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Special issue: Quaternary Period in India

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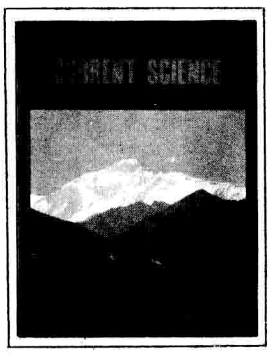

◀ COVER. The great height of Kedarnath of the Himadri resulting from fast movements in the Quaternary period.

Indexed in CURRENT CONTENTS

Guest editor: K. S. Valdiya
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The editor thanks Prof. K. S. Valdiya, Department of Geology, Kumaun University, Nainital 263 002 for agreeing to be guest editor.

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Foreword

I was invited by *Current Science* to be guest editor of a special issue on Quaternary Period in India. The objective of this special issue is to highlight those momentous events in the last 1.6 million years of the geological history which have shaped the landforms, fashioned the landscapes, given rise to invaluable mineral deposits and evolved the unique natural heritage of the Indian subcontinent. It was during the Quaternary period that the Himalaya in the north and the Nilgiri–Cardamon Ranges in the south rose to their spectacular heights, the vast stretch of the Indo-Gangetic plain came into existence, and the productive deltas emerged at the mouths of the great rivers.

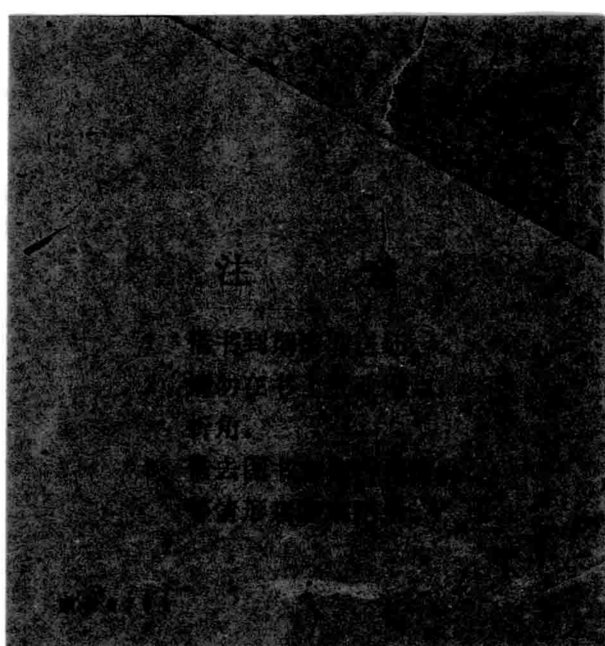
While the peculiar physiographic setting under hot-humid climate and Quaternary tectonics provided propitious conditions for the formation of thick mantles of laterites and bauxites over the extensive shield of Peninsular India, the thick piles of sediments of the alluvial and deltaic plains conceal underneath rich reserves and pools of life-giving water and indispensably essential oil and gas. And there are valuable deposits of radioactive minerals and construction material in several coastal strips and river valleys.

This was the period when Man appeared on the Indian terrain in an environment characterized by rapid tectonic upheavals, drastic topographic modifications and brisk climatic changes—from refrigeration of the Pleistocene to the semi-aridity of the Recent. Braving climatic vicissitudes, resisting the inexorable march of the desert, combating hazards of earthquakes, landslides, floods and sea-storms, and battling against the waywardness of rivers that frequently changed their courses, the Stone-Age Man established footholds in geodynamically favourable and physiographically suitable locales practically throughout the subcontinent, making history that is ours. The flat stretches of the alluvial and deltaic plains not only served as the nurseries for the teeming millions, but also witnessed the stirring events of history that have welded the disparate racial stocks and ethnic groups into one nation.

Obviously, the Quaternary is the most fascinating period of the geological history of the Indian subcontinent.

I am deeply grateful to H. K. Gupta (Hyderabad), R. Vaidyanadhan (Bangalore), T. C. Devaraju (Dharwad), N. H. Hashimi (Panaji), K. B. Powar (Pune), S. N. Rajaguru and G. L. Badam (Pune), H. N. Srivastava (Pune), S. S. Merh (Baroda), Kanchan Pande (Ahmedabad), S. B. Bhatia (Chandigarh), Ashok Sahni (Chandigarh), O. N. Bhargava (Chandigarh), S. K. Tandon (New Delhi), R. K. Verma (New Delhi), Brahma Parkash (Roorkee), Sriniwas (Roorkee), V. C. Thakur (Dehradun) and P. B. Banerjee (Calcutta) for very painstaking critical review of the papers. Arun K. Sharma of Geology Department, Kumaun University, processed the manuscripts and Keshav Mathela, Om Sagta, Mohan Bisht and Vishwa Ghoshal extended their unstinted help. I thank them.

K. S. VALDIYA



This issue

Painting a broad picture of landscape of the rigid and stable Peninsular Indian shield, B. P. Radhakrishna (**page 787**) reconstructs the history of uplifts, including the rise of the Nilgiri mountain, and resultant geomorphic rejuvenation of the South Indian region. K. B. Powar (**page 793**) demonstrates that episodic cymatogenic movements in western Maharashtra have given rise to high Sahyadri uplands with their spectacular Western-Ghat scarp and the Konkan coast, characterized by its peculiar drainage system. The evolution of the petroliferous Krishna–Godavari Basin in the East Coast is attributed by S. K. Biswas (**page 797**) to rifting and separation in the mid Cretaceous of the continental margin, which has experienced at least five movements along Precambrian lineaments in the Quaternary times as the deltas prograded rapidly. R. Vaidyanadhan and R. N. Ghosh (**page 804**) describe the physiographic layout and stratigraphic correlations of the sedimentary successions in the Bengal-to-Kerala East Coast and demonstrate that the considerable modifications it has undergone are due to progradation of deltas, impacts of glaciation–deglaciation on the continents, and neotectonic movements. On the basis of geomorphic and chronostratigraphic data, S. N. Rajaguru, Vishwas Kale and G. L. Badam (**page 817**) reconstruct the history of changing flow-regimes of rivers in Upland (northwestern) Maharashtra resulting from climatic changes.

S. S. Merh and L. S. Chamyal (**page 823**) describe geomorphic peculiarities of the coastal belt and alluvial plains of Gujarat which, they believe, evolved under control of tectonic framework due to the interplay of eustatic sea-level fluctuations and climatic variations. The Sabarmatic alluvial plain of Gujarat, characterized by flow deviatory trend from the regional slope, is interpreted by B. K. Sareen, S. K. Tandon and A. M. Bhola (**page 827**) as a product of the interaction of fluvial and aeolian conditions and sea-level changes in an environment of reactivation of pre-Neogene faults of the basement. In the Barmer region of western Rajasthan, N. Krishna Brahmam (**page 837**) attributes recent seismicity to reactivation of zones of weakness in the uplifted block of the dense lower crust (or upper mantle) he recognizes on the basis of gravity high. Studies of loess with palaeosols in Rajasthan and Kashmir Basin by R. K. Pant (**page 841**), combined with deep-sea oxygen-isotope record reveal that the Thar desert has resulted from and expanded due to the interaction of neotectonism and climatic changes—primarily the onset of strong north-east monsoon conditions following the Pleistocene Ice Age.

On the basis of magnetovariational studies in NW India, B. R. Arora (**page 848**) interprets the underground NE-SW trending conductive structure as representing a Proterozoic accretion zone between ocean-type crust in western Rajasthan and continent-type crust under the Indo-Gangetic Plain, the accretion zone undergoing movements in response to stresses generated by the locking of the Indian and Asian plates. Charu C. Pant and A. K. Sharma (**page 855**) present a summary of the studies carried out on the nature of the basement, geophysical conditions prevailing, and pattern of sedimentation in the Indo-Gangetic Basin of the North Indian plains, which has experienced neotectonic movements as testified by shifting courses of rivers.

Analysing the magneto-stratigraphy backed up by the testimony of vertebrate fossils of the 5.6 to 0.22 m.y.-old Upper Siwalik in Jammu and Panjab region, A. Ranga Rao (**page 863**) demonstrates that the accelerated rate of sedimentation (varying from 0.27 to 0.71 m/1000 years) was due to foreland-directed migration of depositional centres of the foredeep in front of the rising Himalaya. Pointing to pronounced effects of rejuvenation of the geomorphically very mature terrain of the Lesser Himalaya that must have had very gentle and low relief (< 1000 m high) where Stone-Age people lived and intermigrated freely, K. S. Valdiya (**page 873**) demonstrates very rapid uplift of the mountains along active faults and thrusts. The Himalaya rose to its present formidable height after the middle Holocene and became forbiddingly difficult and locally inaccessible as a consequence of brisk neotectonism, argues Valdiya. K. N. Khattri (**page 885**) identifies three major sectors in the Himalaya where no great earthquakes have occurred for a long time because the active faults there have become locked. According to him these are the likely locales of future great earthquakes. On the basis of the observations that major earthquakes are preceded by precursory swarms of smaller events or periods of quiescence, H. K. Gupta (**page 889**) made a forecast of a great earthquake, which came true in the vicinity of the Indo-Burma border. The palaeontological studies of the lake deposits carried out by Ashok Sahni and B. S. Kotlia (**page 893**) demonstrate that the vertebrate assemblage comprising rodents migrated some 2.5 m.y. ago into the intermontane Karewa Lake in the Kashmir Valley across Afghanishtan from Europe, while the Siwalik fauna came from Africa via Pakistan. The lake basins in the Tethys realm across the Great Himalaya Range were formed as a result of neotectonic movements according to T. N. Bagati and V. C. Thakur (**page 898**). The lake sediments bear influence of differential uplift in the past 35,000 years, which was responsible for climatic changes and vegetational variations. According to M. E. Brookfield (**page 903**), the lacustrine deposits along the courses of major rivers in northwestern extremity of Himalaya comprise a complex of glacial tills and fluvial valley-fills of the Late Pleistocene age, testifying to the events which cannot be disengaged from those of earlier Pleistocene. From the relative abundance of planktonic foraminifers and analysis of isotope records for deep-sea cores from sites in northern Indian Ocean, A. D. Singh and M. S. Srinivasan (**page 908**) deduce that there were four intervals of cooling of the climate in the past 3 million years, including three in the Pleistocene. P. C. Shrivastava and P. R. Chandra (**page 915**) have shown that the inner marine shelves of the continental margin are mantled with terrigenous sediments, while the outer shelves are covered with 7,500 to 12,500-year-old ooids, with algal and coralline reefs which must have formed when the sea level was down by about 100 m.

There are eight notes on the findings and opinions on the characteristics and tectonic significance of laterites-bauxites by T. C. Devaraju & S. D. Khanadali (**page 919**) and by P. K. Banerjee (**page 921**); the evidence for Quarternary volcanic activity in the Maharashtra plateau by B. M. Karmarkar, S. R. Kulkarni & S. S. Marathe (**page 923**), the age and mineralogical composition of the miliolite deposits of Gujarat coast by B. L. K. Somayajulu (**page 926**), the testimony of palynospores from lake deposits on the climatic changes in the Himalayan realm by Chhaya Sharma (**page 930**), the sedimentogical–geomorphological indication of occurrence of earthquakes in the recent past in Meghalaya by B. K. Rastogi, R. K. Chadha & G. Rajagopalan (**page 933**), and the changes in monsoon rainfall pattern as borne out by the foraminifers of the ocean shelves by Rajiv Nigam (**page 935**). V. Subramanian (**page 928**) writes about the sediment load of Indian rivers.

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Neogene uplift and geomorphic rejuvenation of the Indian Peninsula

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Events in the Quaternary which have fashioned the Peninsular Indian landscape are briefly narrated. The break-up of the Gondwana supercontinent of which India formed a part, the northward flight of India, the sudden burst of volcanic activity, the uplift of the Peninsula and its breakup, the creation of the Arabian sea and the Western Ghats paralleling the West Coast, the development of cyclic erosion surfaces preserving a faithful record of past events — these make a fascinating story of landscape development. Forces of constructive uplift and destructive erosion are seen continuously at work shaping the Peninsular Indian landscape.

Introduction

THE view that the Peninsular Indian shield has remained a rigid and undeformed mass, subject only to subaerial denudation throughout geological history, is so much ingrained in our mind that any suggestion of Quaternary tectonic activity in this region is viewed with disbelief. Nevertheless, it is now becoming increasingly clear that even this stable Peninsular shield has had its share of earth movements, although somewhat different from those which have affected the extra-peninsular region. The object of the present paper is to paint a broad picture of the Peninsular Indian landscape — a landscape which is the result of sculpture during the latest periods of earth history, including the Neogene and Quaternary.

Peninsular Indian Shield

Traditionally, the Indian sub-continent has been divided into three major physiographic units: (1) the elevated triangular Peninsular shield south of the Vindhyas, (2) the mighty Himalayan mountain range in the north, and (3) the vast plain in between, filled up by the Indo-Gangetic alluvium.

Our main concern in this paper is the geomorphic analysis of the Peninsular Indian landscape made up, to a large extent, of rocks which were formed almost at the very dawn of geological history, thousands of million years ago. Over certain segments of this ancient landmass are sedimentary cover-rocks of Proterozoic age (the Cuddapah, Pakhal, Kaladgi and Bhima) and Gondwana (upper Carboniferous – upper Jurassic). A vast stretch of volcanic flows piled one upon the other, is recognized as the Deccan Traps (Paleocene?) covering a good part of western and central India. Despite this fundamental difference in stratigraphical and structural history of the Peninsular Indian and Himalayan region and the absence of evidence of compressive stresses, surprisingly, the Peninsula too presents physiographical diversity and youthful character of its mountain ranges, as significant as those in the extra-peninsula. This is especially so with the mountains bordering the western margin known as the Western Ghat or the Sahyadri Mountains. Segments of the Sahyadri are as magnificent and awe-inspiring as those of the Himadri. Both the mountain ranges were moulded by tectonic forces of recent origin. While in one case the orogenic laterally-operating forces were responsible for folding and thrusting, giving rise to the stupendous Himalaya mountain barrier, in the case of the Peninsula, the movements were epeirogenic in nature caused by vertical uplift of the rigid continental mass as a whole. It is this vertical movement which has left the cover-rocks in the Peninsula practically undisturbed, giving the impression of apparent stability. The most important point to note is that in both the instances spectacular physiographic diversity in landscape is the result of the sculpturing by denudational forces on land masses which were rejuvenated due to uplift in the Tertiary and Quaternary times. The consequences of such uplifts on the Peninsular Indian landscape are profound.

Geomorphological consequences of uplift and rifting

The effects of recent earth movements can be observed particularly in regions where erosion has had no time to obliterate the evidence altogether. The youthful character of the mountain ranges and the streams, the several drainage anomalies, and the present-day aspect of the erosion surfaces are noteworthy.

Straightness of the West Coast

The straight-line aspect of the West Coast of India and the Western Ghat scarp paralleling the coast are very striking. The abrupt termination of the Deccan Trap-flows along the line of Western Ghat is a clear indication of Cenozoic uplift, rifting and down-faulting. The western extension of the uplifted plateau was submerged under the waters of the Arabian Sea. The narrow coastal belt between the Ghat edge and the sea is arranged in step-like terraces, pointing to the possible effect of recent oscillations in sea level, and of submergence as evident from drowned river valleys, lagoons and bars. Wave-cut cliffs are common along the coastline pointing to former changes in sea level.

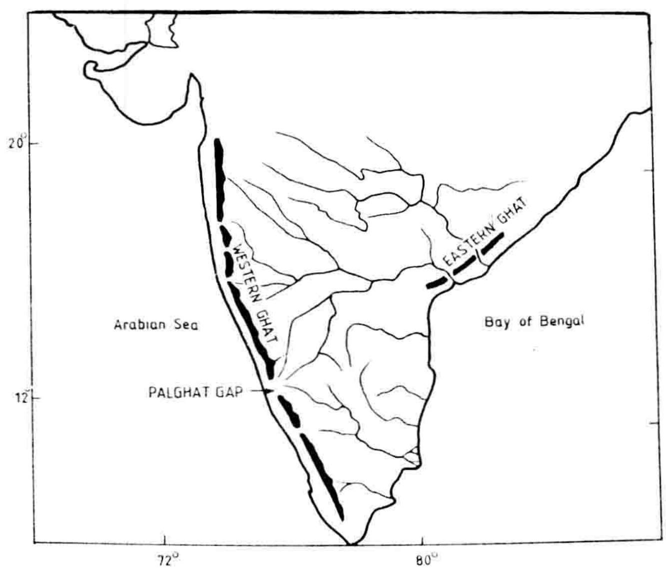

Figure 1. Sketch map of the Indian Peninsula showing positions of the Western and Eastern Ghat. Note the remarkably straight edge of the Western Ghat paralleling the coast. The only gap in the mountain range is at Palghat.

Sahyadri: the edge of an uplifted scarp

The Sahyadri ranges running almost parallel to the West Coast (Figure 1) and lying only 50 km away is the most prominent physiographic feature of the Peninsula. It is a great escarpment which can be traced for 1500 km in the form of a formidable wall extending from near the Tapi River in the north to Kanyakumari in the south. Whatever be the rock type—the flat-lying Deccan Trap in the north, foliated Dharwar schists and Peninsular Gneisses in the middle and massive charnockites in the south—these ranges have an average elevation of about 1200 m and in certain sections rise even up to 2500 m as in Nilgiri, Palani and Anaimalai. The ranges have a steep and abrupt western front, the result of uplift along an axis paralleling the present-day West Coast.

Palghat Gap

The Palghat gap (Figure 1) in the unbroken Western Ghat face, observed north of 10° Latitude, is a striking feature in the Peninsular Indian landscape. The gap is about 13 km wide at the narrowest point and about 170 m above sea level. The gap in the form of a valley is inferred to have been carved by a major west-flowing river in the past[1,2]. This river appears to have got beheaded during the elevation of the Ghat. The present insignificant stream Ponnani flowing westward in the valley is obviously a misfit stream—a river too small to have eroded the broad valley in which it is flowing. The valley floor has all the characters of a plain of marine denudation[3,4]. The occurrence of black soils and gypseous beds in the Coimbatore region east of Palghat is indicative of former marine incursion and estuarine condition in the past. A recent suggestion is that it marks the fusion of two discrete continental blocks—the Tamil Nadu–Kerala triangular block lying to the south and the Archaean Karnataka block to the north[5] (Figure 2). The E–W shears seen along this belt possibly

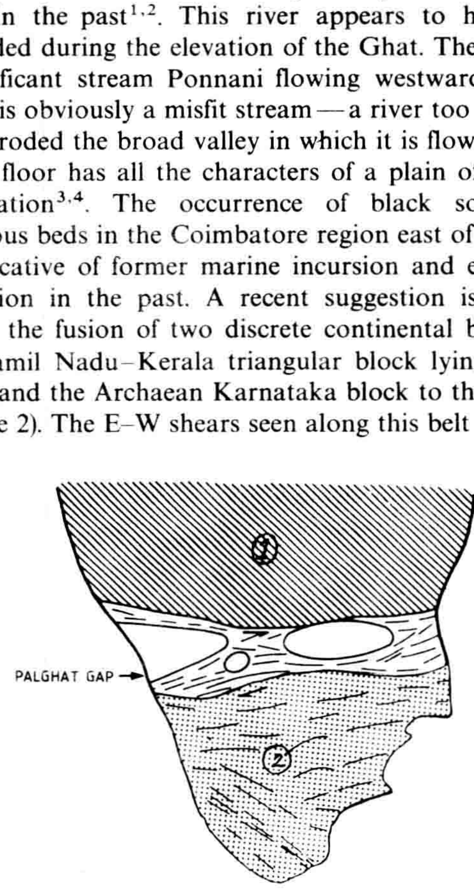

Figure 2. The position of the Palghat Kaveri suture marking the fusion of two discrete continental blocks. 1. Karnataka. 2. Tamil Nadu–Kerala.

represent reactivated tectonic sutures[6]. The existence of this suture appears to be in some way connected with the sculpturing of the Palghat Gap. As yet, no convincing explanation is forthcoming for the origin of this physiographic anomaly.

The Eastern Ghat

The Eastern Ghat fringing the East Coast between Madras and Balasore is not so spectacular as the Western Ghat but represents discontinuously elevated ground whose elevation does not exceed 1200 m. The geology is also varied, the ranges being composed of granulites and gneisses in the north, quartzites and charnockites in the south. The escarpment character of these ranges paralleling the coast north of Madras is also not so well pronounced as in the case of the Western Ghat. The Godavari and the Krishna rivers have cut deep gorges through the Ghat, irrespective of structure and lithology, and are clearly antecedent. The easterly drainage had been well established before the Eastern Ghat was upwarped[7]. The intrusion of magma into the lower crust could be one of the mechanisms of uplift, as suggested by McKenzie[8]. Not much of work has been done in deciphering the denudational history of these ranges.

Youthful aspect of the Western Ghat scarp

The Western Ghat scarp still preserves its youthful character. West-flowing rivers have hardly been able to make a dent on the scarp face. Eastward, the drop in elevation is gradual, with an undulating landscape deeply dissected into mountains and valleys close to the Ghat edge, but becoming a featureless plain at an average elevation around 1000 m, to the east. This feature clearly brings out the fact that the Sahyadri or the Western Ghat as we observe today is the precipitous western edge of an elevated plateau. Since the Deccan Traps straddling the Cretaceous–Tertiary boundary (KTB) are involved in this uplift, it is inferred that the uplift took place in Mid to Late Eocene. On the steep western side, narrow segments of the elevated plateau appear to have been let down to form the present-day coastal belt of low ground arranged in step-like terraces.

What is of interest is the erosive power of the west flowing rivers, especially where they have captured the easterly drainage over the plateau. The Sharavathi River near Honnavar (Figure 3) and the Kali (Figure 4) near Karwar are classical examples of river capture. Narrow steep gorges with steep water falls at their head are characteristic of these rivers. The stages by which the easterly drainage over the plateau has been captured by

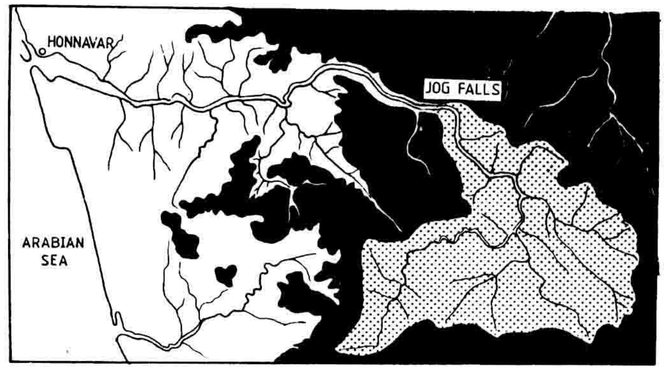

Figure 3. The Sharavathi River, A west-flowing consequent stream, capturing the easterly drainage above the Ghat. The recession of the waterfall (Jog Falls), and carving out of a 20 km long gorge points to its recent origin.

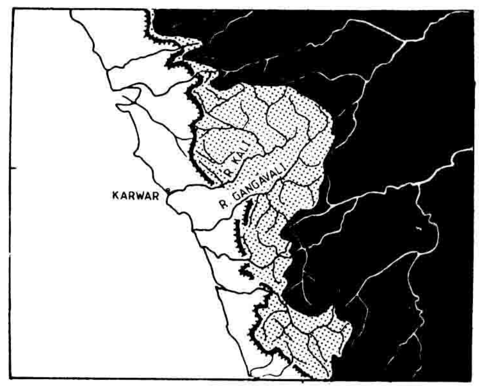

Figure 4. River capture along the Western Ghat. The west-flowing Kali and Gangavali rivers have captured the easterly drainage above the Ghat.

west-flowing rivers have earlier been described by Radhakrishna[9].

There are innumerable evidences of rejuvenation of the earlier planation surfaces. The region immediately east of the precipitous edge of the Western Ghats is riddled with mountains and valleys showing a remarkably youthful aspect. The accordant summits of the hill ranges, however, point to the fact that they represent only an old planation surface which was uplifted during the Tertiary and is getting rapidly dissected as a consequence of the uplift.

Senile character of the plateau

While the western face of the Sahyadri presents a youthful aspect, the Deccan plateau lying to the east, presents a different picture altogether, one of featureless senility. The land shows evidences of having been reduced to base level in an earlier cycle. A thick residual cap of soils, alluvia and laterites, is seen over the peneplaned surface. Major rivers and their tributaries follow sluggish, meandering courses. That such plain-lands are found at present at elevations of 500 to 1000 m above sea level only shows that the region as a whole had experienced repeated uplift which exposed the peneplaned surfaces of earlier cycles to new cycles of erosion.

Plain lands of the peninsula

The bulk of the Peninsular region represents a plateau ranging in elevation from 300 to 2000 m. The plateau can be split up into stretches of plain land demarcated from each other by clear-cut scarps (Figure 5), which are narrow belts of active erosion migrating inwards. The retreating scarps destroyed an older surface giving rise to a newer surface at a lower level. The relict older surfaces of Mesozoic age can be recognized at high elevations in parts of Karnataka, Kerala, Maharashtra and Tamilnadu[10,11]. The highest surface, despite its elevation and mountainous character, retains its original character of a flat and undulating platform. This leads to the inference that it is but the remnant of an older peneplaned surface, reduced to base-level but now uplifted to its present position during the Tertiary. Intermittent tectonic movements have resulted in a number of scarp-demarcated erosion surfaces at different levels. The material denuded out of the surfaces has been deposited in the adjoining basins along the East Coast[12]. A study of the stratigraphy of the sedimentary pile in these basins helps in building a chronology of episodes of uplift experienced by the Indian continent. Erosion and sedimentation have gone hand in hand, one compensating the other. In the same way as a succession of sediments can be recognized along the continental margin in sedimentary basins, a similar succession of different erosion surfaces can be recognized in the landward side (Figure 6). The cumulative effect of uplifts during different periods is that the oldest surface is preserved at the western edge at elevations of over 2000 m.

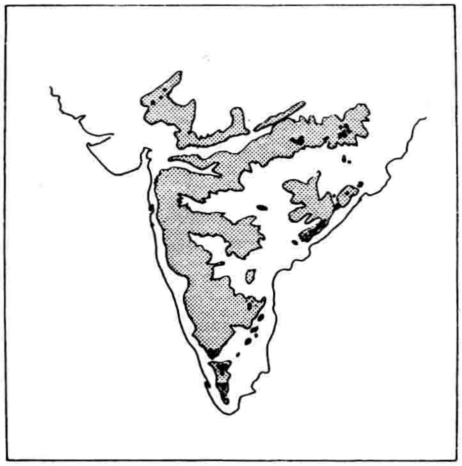

Figure 5. The extent of the vast plain lands (erosion surfaces) of the Indian Peninsula is demarcated by clear-cut scarps. Solid black: oldest erosional remnants (Gondwana surface); stipled: post-Cretaceous second younger surface; Unstipled: the youngest erosional surface (Tertiary-Recent).

Laterite capping (with occasionally economically workable concentration of bauxite) is characteristic of the highest erosion surfaces of late Cretaceous age, as seen over the Nilgiri, Shevaroy and the trap-covered plateaus near Mahabaleshwar. Laterite probably formed a continuous cover over this surface, but in the greater part of the interior, it has been removed through erosion. The laterites fringing the East and West Coasts, however, are detrital and of a more recent date. They are mostly thin as compared to the laterites over high plateaus which are 20 to 30 m thick. The relation between planar surfaces and residual laterite in Kerala and Tamilnadu has been well brought out by Subramanian *et al.*[13].

Drainage anomalies

Easterly drainage: A characteristic feature of the drainage over the Peninsula is the remarkable way in which all the major rivers originate almost at the very edge of the plateau and within sight of the Arabian Sea lying only a few kilometres away. Rivers like Godavari, Krishna and Kaveri originate at the crest of the Ghat but flow eastward traversing the whole width of the plateau (Figure 1). Evidently the easterly drainage is the effect of an easterly tilt that was given to the Peninsular landmass. It is also obvious that the segment lying to the west of the present day Western Ghat scarp has been let down and submerged beneath the waters of the Arabian Sea. The line of the Western Ghat represents a hinge, causing the eastward tilt of the Peninsula.

Antecedent character of drainage: Most of the major rivers flowing in the Peninsula are an inheritance from a previous period of peneplanation. Their valleys are broad even in the source region. They have a meandering course (Figure 7) from their very birth[7,14]. The rivers are antecedent and not consequent to the

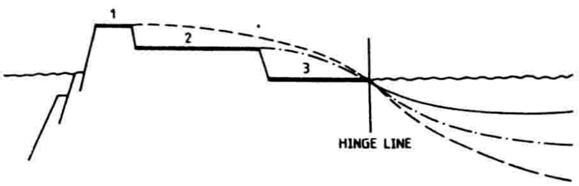

Figure 6. Sketch map showing the relation between uplifted plains and the offshore sedimentary basins.

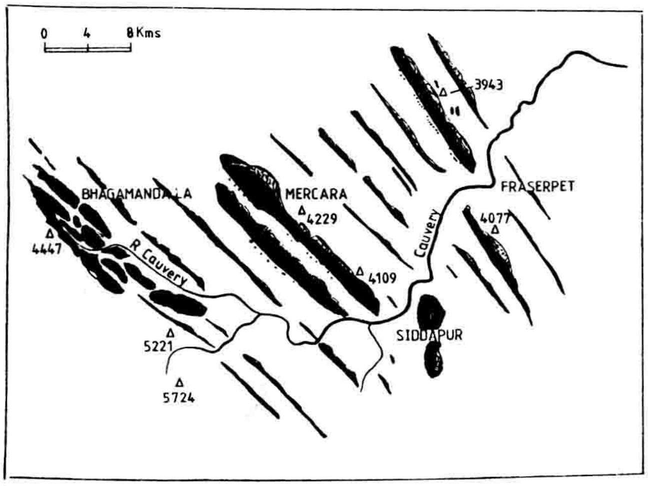

Figure 7. Antecedent drainage of the Kaveri in the mountainous region of Coorg. The mountains are younger and causing rejuvenation of the course of a well-established river.

topography as seen today. They have had a previous denudational history. The erosion of the valleys has kept pace with the elevation of the plateau.

Superposition of drainage: When a senile surface is uplifted, the consequence of such an uplift is revealed by the superposition of drainage over the newer surface. Innumerable examples of such superposition can be seen in various parts of the Peninsula. Rivers having reached a state of senility with hardly any gradient and flowing in meandering courses are now seen cutting through resistant rock formations in narrow gorges again and again. Such superposition of drainage can only happen on a surface which has suffered rejuvenation through recent uplift.

Thermal springs: The western edge of the Western Ghat scarp has been identified as a region of high heat flow. A long line of thermal springs has been identified, a few extending as far south as Puttur (Mangalore), and far away from the extension of Deccan Trap cover. The existence of these thermal springs is an indication of recent faulting[15,16].

Pre-Trappean drainage: Not much attention has been paid to unravelling the pattern of drainage on the pre-Trappean surface. One view is that the major rivers which drained the ancient Gondwanaland discharged into the Tethys Sea along westerly and north-westerly palaeoslope[17]. The Ninety East Ridge and the land to the east of it is believed to have formed an ancient mountainous region covered with thick vegetation. It acted as a watershed and contributed a major part of sediments (and organic matter for the coal deposits) to the Gondwana basins of India to the west of the Ridge. The present-day easterly drainage of the Peninsula appears to be a post Deccan Trap feature, caused by the cymetogenic upwarp of the crust along an axis a little west of the present-day Western Ghat scarp.

Evolution of the western continental margin

It seems very likely that the stupendous volcanic activity, now represented by the Deccan Trap, was initiated when the Gondwana land broke up and the separated Indian continental fragment passed over the Reunion Hotspot about 65 m.y. ago[18]. Further, it is possible to conceive a regional upwarp along the track of the Hotspot due to thermal expansion[19]. This upwarp was followed immediately after by rifting, resulting in the development of a graben along the West Coast. The thickness of the Deccan Trap in the Western Ghat is over 1000 m. The trap flows could not have ended abruptly at this point. The Arabian Sea is clearly a graben with its western segment drifting away. The subsidence of the western limb created the present day West Coast. The time of upwarp, rifting, subsidence of the western fragment, and the exposure of the eastern half as a scarp must have taken place in the Eocene, almost immediately after the cessation of the Deccan volcanic activity. The offshore basins on the west carry sediments from Eocene onwards and set the age limit for the carving of the Indian coastline. From then onwards, monsoonic climate set in over the Peninsula. The Western Ghat scarp, which was more or less a straight coastal margin, started retreating. Headward erosion of the scarp in some of the rapidly eroding consequent streams soon resulted in the capture of the easterly drainage over the elevated plateau, giving rise to waterfalls of great magnificence (Figure 3 and 4).

East Coast sedimentary basins

A study of the sedimentary sequences in the East Coast basins gives an idea of the uplift history of the Peninsula. The earliest sediments in these basins (Figure 6) belonging to Upper Jurassic, are mostly of a continental character formed as a result of downwarping of the eastern part of the Indian shield[20]. The first marine incursion and the bulk deposition of sediments started in the Cretaceous, which accounts for over 2000 m thickness of marine sediment. A pronounced regression is observed at the end of the Cretaceous, denoting major uplift of the land surface, followed by erosion. The onset of the Tertiary era is indicated by oscillatory movements in response to uplift and consequent erosion on the landward side (Figure 6).

Synthesis

Two hundred million years ago, India formed a part of a supercontinenent together with its neighbours, South

Table 1. Sequence of events

West Coast		Main Land	East Coast
Barrier ridges; swales and flats in Kerala	Recent	Reduction of old plateau to new plateau surface; Carving of present-day landscape	Chilka and Pulicat lakes; spits; Progradation of delta-fronts.
Minor oscillation in sea level; sea-cut caves; drowned valleys; estuaries and lagoons in Karnataka	Pleistocene	Migration and knick-points; River capture; Excavation of deep gorges; Retreat of scarps; Water falls	Beach sands and dunes; Building up of deltas of Kaveri, Krishna and Godavari.
Emergence of the western littoral	Pliocene	Formation of Western Ghat scarp and its retreat	Detrital laterite–East coast and lateritization.
Detrital laterite along coastal margin—extensive lateritization		Minor upwarps–rejuvenation of rivers	
Coastal sediments Warkalli beds of Kerala. Gaj beds of Ratnagiri	Miocene	Stability and planation. Reduction of elevated surfaces to newer base levels (plain lands of Mysore and N. Karnataka). Lateritization of part of the surface.	Cuddalore Sandstone; Continuous sedimentation.
Creation of the West Coast as a graben through downfaulting	Eocene	Rifting of the uplifted segment–downfaulting–Creation of Western Ghats and Western Ghat scarp facing the sea. Major uplift giving pronounced tilt to the Peninsular drainage.	
	Cretaceous	Deccan volcanic episode. Extensive trap cover over eroded remnants of an earlier surface. Northward flight of India–Passage over Reunion Hotspot; uplift.	Formation of the East Coast line and commencement of deposition of sediments.
	Jurassic	Disruption of a smooth erosional surface over Gondwanaland.	

Africa, South America, Antarctica and Australia called the 'Gondwanaland'. The oldest surface that can be identified in India belongs to this remote period when India formed a part of the Gondwana supercontinent. It has been possible to recognize this surface as the oldest surviving surface in all continental fragments of the Gondwana supercontinent. The surface as at Nilgiri and Bababudan shows all the characteristics of an old featureless peneplain, but now located at an elevation of over 2000 m above the present-day sea level.

The Indian part of the Gondwana supercontinent broke away and started migrating northward. It witnessed a burst of volcanic activity, represented by the Deccan Trap. Thermal expansion resulted in regional uplift. Still later, a rift developed along the axis of uplift. The western extension of the landmass drifted away and got floundered giving the present-day shape to the western margin. Offshore drilling by the Oil and Natural Gas Commission has shown that the floor of the Arabian Sea has a substantial cover of Deccan Trap indicating that the traps extended for considerable distance to the west. As the drifting Indian plate moved over the Reunion Hotspot, there was volcanic activity, thermal expansion and attendant uplift.

The uplift was followed by a period of crustal quiescence during which period the uplifted Gondwana surface with its cover of Deccan Trap in the north was dissected to produce a smooth planation surface of vast extent at a lower level. The Karnataka plateau is a relic of this surface. Material removed during the period was deposited as Eocene sediments in the coastal sedimentary basins. This can be considered as the widespread ancestral planation surface of south India from which all the rest of the surfaces at different elevations were carved through intermittent upwarps.

The sequence of events on the land and corresponding effects on the East and West Coast of India are summarized in Table 1.

The Peninsular Indian landscape presents several arrested geomorphic cycles, pointing to rejuvenation and uplift during the late Cenozoic and Quaternary.

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Geomorphological evolution of Konkan Coastal Belt and adjoining Sahyadri Uplands with reference to Quaternary uplift

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The western part of the Deccan Volcanic Province comprises two geomorphic divisions—the Sahyadri Uplands and the Konkan Coastal Belt—which are separated by the Western Ghats Scarp. They exhibit different drainage characteristics and landforms as a result of altitudinal and climatic differences. Various lines of evidence suggest that the region has undergone episodic cymatogenic uplift particularly during the Quaternary.

Introduction

At the Cretaceous–Tertiary (K–T) boundary (~65 m. y. ago) the Indian plate was the site of intense intra-plate volcanism which resulted in the formation of the proto-Deccan Volcanic Province. Various lines of evidence suggest that this volcanism was the end-product of a series of related tectonic events and processes, namely, the northward movement of the Indian plate, plume activity related to the Reunion Hotspot resulting in the generation of basalt magma, the rise of this magma into the lithosphere with consequent crustal arching, and finally the rifting related to development of the Cambay tectonic junction[1–3]. Post-magmatic tectonism was responsible for the submergence under the Arabian Sea of part of the proto-province lying to the west of the West Coast Fault[4] and for the development of horsts and grabens (Figure 1). The sedimentary record preserved in the easternmost graben (the West Indian Depression) suggests that submergence was initiated in the Palaeocene-Early Eocene times and has continued spasmodically to the present[5]. The adjacent land area, forming the westernmost part of the present-day Deccan Volcanic Province, has had a related though much less vigorous tectonic history including phases of cymatogenic uplift[4,6]. Though the influence of structural elements on the development of geomorphological features is evident[7–10], the available data do not permit a definitive reconstruction of the history of vertical movements. An attempt is nevertheless made here to adduce evidence to substantiate vertical uplift in the marginal areas of the Deccan Volcanic Province and to tentatively date different phases of uplift.

Geomorphic setting

The westernmost part of the present-day Deccan Volcanic Province constitutes a passive, Atlantic-type

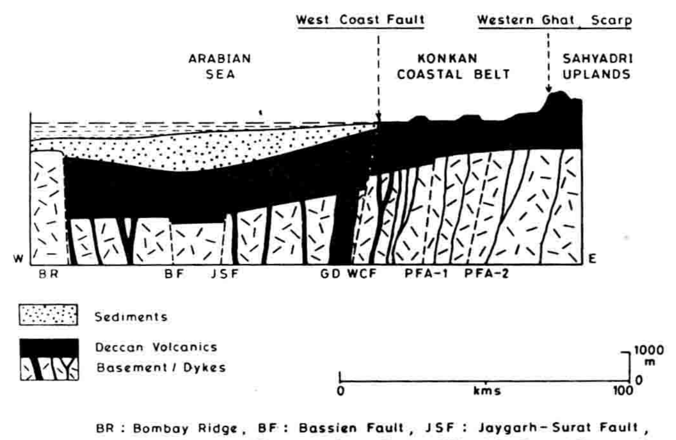

Figure 1. Idealized cross-section along the Latitude 19° N.

continental margin on the trailing edge of the Indian plate. It comprises a narrow coastal belt (referred to in Maharashtra as the Konkan), which is separated from the Sahyadri Uplands on the western edge of the Deccan Plateau, by the spectacular Western Ghat Scarp (Figure 2). These two geomorphic divisions (the Sahyadri Uplands and the Konkan Coastal Belt) have appreciable altitudinal and climatic differences, as a result of which two distinct types of drainage systems have evolved[11]. The drainage network of the Uplands is characterized by a parallel pattern on larger scale, and dendritic pattern on a smaller scale. In the Sahyadri Uplands the streams originate in the elevated (750–1400 m ASL) high rainfall zone of the Western Ghat and flow east to southeastwards, over the semi-arid Deccan Plateau, discharging into the Bay of Bengal. The valleys in the upper reaches have broad, box-like forms, flattening eastwards. The streams of the Konkan Coastal Belt display a subdendritic pattern characterized by sharp, nearly right-angled bends. They are short and flow westwards over a humid tropical landscape at 100–280 m ASL, along narrow to broad V-shaped valleys. The values for various hydrogeomorphic parameters like absolute relief at stream source, relative relief, catchment area, channel length, channel slope, valley-floor slope and basin circularity emphasize the differences between the two geomorphic divisions[11]. There are, however, many common features. The rivers in both the regions display high sinuosity marked by incised meanders, they have major inflection points, alluvial terraces occur on one or both banks, and presently all of them are in the incision phase. Planar surfaces and laterites are observed in both the divisions. The landforms observed in the Sahyadri Uplands are the result of fluvial processes while those developed in the Konkan Coastal Belt are the result of fluvial, marine and aeolian activities. Significantly, in the northern part of the Konkan Belt, amongst the marine landforms, those related to submergence dominate, while in the southern part the landforms are indicative of emergence. This suggests rotational movements on an E-W pivot centred in the region of the Alibag, between the Amba and Kundalika rivers[7].

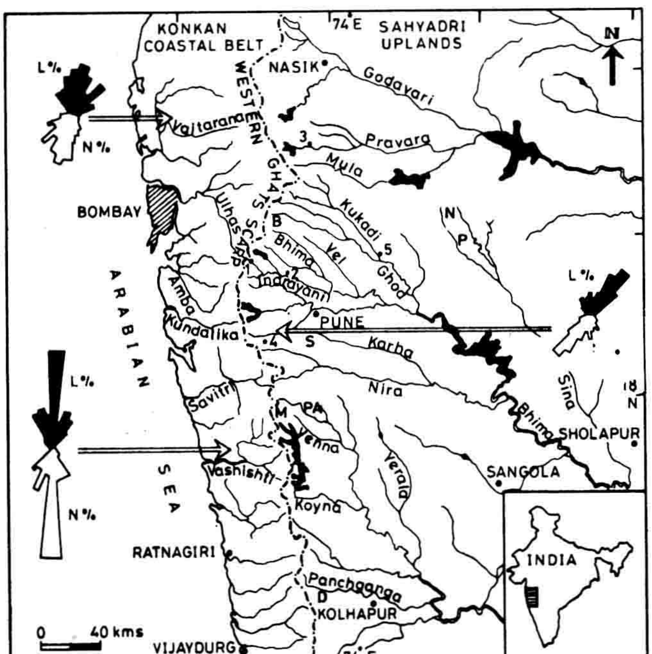

Figure 2. Index map showing drainage in the Konkan Coastal Belt and Sahyadri Uplands in Western Maharashtra. Location of townships: 1-Khandala, 2-Shelarwadi, 3-Ranadha, 4-Baneshwar, 5-Nighoj. Location of townships on planar surfaces: B–Bhimashankar, N–Nagar, P–Parner, S–Saswad, PA–Pachghani, M–Mahabaleshwar, D–Dhangarwadi. Also shown are Azimuth Frequency Patterns for lineaments. L%: Length percentage and N%: Number percentage.

Altimetric analysis, substantiated by field investigations, reveal the presence of a number of planar surfaces, both in the Sahyadri Uplands and in the Konkan Coast. In the Uplands the surfaces occur at 1320–1340 m ASL (Panchgani), 1200–1250 m ASL (Mahabaleshwar), 980–1020 m ASL (Pokhari), 900–940 m ASL (Dhangarwadi) and 580–620 m ASL (Pune, Kolhapur). These have been grouped into 3 prominent levels of planation at 1200 ± 100 m ASL (Mahabaleshwar), 1000 ± 100 m (Bhimashanker) and 700 ± 100 m ASL (Saswad-Parner). In the intermediate sub-Ghat section of the Konkan Belt narrow flats occur at 750 ± 50 m ASL ($\equiv$Saswad-Parner) and $300 + 50$ m ASL. In the Konkan Coastal Belt proper, planar surfaces occur at 180–260 m ASL, 100–130 m ASL, 60–75 m ASL and 3–15 m ASL; the last being of marine origin with its eastern limit delineating the Flandrian strandline[12,13]. Laterites and latesols occur at different levels in both the geomorphic divisions. They are well developed on the Mahabaleshwar and Bhimashankar surfaces of the Uplands, and on the Lanza-Math (100–130 m ASL) surface of the Konkan Belt.

The Western Ghat Scarp, which separates the coastal plains of western Peninsular India from the Sahyadri Uplands, is spectacularly developed in the Deccan Volcanics. At places, like the western sides of the Mahabaleshwar and Bhimashankar plateaus, it is represented by vertical faces, locally 600 m high. The crest of the escarpment corresponds more or less with the continental watershed. This scarp originated, in all probability, during the Palaeocene as a fault scarp corresponding to the simple chasmic fault at the edge of the continental shelf, and has since retreated to its present position[14].

Evidence of uplift

It has been postulated[2,15,16] that in the aftermath of the effusion of the Deccan basalts the whole Peninsular

Indian shield was subjected to episodic uplift. Various lines of evidence, which substantiate Cenozoic uplift in the western part of the Deccan Volcanic Province are briefly described below.

Geophysical data

Geophysical data collected in recent years have helped in establishing the structure of the Indian lithosphere. DSS studies indicate that the Mohorovicics discontinuity, which is at a depth of 37–42 km[17] below the Deccan plateau, rises to about 30 km along the West Coast[18] and then to 13–14 km below the continental shelf of the Arabian Sea[5]. This conclusion is also reflected in the MAGSAT scalar anomaly map prepared by Mishra and Venkatraydu[19]. The crustal thinning reflects hot-spot epeirogeny[20], a characteristic feature of which is isostatic uplift. Regional gravity surveys have revealed the presence of gravity 'highs' (Nasik, Sangola) and 'lows' (Koyna, Kurduwadi) in the western part of the Deccan Volcanic Province. These are suggestive of marked uplifts or subsidences involving the crust[15,21].

Lineament fabric

In earlier studies[4,6–8,10,22], the lineament fabric of the Deccan Volcanic Province, as traced from satellite imagery and aerial photographs, has been documented. The length and number azimuth frequency diagrams for the Konkan Coastal Belt are characterized by a strong concentration of lineaments in an approximately N–S direction. The lineament patterns, are characteristic of vertical uplift[23]. The pattern for the Sahyadri Uplands is similar, though the orientation is NE-SW, and suggestive of regional uplift. Additional conjugate systems indicate that compressive stresses were also operative. According to Powar and Patil[6] the lineament patterns reflect the joint role of compression (resulting from the collision of the Indian plate and its subsequent subduction, beginning Middle Eocene, below the Eurasian plate) and vertical uplift due to isostatic adjustment.

Knick points and incised meanders

The rivers of the Sahyadri Uplands exhibit prominent knick points in the zone 580–680 m ASL[11]. The knick points on the Pravara (at Ranadha), Kukadi (Nighoj), Indrayani (Shelarwadi) and Shivaganga (Baneshwar) are particularly striking. Most rivers in the Sahyadri Uplands show meanders in their source regions and spectacular incised meanders are observed along the Pravara, Mula (Nagar) and Pushpawati. The incision in bedrock is as much as 35 m. A very intense state of over-grade condition is evident, and this can be attributed only to vertical uplift, as base-level changes or climatic changes cannot revive river energy to the required extent[24].

Valley-fill deposits

Valley-fill deposits occur along the courses of many rivers of the Uplands, the best development being in the northern part, in the Godavari, Pushpavati, Pravara and Kas valleys. In the case of the Pravara and Kas valleys, the deposits of gravelly nature are locally more than 25 m thick and exhibit graded and cross-bedding. These deposits are considered to be 'anamolous geomorphic situations' suggestive of tectonic uplift in Late-to-Middle Pleistocene to 50,000 yr B.P.[24]. In the Konkan Coast, siliceous gravel beds occur at about 20 m ASL near Ratnagiri and Vijaydurg[11] indicating uplift.

Indrayani-Ulhas continuity

A remarkable feature of the study area is the apparent continuity of alignment displayed by the initially southeast-flowing Indrayani and the northwest-flowing Ulhas rivers in their source region near Khandala. Both occupy broad U-shaped valleys, with the continental divide being so inconspicuous that it is difficult to decide in which catchment a particular place is situated. The only explanation is that the alignment represents a pre-Tertiary valley once occupied by the ancestral, east-flowing Indrayani river, which was subsequently uplifted and warped; the portion of the valley to the west of the warp-axis being reversed to become the headwaters of the Ulhas[14].

Elevated lignite beds

Lignite beds, formed in warm and humid, estuarine environment, have been recorded at several places along the Konkan Coast. They have also been reported further inland at altitudes of 43–50 m ASL[25] and 168 m ASL[26]. The deposits are considered to be of Neogene age, and their elevated occurrence suggests post-Neogene uplift.

Planar surfaces and laterites

The occurrence of planar surfaces at various levels is suggestive of polycyclic evolution of the landscape. The surface at 3–15 m ASL in the Konkan Coastal Belt almost certainly represents an uplifted marine platform[13]. The other surfaces of the Konkan could possibly represent uplifted surfaces. It has been suggested that