajmahal belt in eastern India are attributed to the Crozet Hotspot, the 67 to 62.5 Ma Deccan Traps covering a very large area in western India is linked with passage of the Indian plate over the Reunion Hotspot -- the one which gave rise to the Chagos-Lakshadweep oceanic ridge. Progressive southward younging of the lavas of Deccan Traps and their overstepping relationship bear out this deduction. The mineralogy and petrology of the Fe-Ti (iron-titanium) rich Deccan flood basalt indicate dominant role of crystal-liquid fractionation of picritic magma in crustal sills with characteristic open-system with magma chamber, affected by varying degrees of crustal contamination. It is inferred that the melts were formed at 35-45 km depth in the mantle where the pressures were 10-15 kb, as borne out by nodules of spinel-peridotite and dunite occurring in the Deccan lavas of Kutch. Associated alkaline ultrapotassic and acid intrusives occupy shear zones along the west coast, the Cambay graben and the Narmada-Son rift valley. Palaeomagnetic polarity-reversal study of the 2,500 m-thick succession, constrains the duration of the Deccan volcanism from 67 to 62.5 Ma. Remains of foraminifers, nanoplanktons and dinoflagelletes in the sediments associated with the lavas confirm that the volcanism straddles the Cretaceous-Tertiary boundary. Buried under the volcanics are the Maastrichtian regoliths with pedogenic carbonates in the Narmada Valley.

The magnetic polarity-reversal studies of the 900-1200m thick Neogene succession in Jammu, Himachal and Nepal showed that the Siwalik spans the temporal interval of 18.3 Ma to 0.22 Ma -- the Lower Siwalik 18.3 to ~10 Ma, the Middle Siwalik ~11 to 5.3 Ma, the Upper Siwalik 5.3 to 0.22 Ma. These chronological limits are in broad agreement with the boundaries fixed earlier on the basis of appearance and presence of vertebrate fauna.

Benchmarks in the Evolutionary History of Life

The appearance of Lower Cambrian (Tommotian-Botomian) fauna including the protoconodonts that had developed grasping mechanism, conodonts, trilobites and small shelly fauna in the 522 ± 22 Ma black shale, limestone and phosphorite of the Tal Formation in Uttaranchal, marks the beginning of the invertebrate life in the Indian subcontinent. The vertebrate fauna from the Kundaram horizon in the Pranhita-Godavari Valley, known for prosauropod dinosaurs, testifies to the coming of the dinosaurs by the Late Permian age. The dinosaur skeletons in the Jurassic beds in Kutch, the eggs of Titanosaurids in the Narmada Valley, and the recent find of dinosaur fossils from southern Meghalaya, define the large domain that the dinosaurs ruled in the land then.

There were drastic changes in the structure and evolution of over 80 per cent of both the land and marine organisms at the transition of Upper Cretaceous-Lower Tertiary period some 66 million years ago. Several successful and well-established groups, including the dinosaurs, disappeared altogether, while nearly 20 per cent new groups, including foraminifers, mammals and flowering plants, became dominant and diversified in the Tertiary period. The mass extinction was quite gradual spanning over 2-3 million years. This event, marked in the boundary beds by anomalously high amount of iridium, is attributed also to the impact of gigantic meteorites or comets.

The joining of India with mainland Asia opened the gates of immigration of a variety of terrestrial fauna from different parts of Eurasia. The first appearance in the early part of the Himalayan foreland basin (Subathu) of the mammals which have a striking resemblance and close affinity with those of Eurasia, indicate that by ~ 49 million years ago, a land-bridge between Eurasia and India had been established.

The finding in the upper part of the Kuldana-Subathu succession in northwest Himalaya of the *Himalayacetus subathuensis*, an animal representing the transition from the terrestrial mammal to the marine mammal, at 53.5 Ma, and of *Ambulocetus natans* shows that it was in the sub-Himalayan domain where the whales first evolved.

The expansion of grasslands in the Siwalik realm attracted grazing animals from neighbouring lands -- from as far as Africa, Europe and Central Asia. The immigration of quadrupeds brought about major faunal turnovers in the period 7.5 to 9.5 Ma. The invasion of exotic fauna and resultant marginalization or even extermination of the indigenous animals such as rhinos, buffaloes and cows, brought about substantial changes in the composition of the Siwalik life. *Hipparian,* the pigs, the bovid *Selenoportex*, the proboscid *Stegodon*, the hippopotamus *Hexaprotodon*, the elephant *Elephas planifrons* and the horse *Equus*, came from different parts of the world -- Africa, Europe and Alaska -- in different times between 9 and 2.5 million years ago.

Significant is the finding of skull of the human *Homo erectus* from the Middle Pleistocene sediments in the Narmada Valley.

Emergence and Evolution of Himalaya

Following the contact of India with Asia ~ 65 million years ago and their complete welding by Ma, there was a resurgence of very strong tectonic movements in the period 25 to 18 Ma ago. The northern part of the Indian plate broke up all along its 2,500 km length. The southern plane of breaking (main Central Thrust) is perceived as the contact between the high-grade metamorphic rocks with mid-Tertiary granites and low-grade metamorphic rocks intimately associated with 1,900 ± 100 million year-old porphyroids. The northern discontinuity (Trans-Himadri Fault or Zanskar Shear) marks the plane along which the Phanerozoic Tethyan sedimentary cover got detached from its foundation of the Great Himalayan high-grade metamorphic rocks. The Great Himalayan metamorphic rocks evolved at a depth of 25 to 30 km under pressure of 6 to 10 kb (locally up to 12 kb) and in the temperature range of 600°C to 800°C. These are injected with and pervasively migmatized by anatectic granite characterized by high strontium isotope ratios, and presence of sillimanite, garnet and cordierite. They were emplaced in the period 25 to 18 Ma, the peak granitic activity occuring at 21 Ma.

Concordantly folded with the Lesser Himalayan Proterozoic sedimentary succession, the Lesser Himalayan metamorphic rocks, occurring as thrust sheets or nappes, travelled different P-T-t paths, as evident from the range of temperature 250°– 450° C and pressure conditions of 3 to 6 kb. Synmetamorphic ductile shearing of the thrust succession has been explained as the cause of inverted metamorphic successsion.

The magnetic polarity reversal studies put the upper limit of the youngest marine sediment of the Subathu Formation at 42.6 Ma, and the commencement in the continental setting of fluvial sedimentation represented by the Dagshai (Lower Dharamsala) at 23.55 Ma. This suggests a gap of nearly 15 million years. However, recent dating of 36-40 million year-old heavy minerals in the basal sediments indicates that the gap is not that big. Patterns of sediment dispersal and palaeocurrents indicate that there was in the Oligocene a drastic reversal of the direction of drainage from the earlier northerly or northwesterly to the present southerly and southeasterly. This development implies that the Oligocene tectonic upheavel created a water-divide in the Himalayan provice.

In the Kailas-Kargil belt along the India-Asia collision zone more than 2,000 m-thick succession of conglomerates and sandstones was emplaced in the channels and flood plains of rivers that alternately meandered and flowed as a braided system. Remains of palms, rosewood and charophytes indicate a warm-moist climate prevailing in the then Sindhu-Tsangpo floodplains that could not have been higher than 2,100 m above the sea level. The vertebrate fauna, including crocodiles, turtles, python-like snakes and mammals (goat and deer) of strong Eurasian affinity assign the sedimentary succession to the period from the Later Upper Oligocene to Middle Miocene time.

The chronological limits of the Siwalik are put at 18.3 Ma and 0.22 Ma on the basis of magnetic polarity reversal studies carried out in Jammu, Himachal and Nepal. The rate of the Siwalik sedimentation is estimated to be very fast, varying from 10 cm/1,000 yr. to 71 cm/1,000 yr. The great volume of sediments brought by the Himalayan rivers converted the neogene Siwalik Foreland Basin into extensive floodplains in which rivers migrated laterally, formed coalescing aprons, and built multistoried sand complexes. Intense compression of this basin at ~ 0.8 Ma culminated in the emergence of the Siwalik Hills in the north, the breaking up of the basin along what is known as the Himalayan Frontal Fault, and the development of subsiding Sindhu-Ganga-Brahmaputra Basin in the south. Filled up with sediments, it eventually became the Indo-Gangetic Plains.

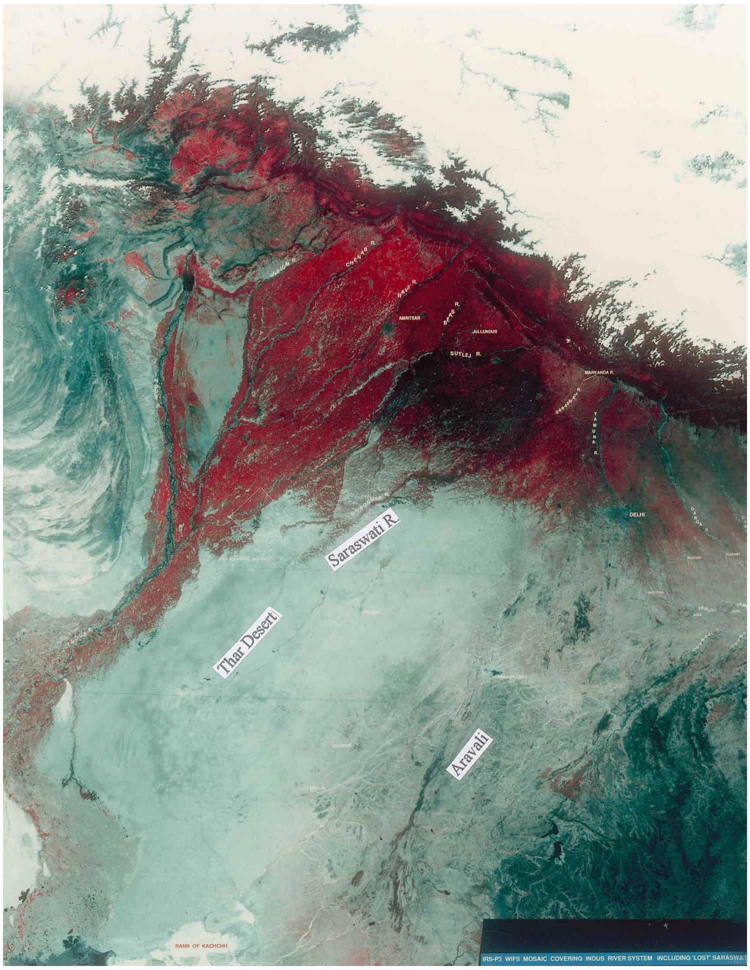
Most of the major faults of the Himalaya are proved to be quite active . This is borne out by dismemberment, dislocation, uplift and deformation of Late Quaternary fluvial terraces, colluvial fans and cones, and lacustrine flats in many parts of the Himalaya. Movements on active faults caused blockage of rivers and streams and formation of lakes practically in all the four terranes of the Himalaya. Radiocarbon dating of the basal clays of the palaeolakes and thermoluminescence dates of the gouges in the shear zones of the causative faults suggest that the lakes originated in the period 60 and 40 ka.

The lacustrine deposits preserve records of the change of climate in the Late Quaternary. The wet-cold phase alternated with dry hot spells a number of times all over the Himalayan province. It was a warm-wet spell between 6,000 and 4,000 yr B.P. and the 3,500-2,000 yr B.P. was a time of considerable dryness throughout the Indian subcontinent.

Impacts of Continuing India-Asia Convergence

The GPS geodesy has established the rate of India–Asia convergence at 54 ± 4 mm/yr. Only about 30 per cent (e.g. 18 ± 2mm/yr.) of India-Asia convergence is absorbed across the Himalaya, the average rate of accomodation derived on the basis of slip rates of great earthquakes being ~17 mm/yr. Recent GPS measurements along the Delhi-Malari and Delhi-Milam sections across the Kumaun Himalaya show that the Tethyan domain beyond the Great Himalaya is advancing southwards at the rate of 18 to 20 mm/yr. The Great Himalayan terrane is rising at much faster rate of 7 ± 2 mm/yr. in northcentral Nepal. Relevelling by Survey of India demonstrated that the Siwalik terrane in the Dehra Dun Valley in the central sector is rising at the rate of 0.8 to 1.0 mm/yr.

The Aravali mountain is registering a slow rate of uplift, as evident from the deflection of the rivers, including the Yamuna eastwards and the Satluj westwards. Saline lakes of the desert realm in Rajasthan resulted from segmentation of river



The tectonically resurgent Aravali Range, trending NNE-SSW, was responsible for the deviations and deflections of the Himalayan rivers including the legendary Saraswati, that is now represented by the dry channels of Ghaghar River. The Ghaghar loses itself in the vast desert of the Thar in the west.

channels along NE-SW trending faults related to the active faults of the Aravali domain. The Gujarat Plains of the Sabarmati and Mahi rivers are, likewise, experiencing impacts of neotectonic movements, including shifting of river courses. The abandoned channels offer good potential for reserves of water.

The Dharwar Craton in the southern part of the Indian Shield is much more dynamic than previously thought. Cut by active faults trending NNE/S- SSW/S in the eastern part of the Dharwar Craton and NNW/N-SSE/S in the west, the strike-slip and oblique-slip movements gave rise to horst mountains -- the Biligirirangan-Mahadeswaramalai in the east and the Sahyadri in the west. Synchronously, the breaking up of the NNW-SSE striking linear fault-blocks along the ESE-WNW oriented reverse faults and shear zones was responsible for the peculiar en echelon configuration of the high ranges of the Sahyadri and its escarpment the Western Ghat. The buckling and breaking of the crust of the Southern Granulite Terrane along the E-W oriented reverse faults and shear zones culminated in the emergence of the >2,500 m-high Nilgiri Hills. Strong fluvial response to active tectonism including stream ponding, indicates Late Quaternary reactivation of ancient shear zones and faults of the Southern Indian Shield. The time span of the formation of palaeolakes in the Mysore Plateau and the Nilgiri Hills implies Late Pleistocene to Middle Holocene reactivation of the causative faults.

Analyses of teleseismic waves indicate the presence of an anomalously thick (4 to 5 km thicker low-velocity (1-3 per cent) crust beneath the Kodaikanal granulite terrane adjoining the complex of gneisses and granites. This is interpreted as implying underplating related to continent-continent collision, resulting in the evolution of a granulite terrane in the proterozoic belt.

The pattern of epicentral distribution indicates that the Himalayan earthquakes are related to the movements on the MBT -- and its subsurface northward extension , and to the multiplicity of tear faults that cuts the Himalaya transversely. There is an approximately 50 km wide belt of predominant moderate earthquakes (M 5 to 6) located in the inner Lesser Himalaya just south of the MCT. Intense microseismicity also tends to be clustered in this belt, just in front of the Great Himalaya. The depths of hypocentres are quite shallow -- commonly 25 to 20 km. The hypocentres define a shallow-dipping detachment plane which separates the subducting basement from the overlying sedimentary wedge.

The seismicity is confined to the fault-delimited horsts, grabens and transcurrent lineament in Peninsular India.The level of strain accumulation in the whole of Southern Indian Shield is quite low – less than 10 manostrains/yr., implying the release of strain by slow movements on active faults.

Belts and Modes of Mineralization and Mineral Deposits

Most of the mineral deposits including those of rare-earth elements are intimately associated with the thermodynamics and hydrothermal processes related to the rifting of lithosphere and the subduction of plate. Characterized by wide shear zones, the subduction zones have been found to be particularly favoured locales of mineralization. Among the big discoveries that have influenced the resource scenario in the country are the following: the Jaduguda-Bhatin-Naroapahar uranium belt in the Singhbhum Shear Zone, the giant copper (-molybdenum) deposit of Early Proterozoic age in the granitoid rocks at Malanjkhand, M.P., the East-Coast bauxite province, the world-class zinc (-lead) deposit at Rampura-Arucha, Rajasthan, the world's largest barite deposit at Mangampet, A.P., the sandstone-hosted uranium at Domiansat, Meghalaya, and the Proterozoic 'unconformity-type' uranium deposits in the basal Cuddapah at Lamapur, A.P. and in the Bhima Basin.

Recent researches have shown that the main source of hydrocarbons in sedimentary sequence is the vegetable debris, including phytoplanktons, algae and lipid-rich plant remains derived from land as well as marine realms. The Bombay High basins of shelf carbonates (Palaeogene-Holocene) represent very productive offshore synsedimentary grabens containing marine, paralic and continental-facies sediments. The payzones are invariably associated with unconformities and diastems.

The 26th January 2001 earthquake of Mw 7.7 was the latest of the many large earthquakes that ravaged Gujarat in the last 10,000 years. This seismite seen underground near Vadodara was formed when the sediment got remobilized due to severe ground shaking.

The finding of heavy oil in the Cambrian rocks in the western part of the Bikaner-Nagaur Basin in northwestern Rajasthan has added a new dimension to the philosophy of search for petroleum, calling for reinvestigation of the Precambrian-Cambrian boundary sequences in various intracratonic and continental-margin basins, including the offshore continental shelves.

Developments in the Indian Ocean

In the Bay of Bengal, the Eightyfive East Ridge was formed in the Palaeocene period along the spreading axis as a result of a hotspot volcanic activity. A deformation zone extending from the Central Indian Ocean up to the northern Ninety East Ridge marks the diffuse boundary between the Indian and Australian plates. The northern part of the Indian Ocean experienced repeated tectonic deformation, stresses and N-S shortening as testified by folds and faults in the sedimentary cover of the crust, 7.5 Ma, 4 Ma and 0.8 Ma, with a cyclicity of 3.5 million years. Development of submarine NNW-SSE trending grabens and ridges and marginal basins on the marginal shelf and slope of southwestern India tend to corroborate this deduction. The NNW-trending magnetic lineaments marking anomalies have been interpreted as representing a two-limbed sea-floor spreading sequence in the interval 84 to 65 Ma in the Laxmi Basin in the northern Arabian Sea.

Nearly 8,500 m thick sedimentary succession overlying the Early Cretaceous oceanic basement is characterized by four unconformities -- Lower Eocene, Upper Oligocene, Upper Miocene and Upper Pleistocene. The sediment pile of the Bengal Fan documents excessive influx of sediments in the Bay of Bengal at about 10.5 Ma, 8 Ma, 2.6 Ma and 0.8 Ma, primarily derived from the Himalaya. The influx rate increased from 20-70 m per million year to more than 200 m/m.y. suddenly about 0.8 m.y. ago, obviously due to abrupt uplift of the Great Himalayan domain. In the inner shelf off the southwestern coast of India, the rates of sedimentation are very low -- 0.72 and 0.56 mm/yr at the water depth of 35 and 45 m respectively.

Oxygen isotope ratios of Palaeogene foraminifers of the western coast indicated cooling down of sea water from 32° C in the Early Eocene to 20° C in the Early Oligocene, and then a rise to 25° C. The oxygen-isotope systematics coupled with analysis of the Neogene planktonic foraminiferal assemblages of the Central Indian Ocean and the Arabian Sea indicated change in the chemistry of water and its cooling as a consequence of influx of cold water from Antarctica Sea at 22 Ma, 14 Ma, 12 to 10 Ma, 6.2 to 5.2 Ma and 1.8 Ma. Quantitative abundance of radiolarian and foraminiferal assemblages in the Arabian Sea, throw light on the palaeoclimate changes in the ocean realm. The characteristic radiolarians and foraminifers in the sediments in the northwestern Arabian sea, exhibiting distinct geochemical and biological changes, indicate strong upwelling, induced by southwesterly winds which led to the onset of monsoon about 8 ± 1 million years ago.

In the field of marine mineral resources, India has acquired the pioneer investor status over nearly 1,50,000 km^2 area in the Indian Ocean for mining polymetallic nodules -- ferromanganese nodules rich in cobalt and copper sulphides. The high-grade Pleistocene phosphorite and Holocene phosphatized limestone, with glaucony-phosphatic sediments on the western continental margin that show influence of microbial activities, provide a Quaternary analogue of the Precambrian phosphorite deposit.

Shallow seismic reflection surveys indicated presence of methane-charged sediments in the inner continental shelf off the western coast 10-20° N. Nearly 2.60 million tonnes of gas is estimated to be trapped here. The seismic profiles on the outer continental shelf's middle slope show the existence, 500-600 m below the sea floor, of deposits of gas hydrates, the source of methane.

From the lowest level, 150 m below the present sea-level around 18,000 yr B.P. during the Last Glacial Maximum, the sea water has been rising intermittently all through the Holocene. If it stood 25 m below the present during 8,000 to 7,000 yr BP in the Visakhapatnam area, it was 2 to 5 m above the present at 6,000 yr BP in the Rameshwaram sector on the eastern coast. On the westesrn coast the rise of sea level has been quite rapid in the interval between 9,000 to 7,000 yr BP, when the whole of the Rann was inundated by sea water and thus connected with the gulfs of Cambay and Kutch.

The Ganga-Brahmaputra rivers together annually transfer ~ 1,000 tonnes of uranium to the sea – which is ~ 10 per cent of the estimated global supply. The dissolved uranium concentration of ~ 2 μg/1 (compared to the global average of 0.3 μg/1) is thus a conspicuous characteristic of the Ganga water. In the Bhagirathi and the Alaknanda waters the dissolved ^{238}U content is typically ~ 2μg/1 while the ^{226}Ra content is 0.2 dpm/1. The rate of weathering (~ 2 kg/km^2/yr) of uranium (comparable in the Yamuna, Ghaghra and Gandak basin) is two orders higher than that in the Amazon and Congo basins. The $^{87}Sr/^{86}Sr$ value of the Alaknanda, Bhagirathi and their tributaries varies between 0.7300 and 0.7986. The Ganga mean of 0.7239 is higher than the global average of 0.7119.