CURRENT SCIENCE

Volume 64 Numbers 11&12 10&25 June 1993

Neogene uplift and geomorphic rejuvenation of the Indian Peninsula

B. P. Radhakrishna

Geological Society of India, Bangalore 560 019, India

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.

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

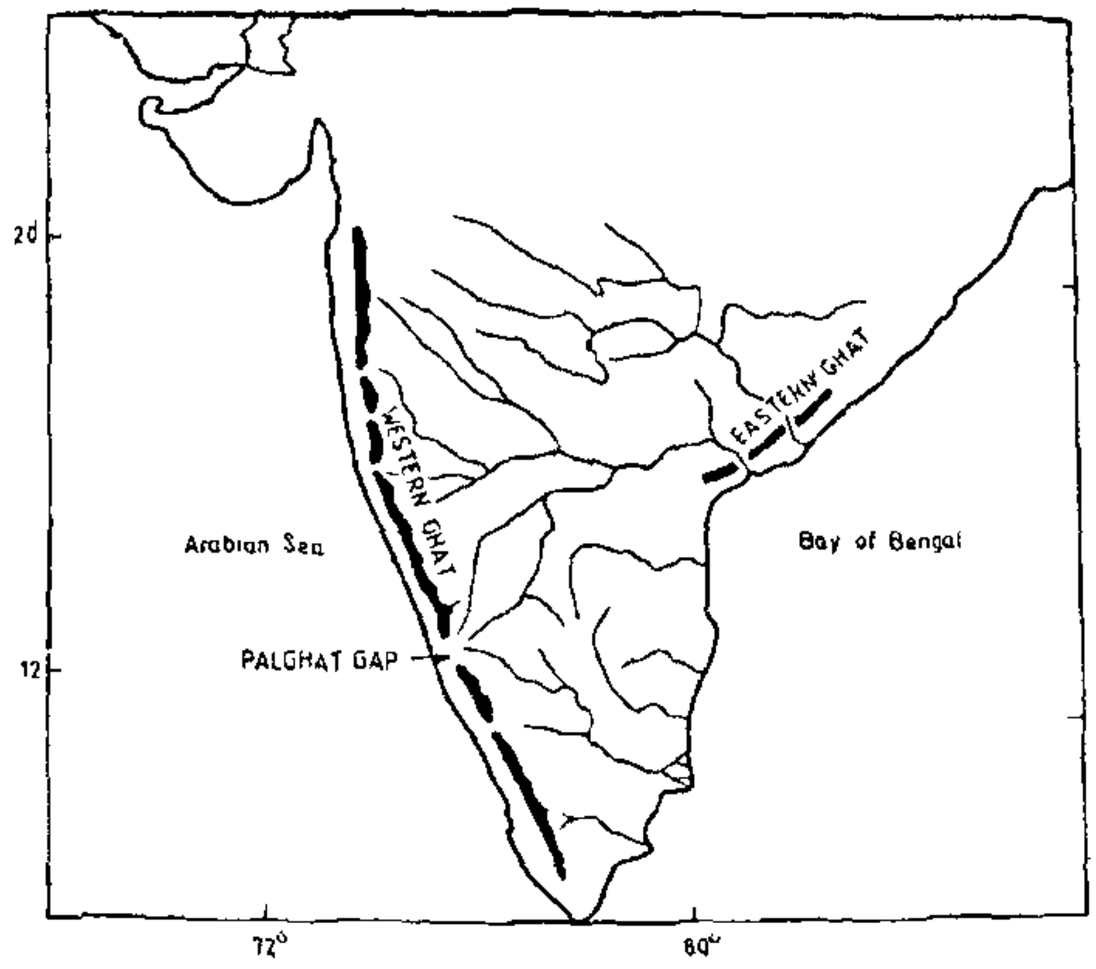

Figure 1. Sketch map of the Indian Peninsula showing positions of the Western and Eastern Ghat. Note the remarkably straight edge of the Western Ghat paralleling the coast. The only gap in the mountain range is at Palghat.

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

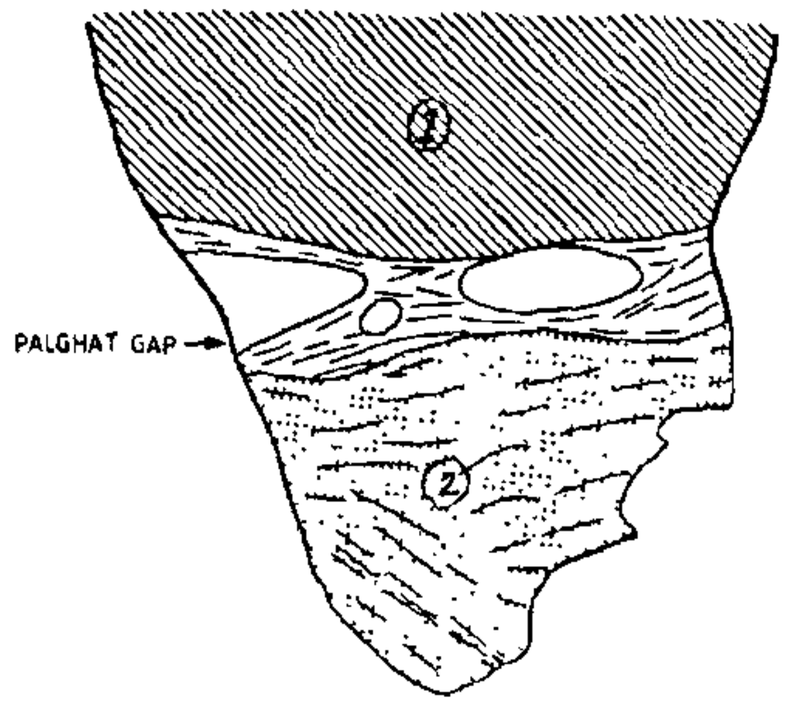

Figure 2. The position of the Palghat Kaveri suture marking the fusion of two discrete continental blocks. 1. Karnataka. 2. Tamil Nadu–Kerala.

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

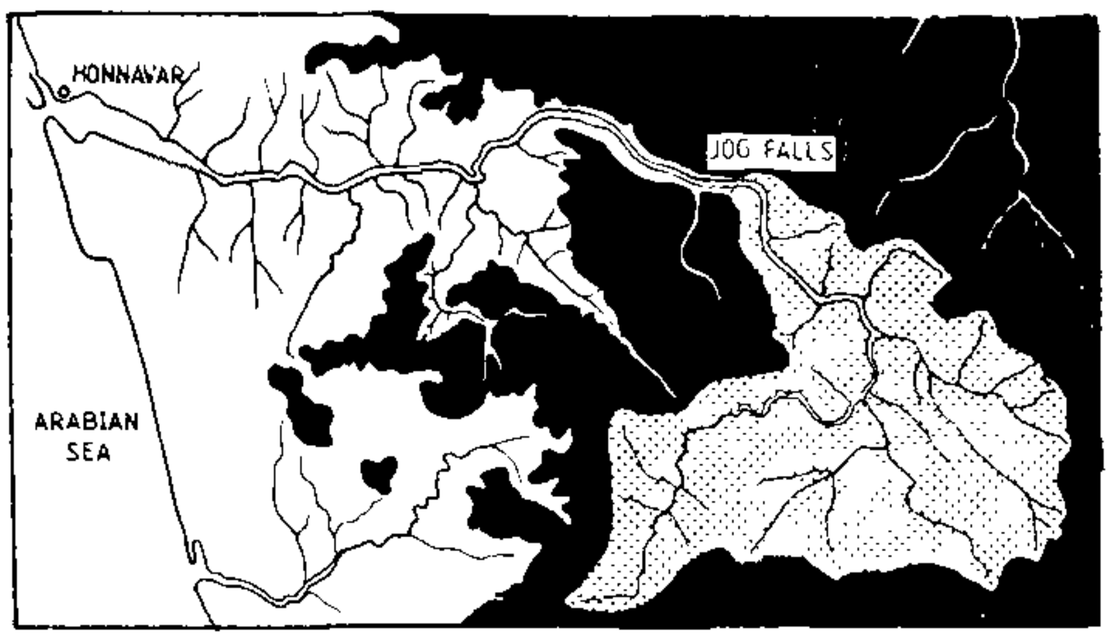

Figure 3. The Sharavathi River, A west-flowing consequent stream, capturing the easterly drainage above the Ghat. The recession of the waterfall (Jog Falls), and carving out of a 20 km long gorge points to its recent origin.

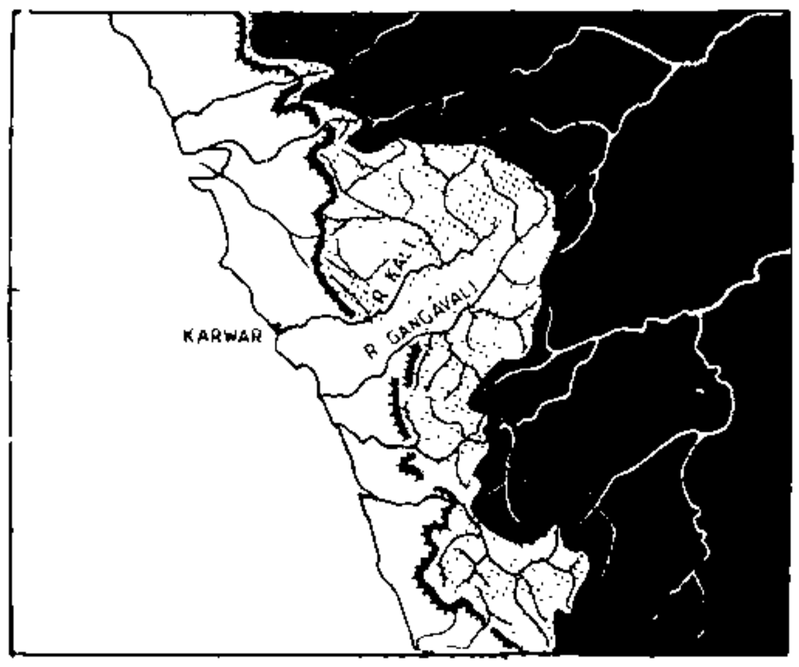

Figure 4. River capture along the Western Ghat. The west-flowing Kali and Gangavali rivers have captured the easterly drainage above the Ghat.

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.

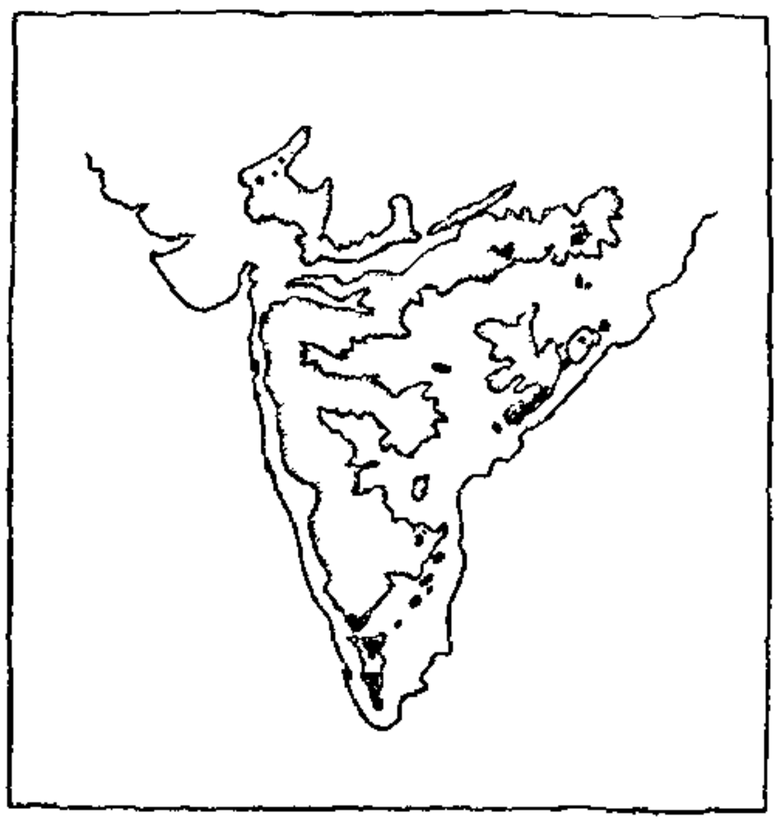

Figure 5. The extent of the vast plain lands (erosion surfaces) of the Indian Peninsula is demarcated by clear-cut scarps. Solid black: oldest erosional remnants (Gondwana surface); stipled: post-Cretaceous second younger surface; Unstipled: the youngest erosional surface (Tertiary-Recent).

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

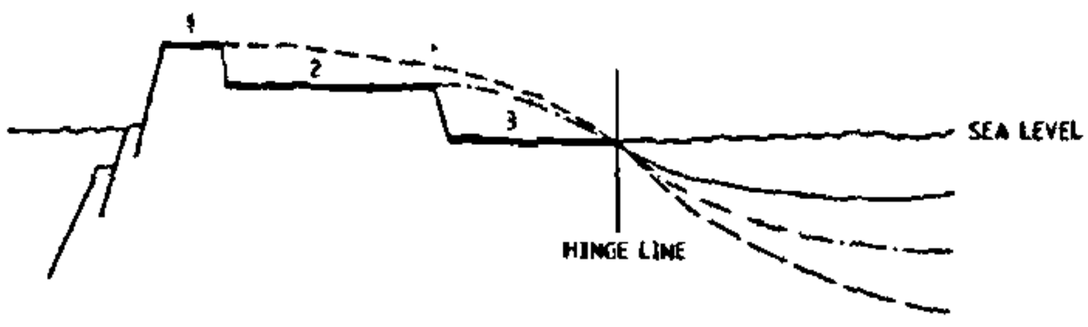

Figure 6. Sketch map showing the relation between uplifted plains and the offshore sedimentary basins.

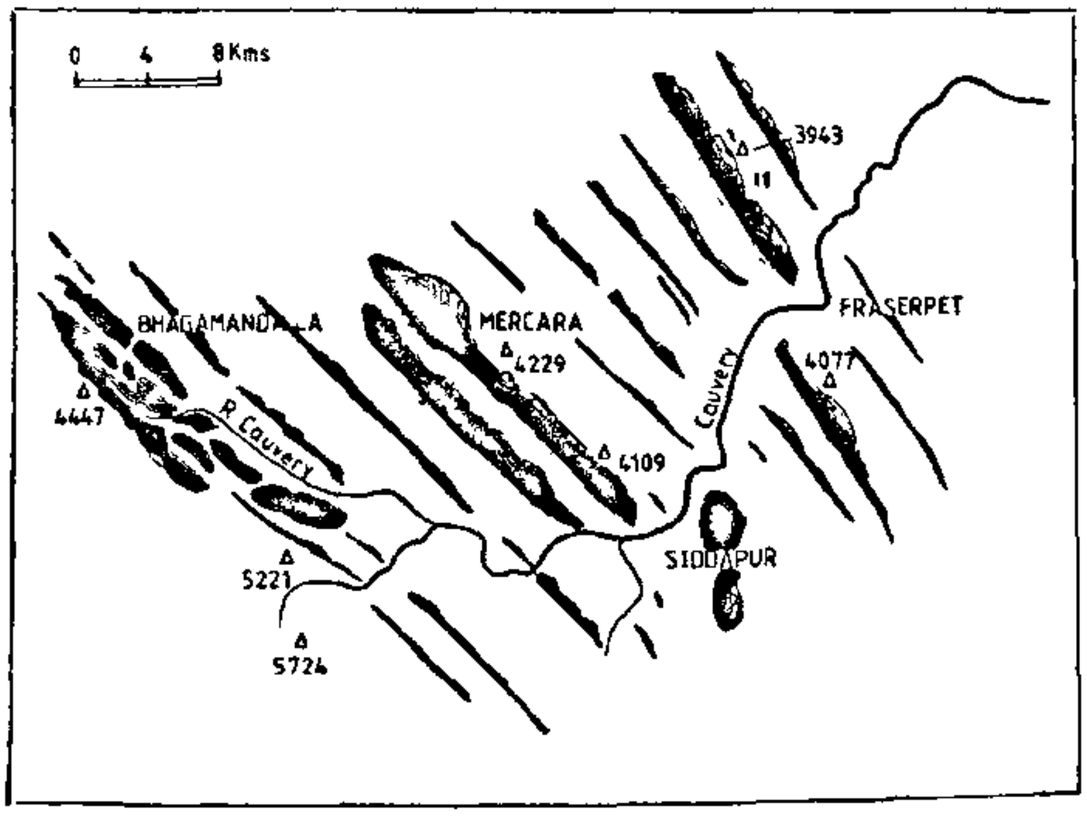

Figure 7. Antecedent drainage of the Kaveri in the mountainous region of Coorg. The mountains are younger and causing rejuvenation of the course of a well-established river.

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.

1. Jacob, K. and Narayanaswami, S., *Proc. Natl. Inst. Sci.*, 1954, 104–118.
2. Radhakrishna, B. P., in Proceedings of the Seminar on Geomorphological studies in India, Sagar, 1965, Centre of Advanced Study in Geology, Sagar, 1967, pp. 4–14.
3. Arogyaswamy, R. N. P., *Rec. Geol. Surv. India*, 1962, **93**, 124–134.
4. Subramanian, K. S. and Muraleedharan, M. P., *J. Geol. Soc. India*, 1985, **26**, 28–37.
5. Radhakrishna, B. P., *J. Geol. Soc. India*, 1989, **34**, 1–24.
6. Raith, M., Srikantappa, C., Asha Manjari, K. G. and Spiering, B., in *Granulites and Crustal Evolution* (eds. Veitzeut, D. and Vidal, Ph.), Kluwar Academic Publishers, 1988, pp. 339–361.
7. Ollier, C. D. and Powar, K. B., *Z. Geomorph. N. F. Suppl. Bd.*, 1965, **54**, 57–69.
8. Mckenzie, D., *Nature*, 1984, **307**, 616–618.
9. Radhakrishna, B. P., *J. Geol. Soc. India*, 1964, **5**, 72–79.
10. King, L. C., Oliver and Boyd, Edinburgh, 1962, 699.
11. Vaidyanadhan, R., *Indian J. Earth Sci., S. Ray Vol.*, 1977, 13–35.

12. Babu, P. V. L. P., *J. Geol. Soc. India*, 1975, **16**, 349–353.
13. Subramanian, K. S., Mani, G. and Prabhakara Rao, P., *Geol. Surv. India*, Spl. Publ., 1980, No. 5, 47–53.
14. Radhakrishna, B. P., *Bull. Mysore Geol. Assn.*, 1985, No. 8.
15. Krishnaswamy, V. S., *Mem. Geol., Soc. India*, 1981, **3**, 1–7.
16. Ravi Shankar, *Mem. Geol. Surv. India*, Spl Publ., 1991, **60**, 120.
17. Desikachar, S. V., Proceedings of the IV International Gondwana Symposium, 1979, pp. 734–745.
18. Morgan, M. J., *in 'The Sea' 7, The Oceanic Lithosphere* (ed. Emiliani, C.), Wiley, 1981, pp. 443–487.
19. Raval, V., Proc. Adv. in Geophysical studies in India, Indian Geophysical Union, Hyderabad, 1981, pp. 314–333.
20. Sastry, V. V., Raju, A. T. R., Sinha, R. N., Venkatachala, B. S. and Banerji, R. K., *J. Geol. Soc. India*, 1977, **18**, 355–377.

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

K. B. Powar

Association of Indian Universities, New Delhi 110 002, India

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

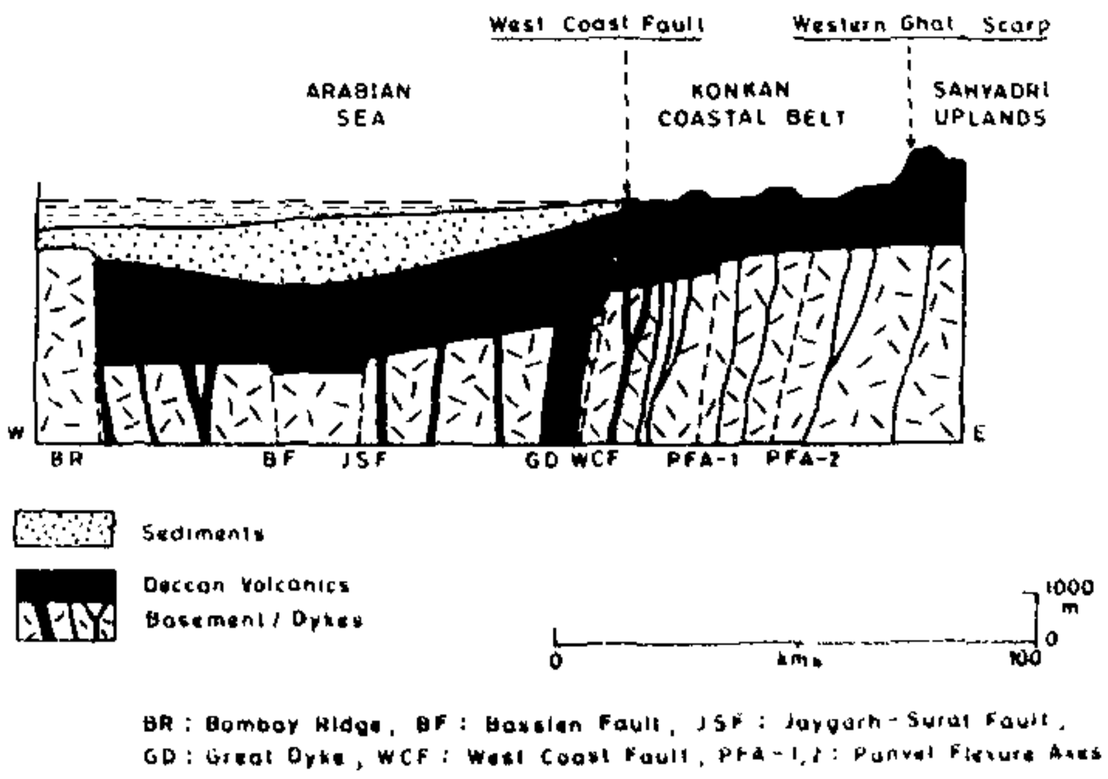

Figure 1. Idealized cross-section along the Latitude 19° N.