



Geomorphological Field Guide Book
on
KONKAN & GOA COASTS

By

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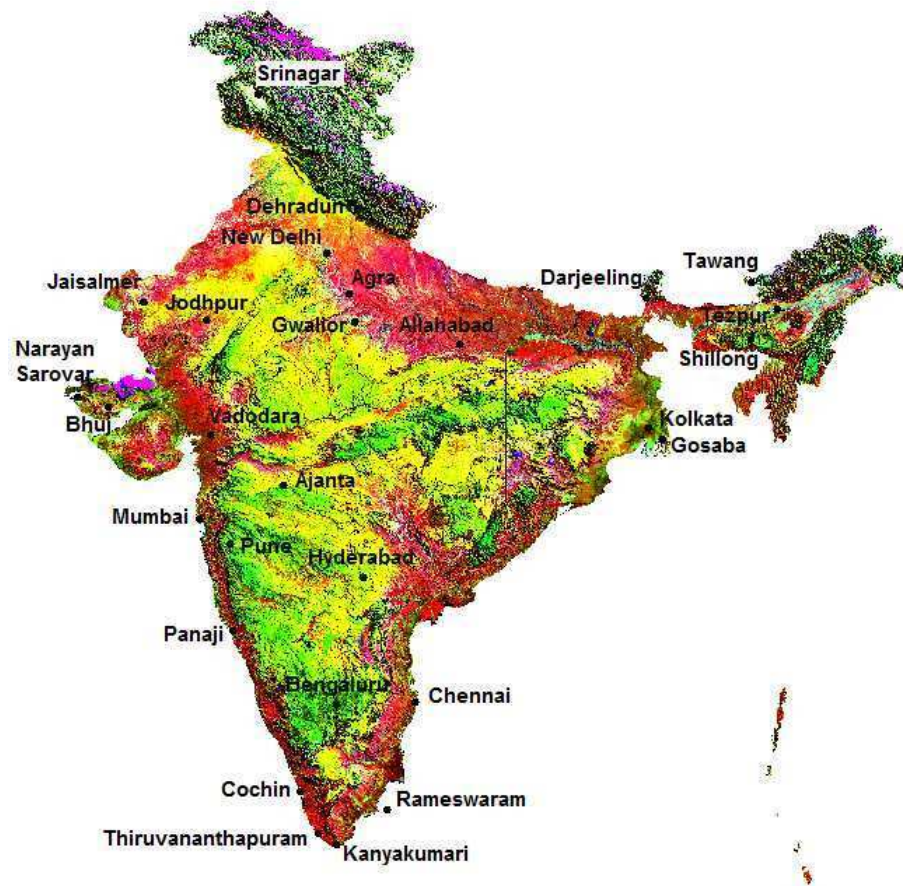


Fig. 1. Image-map of India, showing some places of interest for the 9th International Conference on Geomorphology, 2017 (Map prepared by A. Kar through processing of relevant ETM+ FCC mosaics and SRTM 1km DEM, both sourced from the US Geological Survey site). Boundaries are approximate.

Geomorphological Field Guide Book on Konkan and Goa Coasts

Itinerary

Day	Places from - to	Stay
Day 1	Arrival at Panaji (Goa) Field excursion from Panaji to Ratnagiri (Maharashtra)	Ratnagiri
Day 2	Field excursion, North of Ratnagiri	Ratnagiri
Day 3	Field Excursion, South of Ratnagiri	Ratnagiri
Day 4	Field excursion from Ratnagiri to Malvan	Malvan
Day 5	Field excursion from Malvan to Panaji. Depart from Panaji.	

A. THE KONKAN AND GOA COASTS: AN INTRODUCTION

A 500-km long coastline along the Arabian Sea, extending from the confluence of the Damanganga River with the sea in the north to the confluence of the Terekhol River with the sea in the south, and a narrow coastal plain adjoining this coast, is a distinct physiographic entity of the Maharashtra state of India. This coastal belt forms part of a rugged terrain consisting of hills, plateaus and plains, which are collectively known traditionally as the 'Konkan' (Fig. 2). People here mostly speak in a dialect called the 'Konkani'. Eastward, the Konkan region is separated from the upland Maharashtra by a steep west-facing escarpment of the Sahyadri Mountains or the Western Ghats. The width of the Konkan coastal belt varies from 40 to 50 km. Administratively, it falls within the districts of Palghar, Thane, Raigad, Ratnagiri, Sindhudurg and Mumbai.



Fig. 2. Konkan region in Maharashtra. Map on the right shows relief from SRTM image.

GEOMORPHOLOGICAL BACKGROUND

Before describing the morphological characteristics of the coastal landforms at the field sites, it may be worthwhile to provide a brief account of the salient features of the Konkan region, of which the coastal sector forms a part, as well as the major environmental factors that influence the coastal development.

Physiographic Divisions of the Konkan Region

On the basis of lithology, geomorphic configuration, nature of hinterland and climate, Konkan has been divided into the North Konkan, Middle Konkan and South Konkan. This 3-fold division is also reflected in the broad physico-cultural zonations in the region (Dikshit, 1986).

North Konkan: This coastal belt lies roughly between Bordi-Dahanu in the north and Karanja in the south (Fig. 3). It is characterized by N-S oriented forested hill ranges and a small plateau (~350-m above sea level; ASL), formed of the Deccan Trap rocks with intertrappean beds. The major streams draining the area are the Surya, Tansa, Vaitarana, Prinjal, Ulhas, Kalu and Bhatsai, with narrow flood plains along them. Courses of some streams like the Vaitarana are distinctly controlled by lineaments at places. The Ulhas plain, covered by brown silt, is most probably a marine planation surface of early Quaternary period (Dikshit, 1986). North Konkan receives an annual rainfall of 1500 mm and more.

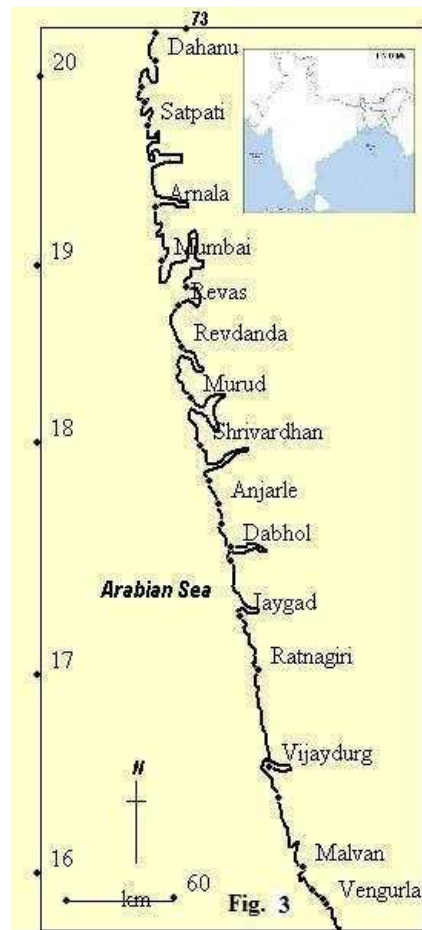


Fig. 3. Map of the major coastal sites in Konkan.

Middle Konkan: The coastal belt from Uran to Shrivardhan forms the Middle Konkan, where the forested hills are more prevalent in the central part, with heights of 300-500 m ASL, and are formed dominantly of Deccan basalt. Dikshit (1986) identified most of these hills as ‘residual hills’, and suggested a planation surface at about 550 m ASL. The major streams are the Amba, Kundalika, Kal and Savitri, which appear to be lineament-controlled in most parts.

South Konkan: This is the longest stretch of the Konkan, and has the distinctive feature of 8-12 m thick capping of laterite over much of the terrain. Barren lateritic plateaus (150-200 m ASL), deeply entrenched stream channels and the piedmont plains at the foot of the Sahyadri escarpment are the significant land facets, and bear the imprints of lithological control (Karlekar, 1981). The major streams are the Vashshthi, Shastri, Kajavi, Muchkundi, Arjuna, Vaghotan, Gad and Karli. The laterite cover gets progressively reduced to the south of Tarele. In contrast to the landforms of the North Konkan and the Middle Konkan, the landforms here are dominantly influenced by granite and gneiss formations, especially around Kankavali, Kudal, Sawantwadi, Malvan and Vengurla. The area is rich in minerals. Iron, manganese, bauxite and silica sand are the important mineral reserves.

Division of the Coastal Sector

The coastal sector, characterized by plains, shoreline terraces, sand dunes, cliffs, numerous sandy pocket beaches, tidal inlets, creeks and estuaries, shows a great amount of variability from north to south. The landward margin of the coastal hinterland can be identified as the north – south hill ranges in the central part of Konkan, roughly parallel to the shore. The coastal strip is wider in the north than in the south. On the basis of the impact of tidal incursion and the tidal range during the spring tide and the neap tide, Konkan coast can be divided into macro-, meso- and micro-tidal regions (Table 1).

Table 1. Division of Konkan coast as per selected parameters (as determined by author)

Parameter	Macro-tidal coast	Meso-tidal coast	Micro-tidal coast
Spring tide range (m)	>3.5	3.5 – 2.0	<2.0
Neap tide range (m)	>2.0	2.0 – 1.5	<1.5
Tidal incursion limit along rivers (km)	40	25	20
Coastal sector	Dahanu to Revas	Revas to Ratnagiri	Ratnagiri to Redi

Climate and its Effects on the Coastal Processes

The climate of the Konkan coastal belt shows a regular seasonal variation dependent upon the alternating southwest and northeast monsoon during a year. December to March is relatively cool with northeast winds. The weather is dry and the cloud cover is very little. April and May are hot, when the winds are light and variable with sea breezes on the coast. June to September is the season of southwest monsoon. Winds on the sea, in this period, are south-westerly and westerly. The winds on the coast, however, are mainly westerly. This is the season of high rainfall. October and November are marked by light winds. Occasional tropical cyclones originate in the Arabian Sea during this period. The period from the end of the southwest monsoon to its recommencement is usually identified as a fair-weather season.

Table 2 provides the average weather characteristics along the three coastal divisions. Based on these characteristics February to May can be treated as Pre-monsoon season along

the coast, June to September as monsoon and October to January as Post-monsoon season. Rough to very rough seas occur during the monsoon season. Moderate to heavy swell waves also persist along the coast during this season.

The width of the surf zone and the breaker zone decreases considerably during fair weather season, when the height of the breakers and the number of waves in a breaker decrease significantly. There is hardly any change in wave period from monsoon to fair weather season. During monsoon the northern ends of the beaches experience high wave energy. A clear shift of energy condition takes place from the monsoon to the post-monsoon season. During monsoon period, the waves are steep everywhere, and the breakers have short wave periods. The sediment supply through the streams is high. These two factors together increase the quantum of sediments in the waves.

Table 2. Weather and waves along the Konkan coast

Parameter	Month	North Konkan	Middle Konkan	South Konkan
Pressure (mb)	April	1010	1010	1011
	July	1004	1006	1007
	October	1011	1010	1011
Relative humidity (%)	April	73	73	72
	July	85	89	86
	October	80	82	82
Dominant wave direction (& % days)	April	NW (56)	W (64)	W (53)
	July	W (55)	SW (48)	W (57)
	October	NW (56)	E (48)	W (41)
Wind speed (knot)	April	3 - 8	3 - 7	5 - 11
	July	6 - 8	11 - 13	10 - 14
	October	4 - 6	3 - 5	5 - 8

Source: Naval Hydrographic Report on West Coast of India (1981).

Waves, Tides and Near-shore Processes

Variation in sea waves and tidal waves, their intensity and frequency, their approach, height and persistence, are the main factors that influence the processes along the Konkan coast. There is a remarkable north-south and seasonal variation in these attributes all along the coast. The variations are site specific within the major regions.

Wind direction and wind speed also show definite trends from north to south (Table 2). It is found that the waves are westerly in pre monsoon period on middle and south Konkan coast and north westerly on northern coast with a speed varying between 3 and 8 knots. The south Konkan experiences winds of 5 to 11 knots in this period. Monsoon is a period of westerly to southwesterly waves with a speed exceeding 10 knots along major part of Konkan coast. The wave approaches and the wind speeds given in Table 2 can change locally due to considerable refraction as the waves approach the indented shoreline. Waves become steeper near the shore especially during monsoon.

On the basis of wave heights two distinct seasons can be identified, namely, monsoon (June to September) and fair-weather (October to May). Wave heights do not normally exceed 2 m in fair weather (Table 3). During monsoon, the waves often exceed 5 m in height, especially along the South Konkan coast. Long-period waves, with a wave period of 10 to 12 seconds, dominate the fair-weather season. During monsoon, the wave period decreases to 3 to 6 seconds. Towards the end of monsoon the wave period increases to 10 seconds, indicating the arrival of swells.

Table 3. Waves and currents (as measured by the author)

Wave character	Time period	Revas	Ratnagiri	Redi
Wave height (m)	Fair weather	1.0 – 2.0	1.0 – 2.0	1.0 – 1.5
	Monsoon	3.0 – 3.5	4.0 – 4.7	4.0 – 5.0
Wave period (s)	Fair weather	10.0 – 12.0	10.0 – 12.0	<10.0
	Monsoon	4.0 – 6.0	4.0 – 6.0	3.0 – 6.0
Tidal current velocity (cm/s)	Fair weather	70 - 90	10 - 20	<10
	Monsoon			

Near-shore Zone

The specific near-shore environment on the Konkan coast is influenced strongly by the factors mentioned above. The breaker zone near the shore is about 200 m wide from June to September, and the very high breakers are produced during this period. Wave breakers during the monsoon are of spilling and plunging type. During fair-weather period, the breakers are characterized by low, surging or collapsing waves. The surf zone width exceeds 200 m during the monsoon and gets reduced to less than 25 m during the fair weather.

Measurement of the long shore currents at a few places reveals that these currents are significant especially to the south of 18° N. The currents are southeastward during monsoon and move with an average speed of 30 to 40 cm/s. During fair weather these are north- northwestward, and usually attain a speed of 8 to 20 cm/s. The direction and the speed of the longshore currents change locally, influenced mainly by the local coastal configuration. North to NNW currents are the strongest in October and the SE currents are powerful in July. During monsoon the nearshore areas are also dominated by rip currents.

Tides

Konkan coast experiences mixed semi-diurnal tides with a tidal range of less than 2 m to more than 3.5 m. The tidal range gradually increases from south to north, i.e., from 1.5 m at Redi to 5.4 m at Valsad. Tidal currents are very weak along the South Konkan coast. Here the velocity rarely exceeds 10 cm/s. Strong tidal currents with a velocity of 70-90 cm/s have been recorded along the North Konkan coast. Table 4 shows the average spring and neap tide and the tidal range at important field sites along the Konkan coast.

Table 4. Tidal range at field sites

Site	Latitude (deg., min.) N	Longitude (deg., min.) E	Spring tide height (m)	Neap tide height (m)
Jaygad	17, 18	73, 14	2.7	1.5
Ratnagiri	16, 59	73, 18	2.1	1.3
Musakagi	16, 37	73, 20	1.8	1.4
Vijaydurg	16, 33	73, 20	1.8	1.3
Devgad	16, 23	73, 23	1.9	1.3
Malvan	16, 03	73, 28	1.5	1.2
Vengurla	15, 51	73, 37	1.6	1.2

Source: Naval Hydrographic Report on West Coast of India (1981).

Sea Levels and Sea Level Fluctuation along the Coast

There is no monitoring station along the Konkan coast to measure the actual sea level fluctuation, and so a definitive chronology of sea level events in modern times is still awaited (Karlekar, 2000). Many of the geomorphological features on the coast, however, indicate a slightly higher sea level during the early Holocene period. Cliffs formed by wave action and shore platforms are very frequent along the coast. The shoreline terraces (Fig. 4) and the two / three generations of fossil dune ridges (Fig. 5) provide some convincing evidence of former shorelines. The wide coastal plains and the narrow shoreline terraces appear to be covered with Tertiary sand.



Fig. 4. An example of shoreline terraces along the Konkan coast.



Fig. 5. A typical fossil beach dune ridge along the Konkan coast.

The land between 2 and 10 m ASL provides evidence for numerous shore marks (Karlekar, 2000). Extensive flat plains on the late Holocene sediments suggest their development from tidal basins. There is no data to suggest that major storm accretion happened along this coast for at least the last 3000 years, and the fossil deposits found inland cannot be attributed to stormy episodes.

About 6000 BP the sea was more or less at the present level. Between 6000 and 2000 BP the sea level gradually rose to 6 m ASL. Studies so far suggest that the highest sea level

was attained around 3000 years BP (Guzder et al., 1975; Dikshit, 1976; Karlekar, 1981; Kale and Rajaguru, 1985; Bruckner, 1987; Hashimi, 1995). There is no convincing data yet to mark the sea level changes during the last 500 years.

Despite the lack of actual sea level measurements, some geomorphic features along the coast have been used to infer a general rise in sea level during the last few years. The features are: breaching of the beach ridges, scouring of ancient tidal channels, submergence and decaying of mangroves (Karlekar, 1986), breaching and undercutting of anti-erosion walls, appearance of offshore mud on sandy beaches and an overall increase in the salinity of well water along the coast. The disaggregation of sand accumulation forms and the redistribution of sediments in the bays and the creeks, e.g. at Shrivardhan (Karlekar, 1997), Kelshi (Karlekar, 2000) and Karli, also indicate a recent rise in sea level along the Konkan coast.

Landforms along the Konkan Coast

The shoreline all along the Konkan coast is broken by numerous headlands and promontories, which are the sites of steep sea cliffs, beautiful sandy pocket beaches, drowned river valleys, small tidal inlets and major river creeks. One is thrilled by an almost regular sequence of headlands and tidal inlets. Narrow, flat and low shoreline terraces, covered with a thin apron of coastal alluvium, border the tidal inlets. These land facets have contributed immensely to the distinctiveness of the Konkan coast.

Beaches of Konkan

Konkan coast is dotted with innumerable, small, sandy pocket beaches (Fig. 6). Tables 5 and 6 provide a summary of the morphological properties of the beaches to be visited. Sandy beaches are predominant, but a few mud beaches do also occur, e.g., at Rewas, as also the shingle beaches, e.g., at Shekhadi. The sediment characteristics and the morphodynamics of these beaches are controlled mainly by the specific wave and tide environment related to seasons and tidal ranges. The entire beach zone consists of depositional facies formed by waves, wave-induced currents and associated flows. Wide beaches with a well-developed berm and beach face are characteristic of the fair weather period (Karlekar, 2014). These get transformed into narrow beaches with steep to very steep beach faces during the monsoon period, the degree of steepness and beach cutting varying from place to place.

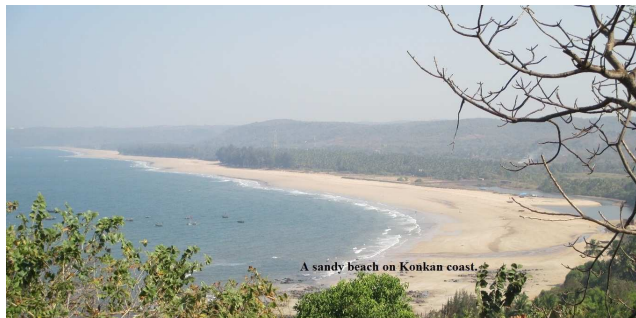


Fig. 6. A sandy beach along the Konkan coast.

Most beach sediments are well sorted. Major differences in the grain size reflect the differences in wave energy levels. Tides are the main force in macro- and meso-tidal environments in north Konkan. Decrease in the velocity of tidal currents at ebb results in sediment deposition in the swash zone. The flood tide currents, on the contrary, induce erosion and cutting of the beach profiles. In addition to these daily changes, Konkan beaches also undergo periodic changes with the seasons. Low, flat, swell waves during fair weather period build up the berm or beach face, while the high, steep, storm waves during the monsoon cut the beach face (Karlekar, 1997). Flat beaches in Konkan are usually associated with the low and spilling breakers of fair weather, whereas plunging breakers front the steep beaches.

Table 5: Konkan beaches to be visited

	Site	Latitude (deg., min) N	Longitude (deg., min) E	Length (km)	Beach type
1.	Guhagar	17, 29	73, 11	6.0	Sandy, Pocket
2.	Velneshwar	17, 22	73, 12	1.5	Sandy, Pocket
3.	Varavade	17, 13	73, 15	4.0	Sandy, Pocket
4.	Kalbadevi	17, 04	73, 16	5.0	Spit, Bar
5.	Mirya	17, 01	73, 17	4.5	Bay head
6.	Talashil	16, 01	73, 27	13.0	Sand bar
7.	Devbag	15, 58	72, 57	06	Sand bar
8.	Vengurla	15, 51	73, 37	03	Sandy

Source: Author.

Table 6. Beach properties as measured by the author

Site	TR (S)*	TR (N)	Length (km)	Br. distance (m)	Br. W surf zone	Swash	Beach W (m)	Slope (deg)
Guhagar	2.6	1.5	6.0	77.8	33.4	22.2	18.2	6.3
Jaygad	2.7	1.6	2.4	105.6	27.1	32.0	35.2	10.2
Ratnagiri	2.7	1.5	0.8	85.6	45.2	35.7	28.2	1.1
Vijaydurg	1.8	1.4	0.6	98.1	32.7	43.3	41.6	2.8
Devgad	1.8	1.3	0.5	87.8	26.5	50.4	50.0	1.3
Malvan	1.9	1.3	1.7	159.8	35.1	23.5	64.5	4.9
Dabholi	1.5	1.3	2.3	151.7	34.3	15.5	48.6	12.1
Vengurla	1.5	1.2	5.0	102.6	22.4	24.7	66.4	3.2

*TR(S): Tidal range, Spring; TR (N): Tidal range; Neap, Br, Breaker.

Swash-aligned beaches (Davies, 1977) along this coast are found in the indented and irregular stretches. In some cases these are transformed to drift-aligned beaches during the monsoon. The ridge and the runnel and the rhythmic forms, such as the cusps, ripple marks, mega-ripples, crescentic bars, berms and the dunes, are the essential morphological

features seen on the Konkan beaches. A large variation in size, shape and location of these features is remarkable.

The quantum of swash and backwash is more or less equal on the fine sandy beaches, especially due to restricted percolation. On the coarse sandy and gravel beaches, however, the deeper percolation of swash waves causes the formation of steep beaches. Such beaches are too infrequent along the Konkan coast, and can be seen at places like Shekhadi, Uran and Karanja.

The sandy beaches are steep only during the monsoon when the maximum slope attained by a beach is as high as 7 to 11 degrees. The average beach slope during fair weather is 2 to 3 degrees or less. During monsoon the sands become poorly sorted and show a positively skewed, leptokurtic distribution.

Sediments on the Konkan beaches are subjected to reworking by aeolian, biological and coastal processes every year. Many beaches such as Kihim, Revas, Adhe, Anjarle, show a vertical sequence of fine sand, coarse sand, silt clay and mud even upto a depth of 40 cm. The subsurface sands are poorly to moderately sorted. The mud at depth is scoured, reworked and spreads on the beaches in monsoon (Kale and Awasthi, 1993). This phenomenon is especially seen at Avas, Revadanda, Kelshi and Adhe. This seems to be a recent event (Karlekar and Devane, 1995) and is restricted to meso-tidal beaches.

Konkan is also endowed with long, beautiful sandbars and spits, which are essentially the sandy beaches attached to the mainland at one end. Dandy, Revas, Revdanda, Devbag and Ubhadanda are some of the striking examples of sandbars on Konkan coast. These are usually the drifts aligned, built parallel to the line of maximum drift. The beach construction ends abruptly where littoral currents meet the coastline. At such locations the beach turns landward, at the entrance of tidal inlets. Spits like the one at Rewas, produced by the combination of drift and tide, show features of tidal and drift dynamics. The swash-aligned beaches on Konkan coast are crescentic beaches. A few spits end in one or more hooks or recurves, producing distal convexity.

Beach pits, low tide fans and mud balls are other important sedimentary structures characteristic of the Konkan beaches. The occurrence of mud on beaches is a recent phenomenon and probably indicates a slight rise in sea level.

Coastal Dunes

Sand dunes are a well-marked and distinct feature of this coast. On the backside of many beaches primary dunes with characteristic wind ripples can be easily recognized, which are followed landward by parallel ridges of secondary dunes. The embryo dunes, foredunes and backdunes are more conspicuous at Diveagar, Kelshi, Tambaldeg, Mochamad and Velaghar (Fig. 7). There is large variability in their morphology, orientation and the degree of preservation (Deswandikar and Karlekar, 1996).

On the narrow sandy beaches with a width not more than 50 m, the dunes are low and quite inconspicuous. On the wide sandy beaches, on the other hand, extensive dune systems can

be found to occur. The dune systems at Diveagar, Kelshi, Mirya, Sagartirth, Ubhadanda, Mochamad and Velaghar are typical examples. The outer foredunes and the farthest backdunes are often higher than the central dunes. The foredunes actually form a dune wall sloping steeply seawards and gently landwards. The backdunes are more or less symmetrical but scattered. The scattered dunes give an impression that they are the residuals of ancient, continuous, foredune ridges. The interdune flats between the foredunes and the backdunes are occupied by low, discontinuous, shapeless and scattered mounds of blown sand. The foredunes, and to some extent the central dunes, are normally covered by plants like the Ipomoea creepers, which form a thin mat on the dune surface. These plants have helped in trapping the sand blown in from the beaches, and thus in building the dunes.

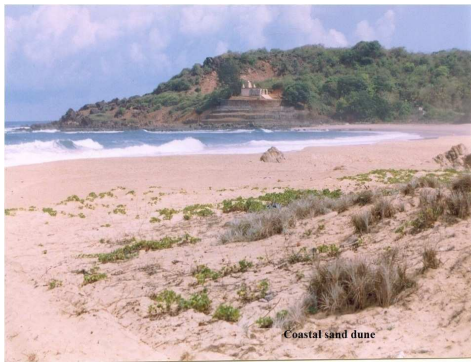


Fig. 7. A coastal sand dune in the foreground.



Fig. 8. Sea cliff, cave and shore platform along the Konkan coast.

The most landward backdune ridge is often a partly lithified, aeolian sand mass. Some of the important coastal settlements like Nandgaon, Diveagar, Guhagar and Mirya are virtually on top of such lithified fossil dunes, comprised of aeolianites that are locally called the ‘Karal’ rocks (Dikshit, 1976; Deswandikar and Karlekar, 1996; Karlekar and Gadkari, 1998). These are the places of ample and shallow groundwater that is utilized by the inhabitants for drinking as well as for growing coconut trees.

Sea Cliffs, Caves and Shore Platforms

Impressive sea cliffs, sea caves and shore platforms characterize the rocky coast of Konkan. These features are usually found along joints, cracks and other weaker sections of the rocky headlands (Fig. 8).

The destructive impact of waves along this coast is often far greater than is generally realized (Karlekar, 1981, 1993). The headlands and promontories of the coast are subjected to shocks of enormous intensity, especially during the monsoon. Cracks and crevices are quickly opened up and extended. High-pressure spray of waves is forcibly driven into every opening. At any given time and place the actual form of the sea cliff and cave depends on the nature and structure of rocks exposed and the relative rates of marine erosion and subaerial denudation.

Cliffing is the dominant process on this coast. In general the cliffs in the area have a wave-cut bench at the foot. The predominant cliff face angle is commonly about 60 degrees. Average height of the cliffs is about 9 m. Overhangs and notches slightly above the influence of present-day waves characterize the lower sections of the cliffs. At places like Korlai, Hareshwar, Kolthare, Velneshwar, Jaygad, Agargule, Vetye, Kunkeshwar, Sarjekot, and Kondura the cliffs and caves appear to have been left high and dry due to recent fall in the sea level.

The near-absence of quarrying material at the foot of cliffs, insignificant mass movement on the forested upper sections and the lateritic cover on the cliff tops, especially in Middle Konkan suggest insignificant subaerial erosion. The spray marks, caving and undercutting, however, confirm strong marine erosion of the lower sections of the cliffs.

The shore platforms at the foot of the cliffs are also a striking feature in Konkan. Their average width rarely exceeds 30 m. The platforms are intertidal and are shaped by abrasion and water layer weathering. A low tide cliff of about 1 m height, bordering the seaward margin, is a typical feature of the platforms on the Raigad and the Ratnagiri coasts. The surface of the platforms all along the coast is dotted with innumerable shallow pools and potholes of varying sizes. The shore platforms are mainly produced on basalt but large number of lateritic platforms also exists, e.g., at Ambolgad, Devgad, Kunkeshwar and Bhogave.

The features like 'Geos' and 'Blowholes' are not very common along the Konkan coast. Few examples could be noticed at Korlai, Velneshwar and Hedvi.

Estuaries and Creeks

The estuaries and creeks on this coast are distinct, especially due to their tidal and fresh water regime (Fig. 9). They also exhibit a complex pattern of sediment input. The tidal inlets to the south of 18° N are mainly wave-dominated. Northern estuaries have a strong tidal control. Most of the estuaries on Konkan coast are NW – SE oriented and suggest a structural control in the tidal sectors of the streams. In North Konkan, the creeks and estuaries are found to be the bar-built and coastal-plain estuaries. Lengthening of ebb condition is an important aspect and is reflected in the tidal delay period (residence time) of about 1 to 2.5 hours (Karlekar, 1996). Imbalance between the length of the estuary and the contemporary tidal range is seen in the ponding of tidal water in the middle portion of some estuaries, e.g., at Kelshi and Anjarle.



Fig. 9. A tidal creek along the Konkan coast.

The major sedimentary features of the Konkan creeks and estuaries are the marsh and swamp edges, high and low tide flats, sand lenses, sand banks and islands and scoured channels (Karlekar and Keskar, 2014). These are produced by site-specific hydrodynamic conditions like wave action, flow velocities, turbulence, mixing and scouring. The mid-estuarine sectors are the areas of silty-clayey bars. The depth of these tidal inlets varies normally from 1 m near the head to about 4 m near the tidal mouth. Tidal water penetrates to a distance of more than 30 m in many estuaries, like at Amba, Kundalika, Dabhol, Arjuna and Karli (Table 7). The estuaries of Middle Konkan and South Konkan occur as narrow, elongated inlets with relatively little human interference. Some of the tidal inlets are known to have placer deposits (Karlekar, 2001).

Table 7. Major creeks, creeklets and estuaries of Konkan

	Name	Latitude (deg., min) N	Longitude (deg., min) E	Tidal incursion limit (m)
1.	Kalbadevi Creek	17, 02	73, 17	06
2.	Bhatye Creek	16, 59	73, 19	20
3.	Purnagad Creek	16, 48	73, 20	20
4.	Rajapur Creek	16, 36	73, 20	25
5.	Vaghotan Creek	16, 34	73, 23	25
6.	Arjuna Creek	16, 23	73, 26	20
7.	Achara Creek	16, 12	73, 28	15
8.	Kalavali Creek	16, 05	73, 28	25
9.	Kolamb Creek	16, 04	73, 28	03
10.	Karli Creek	15, 58	73, 28	30

Freshwater flow during monsoon is one of the fundamental controls on salinity in these estuaries (Karlekar, 1996). A pronounced salt wedge during dry season is a dominant feature. High freshwater flow during the monsoon dilutes much of the salinity to a distance of 1-2 km in the estuaries. However, some salinity still remains in the lower column of the tidal waters. During the post-monsoon period salt wedges are re-established rapidly.

There exist several pools of high salinity and suspended sediment concentration in most of the Konkan estuaries. A substantial part of the suspended sediments entering the estuaries is deposited within the estuaries only. A large part settles on the mud flats and other areas outside the main tidal channel. The deeper sections act as sediment traps. Sedimentation in these estuaries appears to be governed by factors like length of the tidal inlet, tidal range and the process of flocculation.

Mangrove Swamps

Mangroves are thickly vegetated intertidal estuarine wetlands, confined to silty bog formation. Along the Konkan coast these are restricted mainly to the sheltered shore zones regulated by tidal flooding (Fig. 10). The most widespread genera of mangroves on this

coast are *Rhizophora* (red mangroves) and *Avicennia* (black mangroves). All the shrubs and trees in mangrove swamps are characterized by adaptation to the loose, wet substratum, tidal submergence and periodically changing salinity level. Prop roots and aerial breathing roots are the most frequent adaptations. Everywhere the mangroves are the nurseries for fishes and crustaceans.



Fig. 10. A typical mangrove swamp along the Konkan coast.

The mangroves are usually found near muddy creek banks with fine silt and clay, which are rich in organic matter. Their dense growth can be seen in the tidal sectors of Ulhas, Amba, Savitri, Mhasala, Kalbadebi, and Rajapur creeks, where shores are free from strong waves and tidal velocities are not very high. Here, the vertical tidal range is 2-3 m. Important varieties of mangroves on this coast are *Rhizophora mucronata*, *Rhizophora apiculata*, *Brugiera symnorhiza*, *Avicennia officinalis* and *Lumnitzera racemosa* (Deshmukh, 1989).

Widespread destruction of many of these varieties has degraded the age-old mangrove ecology. This in turn has affected the sediment entrapment capacity of the mangroves, and hence the nutrient enrichment capabilities. Consequently, the mangroves at many localities are no longer able to act as feeding and nursery grounds for the commercially important fish varieties. Also, the degradation of the mangroves is making the coast more vulnerable to tides and waves. Since fish production is very important for the livelihood of the inhabitants and since coastline protection is also necessary, the mangroves along the Konkan coast need to be conserved on priority basis.

The Coast of Goa

The coastal tract in the state of Goa lies between 14°48' N and 15°48'N and between 75°40'E and 74°20'E. Lying adjacent to the Konkan coast of Maharashtra, this coastal belt is considered a part of the Konkan coastal belt. It is a narrow coastal strip located at the foot of the Western Ghats. The height of the Western Ghats here is nearly 1000 m, while the plains at the foothills lie at about 100 m ASL. The land between the foothills and the sea is about 40 km wide. This region is characterised by several small hills scattered all over the

area. Physiographically the region can be broadly classified into: (1) the coastal tract, (2) sub-Ghat region, and (3) the high ranges of the Western Ghats.

Temperature in Goa is moderate, with not much seasonal variation. May is the hottest month, while January and February are usually the coldest. Rest of the year usually experiences a tropical weather. Rainfall is copious, and is received mainly during the rainy season from June to September, when the whole of Konkan coastal tract receives high rainfall from the Southwest monsoon. The highest rainfall is received during July while the driest month is February.

Mining is one of the principal sources of Goa's industrial and trade development. It offers considerable scope for employment also. Iron ore is the leading commodity for mining, and occupies the pride of place in Goa's economy. Other mine resources include manganese ore and ferro-manganese ore. Some of the most productive and important mines are located in the northern and eastern parts of Goa.

Goa is also famous worldwide for its golden beaches. Several pocket beach segments are now open to international tourists, and these remain crowded almost throughout the year. The income generated by the state from these beach-based 'tourism industry' competes for high ranks with the revenue generated from mining and industries.

Agriculture is also an important economic activity in Goa. Fishing, both in freshwater and in open sea, is the most dominant economic activity along the coastal strip. Rice cultivation predominates inland. Goa has done much to develop its agriculture, and the farmers now get a better return for their labour. Rice along with fish is the staple diet of the people.

SOCIO-ECONOMIC ASPECT

The North Konkan coastal belt, to the north of Mumbai, has an average width of 15-20 km. The Mumbai-Delhi railway track and the Mumbai-Ahmedabad National Highway run through this coastal strip, and provide excellent glimpses of intensive garden farming, besides the views of rice fields. The region enjoys the advantages of a very effective transport network and a close link with Mumbai. The influence of Mumbai is significant in its primary economic activities and the occupational structure of the population. One frequently comes across large orchards of chikoo and mango, as well as coconut groves and dairy farms, all of which have a thriving market in Mumbai. Many large settlements in this plain work as contact towns and market centres of the Mumbai megalopolis. Nearer the lush green forested hills, inhabited by the tribals, the urban centres provide lucrative jobs to the tribal folks. Timber trade is an important activity near the hills.

The irregular coastal tract of Middle Konkan, often interspersed with hilly terrain, has its cultivated lands confined only to the narrow riverine plains and along the coastal flats. Croplands constitute less than 30% of the total area, where rice is the principal crop. Irrigation is highly localized. A relatively sparse population, with a density of 175 per sq km, lives in small villages and sometimes in widely spaced individual huts.

In the coastal tract of South Konkan, subsistence farming is dominant, as the area is largely stony and barren with shallow soils, interspersed with laterite plateau. Large-scale migration of people, especially men, from the region to Mumbai and its suburbs for job has disturbed the sex ratio. Many villages in this coastal belt are dominated by women who tend to the fields.

B. DESCRIPTION OF THE FIELD SITES

Day 1

Arrival at Panaji (Goa)

Travel from Panaji to Ratnagiri

Stay at Ratnagiri.

The field trip begins from Panaji (Goa). Goa coast is 135 km long, and is characterised by a rocky shoreline with innumerable pocket beaches. The northern coast of Goa looks more like the south Maharashtra coast, and is characterized by old and recent tidal flats, dune systems comprising of fore and back dunes, sea cliffs and shore platforms. The beaches to the north reveal a retrograding shoreline where erosion is dominant.

After landing at Goa International Airport we take the road to Ratnagiri by bus. The distance is about 175 km. En-route it is proposed to visit a few coastal tracts of central Goa coast, i.e., the Zuvari and Mandavi estuaries and the Miramar beach. A visit to the fort at Aguda is also proposed. Because of logistical purposes, the field excursion around Panaji and the North Goa beaches will be taken up on the last day of the tour.

The Mandavi and Zuvari estuaries form the largest tidal system along Goa coast (Fig. 11). The large embayment at the entrance of the Mandavi estuary, Aguada Bay has very complex flow patterns of tidal flow and sedimentation. The siltation in the channel is essentially due to deposition of the suspended sediments due to tidal flows, as well as sand incursion due to littoral drift. Mudflats are found mainly along such estuaries and creeks.

Miramar beach (Fig. 12) is 3 km long and 85 m wide. The dune zone at the back of this beach is short. The headlands at Aguda Fort, Dona Paula and Marmgao are 72m, 35 m and 75 m high, respectively, and show sea cliffs having height of 10 to 12 m above sea level and narrow shore platforms with a width rarely exceeding 10 m.

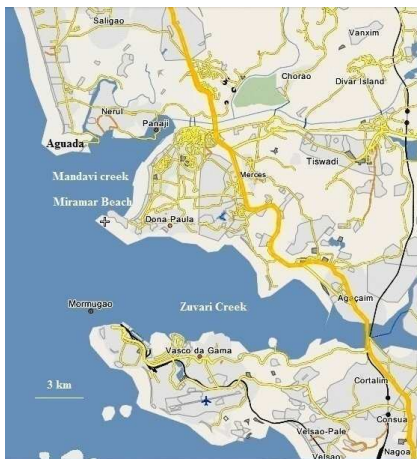


Fig. 11. Mandavi and Zuvari estuaries of Goa

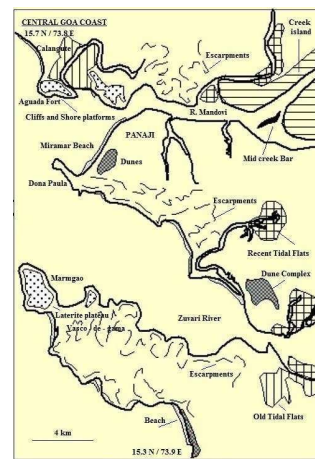


Fig. 12. Miramar beach near Panaji.

Day 2

Field excursion to the north of Ratnagiri Stay at Ratnagiri.

On the second day the coastal sites north of Ratnagiri will be visited up to Ganapatipule.

This will help us in exploring the unique nature of the central part of South Konkan coast (Fig. 13). The tract between Ratnagiri and Ganapatipule is covered by thick secondary laterites (Fig. 14). Barren lateritic plateaus, deeply entrenched river channels, wide creeks and estuaries, beaches, cliffs and shore platforms are the significant land facets of the coast. The coastal plateau is 50-100 m high and the cover of laterite is 8-12 m thick.

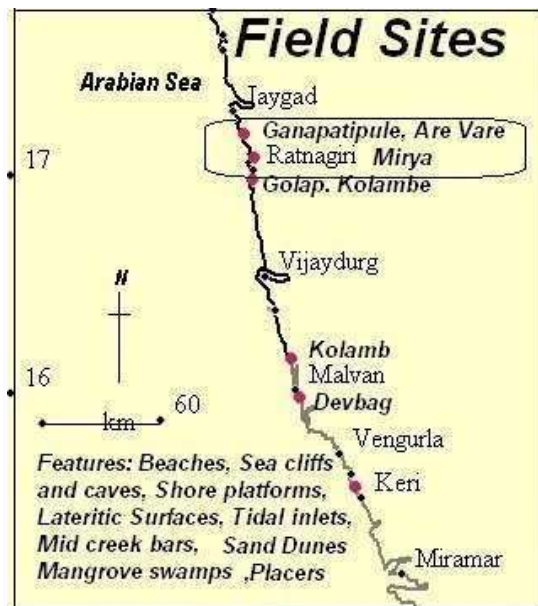


Fig. 13. Field sites from Keri to Ganapatipule.



Fig. 14. Road from Ratnagiri to Ganapatipule

Ratnagiri: Sea cliffs, Shore platforms and Sea caves are the major landforms seen from Bhagavati Fort (or Ratnadurga) headland (Fig. 15). The headland is a 75 m tall promontory on the Ratnagiri sea shore. It has divided the Ratnagiri shore into northern and southern coastal segments.

Ratnadurga, popularly known as Bhagavati Fort, with an area of 120 acres, is situated on this hill. The fort is surrounded by sea. The Legendary Hero from Maharashtra during the Mughal Period, Chatrapati Shri Shivaji Maharaj won the fort in 1670 from the king, Adilshah. The fort was used as a watch tower for keeping vigil on the pirates. A lighthouse is situated in the fort, which guides the ships/vessel's travelling in the Sea (Fig. 16).

A beautiful temple to Goddess Bhagavati is also situated here. Devotees from far-flung areas visit the temple, especially during the famous Navaratri festival in October. The fort is in ruins now. One can see the entire Ratnagiri city from this fort.



Fig. 15. Google Earth image of the Bhagavati Fort area.



Fig. 16. Field sites between Bhagavati Hill and Sakhartar Creek.

Impressive sea cliffs, shore platforms and notches and caves characterize the coast (Fig. 17). The destructive impact of waves along this coast is often far greater than is generally expected. Cliffling is the dominant process. Average height of the cliffs is around 9 m. Overhangs and notches slightly above the influence of the present-day waves characterize the lower sections of the cliffs. The near-absence of quarrying material at the foot of the cliffs suggests insignificant sub-aerial erosion. The shore platforms at the foot of the cliffs are a striking feature in the area. Their average width rarely exceeds 30 m. The platforms are intertidal and are shaped by abrasion and water layer weathering.



Fig. 17. Sea cliff, cave and shore platform at Ratnagiri.

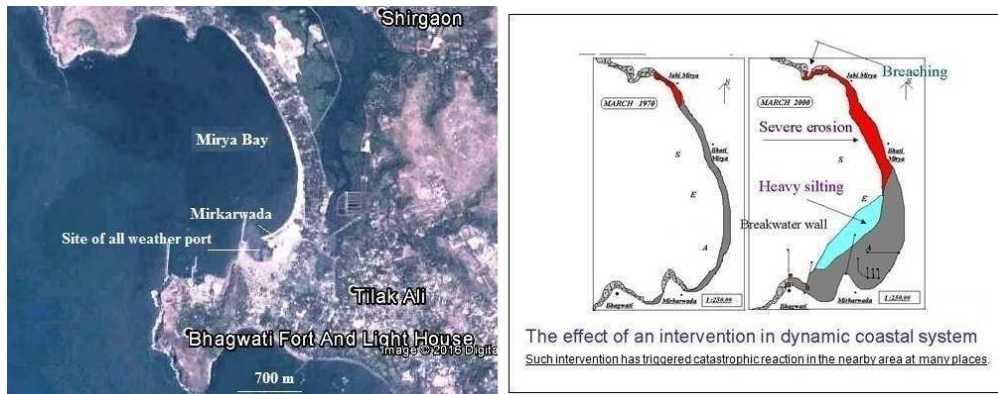


Fig. 18. Mirkarwada harbour and the Mirya Bay.

The caves on this coast have developed on basalts and laterite. A 7 m high cave in the area is fronted by a long narrow and deep channel, which is produced along the weaker zone. An all-weather port can be seen at Mirkarwada harbour in the southern part of Mirya Bay to the north (Fig. 18). The total area of Mirya Bay is about 6 sq. km. Since the construction of a commercial harbour in 1981, the 3.5 km long beach is suffering from severe erosion near the northern end, and severe siltation to the south (Fig. 18).

The modern beaches and dunes of the area are backed by old, fossilized beaches and dunes. The fossil deposits are more or less parallel to the shore. The deposits are calcareous, sandy and shelly in nature (Fig. 19). Mirya village is situated on such a fossil dune and beach ridge. The fossil deposits suggest a higher sea-level in this part of the coast 2800 years BP.

The Tidal inlet at Sakhartar is distinct, especially due to its tidal and fresh water regime (Fig. 20). The major sedimentary environments of the inlet are the tidal flats associated with the high tide, low tide, sub-tidal and inter-tidal regimes, as well as the sand banks, mangrove swamps and scoured tidal channels. The mid-inlet sectors are invariably the areas of silty-clayey bars. On an average the depth of the tidal inlet varies from 1 m near the head to about 4 m near the tidal mouth. Saline inter-tidal mud flats are the prime areas of sedimentation in the creek.

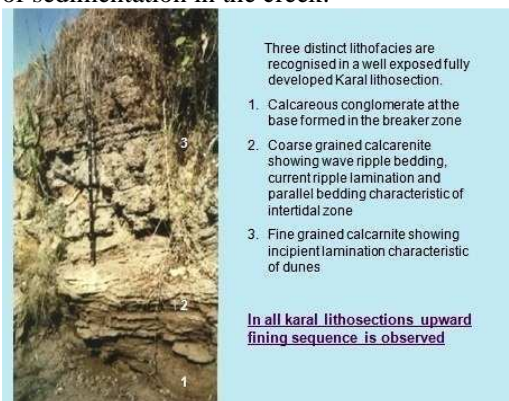


Fig. 19. A typical fossil dune and beach ridge profile near Mirya

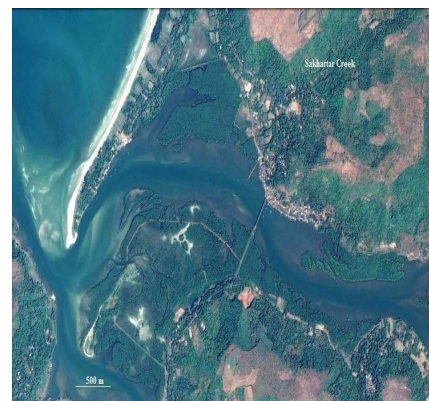


Fig. 20. Google Earth image of the tidal inlet at Sakhartar.

The coastal stretch from Sakhartar to Ganapatipule is characterized by many small pocket sandy beaches, sea cliffs and caves (Fig. 21). There is large variability in sandy beaches, which is a result of wave environment. The entire beach zone consists of depositional facies formed by waves, wave-induced currents and associated flows.

Swash-aligned beaches on this coast are found along the indented and irregular stretches. In some cases these are transformed to drift-aligned beaches during the monsoon. The ridge, the runnel and the rhythmic forms such as cusps, ripple marks, mega ripples, crescentic bars, berms and dunes are the essential morphological features seen on these beaches.

Coastal dune is a well-marked and distinct feature of this coast (Fig. 22). On the backside of many beaches primary dunes with characteristic wind ripples and parallel ridges of secondary dunes can be easily recognized. The embryo dunes, foredunes and backdunes are relatively more conspicuous at few sites. There is large variability as regards their morphology, orientation and the degree of preservation.



Fig. 21. Shore platforms and cliffs along the Are Vare coast between Sakharter and Ganapatipule.



Fig. 22. A typical coastal dune between Sakharter and Ganapatipule.

Day 3

Field excursion, South of Ratnagiri

Stay at Ratnagiri.

The third day of the field visit will include coastal sites to the south of Ratnagiri and up to Ambolgad.

Near Ratnagiri one encounters a lignite bed below a lateritic cover. Called the Ratnagiri Lignites, this deposit is reported from Golap Kolambe plateau, just south of Ratnagiri. These are the beds of Carbonaceous Clay at sub-surface, underlying the lateritic cap. One of the important aspects of secondary laterites in the area is the occurrence of such carbonaceous clay below the lithomarge (Fig. 23). The lignite deposits exhibit a distinct unconformity with the underlying gravel bed, and yield abundant fossils woods, pneumatophores and fruits. The clay is older than 45000 years BP as indicated by palaeobotanical evidence. The occurrence suggests a higher sea level in the geological past, approximately by 37 m. The earlier environment was meso-tidal, as suggested by the species occurrence.



Fig. 23. A typical lateritic crust.

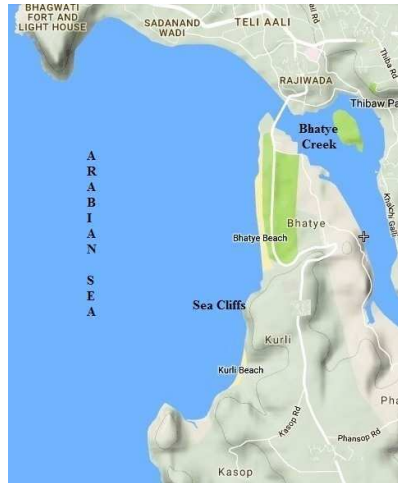


Fig. 24. Map of a prominent sea cliff and pocket beaches near Bhatve.

The coastal stretch is bestowed with numerous pocket sandy beaches and sand spits, especially at Bhatye, Ganeshgule, Gaonkhadi, Vetye and Ambolgad, tidal mouths at Bhatye, Pawas, Purnagad and Jaitapur, and sea cliffs at Bhatye, Ganeshgule and Ambolgad (Fig. 24).

In addition to these features, Bhatye and Gaonkhadi beaches and tidal mouths of some small streams in the vicinity are known for the occurrence of heavy mineral placer deposits, especially ilmenite (Titanium iron ore, FeTiO_2), containing 36.8% iron and 31.6% titanium (Fig. 25 and 26).



Fig. 25. Google Earth image of Bhatve Creek area, known for heavy mineral concentration.



Fig. 26. Google earth image of Muchukundi Creek near Gaonkhadi, where ilmenite is reported.

River channels, shoreline terraces, estuaries, mangrove swamps, tidal channels, tidal flats, bays, beaches, spits and bars are the depositional environments on the coast where heavy mineral assemblages are found in the sediments. Heavy mineral assemblages on this coast usually contain ilmenite, magnetite, kyanite, tourmaline, rutile, zircon, augite, hornblende and olivine, especially in scattered manner in the medium to small size pocket beaches and spits. Kalbadevi, Ratnagiri, Mirya, Golap, Pavas, Ambolgad, Jaitapur bay, are the places where these placer minerals are reported (Fig. 27).

Purnagad Creek is a tidal mouth of Machkundi River. The tidal water ingress into the river is up to a distance of 30 km inland, although normally the lower 800 m of the streams are tidal with placer deposits, especially the ilmenite. The tidal mouth Machkundi River has narrowed significantly around Gaokhadi. The creek and the lower reaches of Machkundi River are surrounded by lateritic plateaus. River banks are steep and the river presents the appearance of an entrenched valley. Small streams joining the creek originate on the nearby lateritic plateau, where the long process of weathering and denudation has resulted in re-lateritisation. Many stream beds are covered with lateritic gravels and boulders.

Sea cliffs at Ambolgad are 5-8 m high and are essentially found on the seaward margin of a wide lateritic headland plateau (Fig. 28). The deep cracks produced on the plateau suggest marginal disintegration and retreat of the plateau margin (Fig. 29).



Fig. 27. Road to Ambolgad.



Fig. 28. Sea cliffs and shore platforms at Ambolgad.



Fig. 29. Marginal back-wearing of a lateritic cliff at Ambplgad.

Day 4

Ratnagiri to Malvan

Stay at Malvan.

Malvan is located at a distance of 143 km from Ratnagiri by coastal highway that joins Mumbai with Panaji.

Beyond Ratnagiri, as one drives southwards towards Malvan via Ambolgad and Kunkeshwar Shore Temple, one passes through a quiet and lush green countryside with a typical rural landscape that includes small streams, vast rolling plains, as well as the backwaters and idyllic beaches before one reaches Malvan via Ambolgad, Kunkeshwar (Shore Temple). Malvan and small settlements like Tarkarli and Deobag are renowned for coastal cuisine, local handicraft, old temples, water sports and scuba diving (Fig. 30). Other sites of interest along this stretch include Vijaydurg, Kunkeshwar, Sindhudurg Fort and Devbag.

Vijaydurg Fort, the oldest fort on the Sindhudurg coast, was constructed during 1193-1205 and restructured by Chhatrapati Shivaji Maharaj. Recent oceanographic evidence supports a traditional view that an undersea wall exists here, constructed out at sea at a depth of 8–10 m. Made of laterite, the wall is estimated to be 122 m long, 3 m high and 7 m wide (Fig. 31).

On August 18, 1868, Vijaydurg lay in the path of a solar eclipse. The English Astronomer Norman Lockyer, founder of the journal *Nature*, discovered the element Helium while observing the solar prominences from Vijaydurg fort during that eclipse. The place from where Lockyer made his scientific observation is marked on the Fort.



Fig. 30. Route from Ratnagiri to Malvan and Devgad



Fig. 31. The Vijaydurg Fort.

Kunkeshwar on the shore is better known for a temple dedicated to Lord Shiva. Lateritic sea cliff, sandy beach and a wide dune zone are the notable features in this area.

Sindhudurg Fort is on a small island in the Arabian Sea, just off the coast of Malvan. It is a protected monument. This massive fort was constructed in the year 1656 by Chhatrapati

Shivaji Maharaj during the peak of his Maratha Empire. The main object was to counter the rising influence of foreign colonizers (e.g., the English, Dutch, French and Portuguese merchants) and to curb the rise of Siddi clan of Janjira. The construction was supervised by Hiroji Indulkar.

Deobag, about 16 km south of Malwan, is a 6 km long sand bar on the coast (Fig. 32). The sand bar is connected to the mainland near Tarkarli, and its southern tip ends abruptly in the sea near Mobar. The eastern edge of the bar is bordered by tidal stretch of River Karli. The western margin faces the Arabian Sea. The tidal range along the bar is 2.6 m at spring and 1.8 m at neap. The dominant wave height is 1.8 m and the maximum surge level is 4.6 m.

Storm surges occur frequently in this area, especially coinciding with the onshore southwest monsoon winds. The atmospheric pressure anomalies and temperature changes cause a rise and fall of sea level by about 30 cm every year. Episodic inundation due to storm surges during every monsoon since the last few years has been recorded.

Redistribution of sandy material inside the creek is very striking here (Fig. 33). The progressive landward movement of waterfront towards Devbag settlement and the inundation of about a 100-m wide stretch of the upper part of the sand bar has become an annual feature. Severe breaching and erosion of shorefront has been reported in the years 1952, 1956, 1980, 1997, 1999, 2000, 2005, 2012 and 2016.



Fig. 32. Map of Malvan to Devbag.



Fig. 33. Google Earth image of the creek at Devbag, which inundates the settlement.

Day 5

Malvan to Panaji (Goa)

Depart from Panaji.

The last day of the field trip will start from Malvan and end at Panaji in Goa, after traversing the coastal stretch of North Goa between Keri and Calangute (Fig. 34).

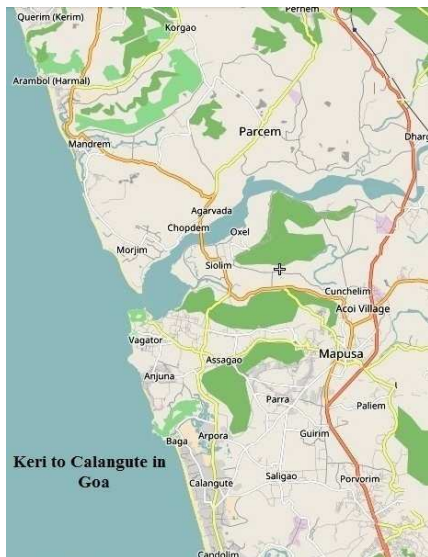


Fig. 34. Map of the Keri – Calangute area.

Like all estuarine mouths on the Konkan coast, the estuary of the Terekhol River at Keri is broad when compared with the width inland. The estuary is blocked by a spit that extends northward and restricts the flow of water at the mouth (Fig. 35). Just to the east of this spit is the ferry point at Keri where one has to cross the River Terekhol before entering the state of Goa.

At **Keri** the waves from the sea enter the estuary from two directions. First they come in through the mouth from the river and travel along it inland. The other set of waves first strikes the headland at the north, then gets deflected by it and enters the mouth.



Fig. 35. Map of the estuary of Terekhol River near Keri.

North Goa Coast: The beach at Keri is quite steep, composed mainly of fine sand. As one travels along the sea face to the south (Fig. 36) the beach becomes broader. The wind and

wave action continuously rework the beach sand, forming many micro-features on the beach. The coast here is also characterized by stable sand dunes in their pristine forms. The fore- and mid-dunes are not very prominent. The backshore is well protected by a thick plantation of *Casuarina* plants. The creek is characterized by many sand lenses, sand bars, tidal mud flats and mangrove swamps.

At **Arambol** (15.7° N / 73.7° E) the sandy shore has very well developed fore- and mid-dunes, which are well covered with *Spinifex* plants. A sweet-water body is located adjacent to the beach at the base of the hill. Mandrem beach in this sector has long stretches of sandy shore with mature sand dunes that are well-protected by vegetation. Apart from the mature backshore dunes, one can also see here the embryo dunes, as well as the fore- and mid-dunes.

Ashvem (15.6° N / 73.7° E), slightly to the south, has a mixed shore with sandy and rocky beaches. The coastal dunes are well protected by plantation.

Morjim preserves a good sandy shore with well-developed dune system. The backshore dunes are not well stabilized, but the embryo dunes and the fore and mid dunes are relatively better preserved.

South of Chapora Fort, and especially at **Vagator**, low sand dunes are common over a limited stretch. It comprises of a rocky coast with some sandy pockets. Similarly, at Anjuna, there are extensive sand dunes covered by vegetation. Many dunes are also degraded. One can clearly see many disturbed chaotic strandlines at several places along the shoreline in this sector.

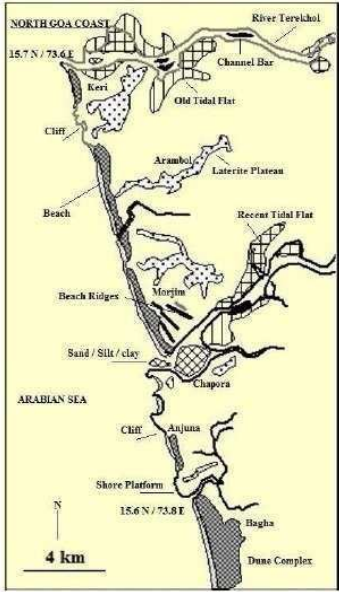


Fig. 36. Map of the beaches to the south of Keri.

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