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Morphology and Planation of Intertidal Rock Platforms Produced by Water Layer Levelling on Dahanu Coast of Maharashtra

Shrikant Karlekar and Tushar Shitole, Pune, Maharashtra

Abstract

Along Dahanu Coast of Maharashtra between Bordi and Tarapur there are very striking rock platforms in the inter-tidal zone with sharp surface relief. They are backed by shallow littoral filled by silt clay deposits, sandy beaches, dunes, dune systems and wide littoral terraces slightly above the high tide level. These intertidal rock platforms are produced in semi diurnal tidal environment where tidal range is more than 4 m.

All the platforms in question are developed at the level of low tide. The platforms are 'non structural' benches, which cut across the local structure of coastal rock formation at the height of 2-3 m above mean sea level. There is no published work on these platforms to date. More studies on various aspects of such platforms are needed.

The purpose of this paper is to describe these platforms, and discuss the probable process of their formation and the level of their planation.

Key words: *Planation, Water Layer Levelling, Rock Platforms.*

Introduction

The shore platforms:

The shore platforms on the coast occur in a variety of localities and different processes may operate depending on where they occur. The formation of shore platforms in a variety of places on coast has been the subject of a long debate centered on whether they are produced by wave erosion or weathering (Trenhaile 1987).

The shore platforms have been defined as horizontal or gently sloping surfaces produced along a shore by wave erosion. This definition which might be better applied to the term wave cut platform assumes that shore platforms are necessarily the product of wave action, which is not always true. The term 'shore platform' which has no genetic connotation is therefore used to refer to rock surface of low gradient within or close to the intertidal zone. The term wave cut platform should be used to refer to a specific category of shore platforms rather than as a synonym for all platforms.

Two types of platforms have frequently been distinguished. The gently sloping platforms with a gradient of less than 5 degrees or the abrupt seaward sub horizontal platforms. Former usually extend from the cliff platform junction to below the low tidal level without any major break of slope and the latter which are intertidal or sub tidal generally terminating in a low tidal cliff or ramp. Geological and other local factors produce sloping and horizontal platforms along a stretch of coast, although the former are most common in macro tidal environment, and the latter in meso and micro-tidal regions. (Trenhaile 1987).

A group of workers is of the opinion that the platforms develop where the rock becomes saturated by sea water, The development is accomplished by wave erosion of the weak weathered material lying above this level. Fairbridge (1968) also appears to have subscribed to this theory although he considers that the saturation level, and therefore the platform, is closer to the low than to the high tidal level. (Trenhaile 1987)

There are several theories on the process by which shore platforms are produced or modified by weathering. The wave erosion assumes an important but rarely recognized, role in the development of shore platform in weathered rocks. (Woodroffe. 2002)

Many workers have attributed varying importance to the role of wave action and weathering in the development of shore platforms. The relative roles of weathering and wave action are expected to vary across the platform profile and with time (Masselink et al 2003). The process of weathering including wetting and drying, salt weathering, and chemical weathering works mainly to weaken the rock. Waves remove the weathered material and actively erode the platform surface.

It has also been stated that wave erosion is presently only modifying the platforms developed in earlier period. This is especially the case in basalts where present rates of platform lowering are too low to account for wide shore platforms since the sea reached its present level around 6000 YBP. The role of inheritance is more important for platforms developed in hard rocks.

Development of different types of platforms is probably more related to balance between wave action and rock resistance. Trenhaile (1987, 1997) found a strong positive correlation between platform gradient and tidal range. He also found that the width of the platform is largely independent of tidal range. It increases with wave intensity and decreases with rock hardness.

The morphology of the shore platforms especially the gradient, width and elevation is associated with their location in embayment, at the foot of the cliff or in front of beaches and bars.

The rock platforms

Rock platforms are conspicuous elements of rock coasts in many parts of world.

They are made principally of hard and resistant rocks with minor softer formations. Wave erosion along horizontal to gently dipping bedding planes gives rise to the gently sloping platform surfaces. Erosion also breaks off rectangular blocks of rock along intersecting vertical joints. This controls the shape and orientation of the platform margins. Such intertidal rock platforms are produced in semi diurnal tidal environment where tidal range is more than 4 m. They may be separated from and backed by beaches.

It is probable, however, that chemical or biochemical processes associated with sea water play a substantial, if not dominant, role in their formation or modification of rock platforms.

Tidal range and shore platforms

The tidal range is a difference between the high tide and the low tide. The typical tidal range in the open ocean is about 0.6 meters. Closer to the coast, this range is much higher. Coastal tidal ranges vary globally and can differ anywhere from near zero to over 11 meters. The exact range depends on the volume of water adjacent to the coast, and the geography of the coast. Larger bodies of water have higher ranges, and the geography can act as a factor amplifying or dispersing the tide. In a tidal cycle sea level rises over several hours, covering the intertidal zone (flood tide stage), then the water rises to its highest level (high tide stage) after which sea level falls over several hours, revealing the intertidal zone (ebb tide stage) and finally the water stops falling reaching low tide stage.

The tidal range is classified as Micro, when it is lower than 2 meters, Meso, when it is between 2 meters and 4 meters and Macro, when it is greater than 4 meters.

Several workers have commented on the possible effect of tidal range on platform morphology. Davies (1977) suggested that large tidal range encourages the formation of sloping intertidal platform and King (1972) mentioned that low platform gradients could be the result of the small tidal range. Apart from a few passing comments, however most of the century old debate on the origin of shore platforms has been conducted in almost total ignorance of the fundamental role of the tidal range.

The distribution of tidal range along the coastal stretch is controlled by coastal configuration. Macro tidal range exceeding 4 m is mostly observed in semi enclosed seas and funnel shaped entrances of estuaries. Micro tidal range below 2 m occurs predominantly along open coast. The environments dominated by tidal processes are not restricted to coasts experiencing macro tidal ranges. They may also be found along micro tidal coasts if the incident waves are weak (Davis and Hayes 1984).

Trenhaile (1987) observed that shore platforms in macro tidal environment (Pethick 1984) are sloping platforms (Masselink et al 2003) and sub horizontal in meso and micro tidal environments. This however seems to be applicable to platforms developed at the foot of the cliffs.

There exists a delicate balance between wave and tide processes. The relation between platform gradient and the total wave energy expended on a rock platform, within the tidal range still remains to be determined.

The possible relationship between platform width and tidal range is much less clear than that between gradient and tidal range. Geometrically, the width of rectilinear platform profile could increase, decrease, or remain constant as the gradient increases with increasing tidal range. (Trenhaile 1987)

Konkan coast of Maharashtra shows tidal range that varies from 2 to 5 m. Along Sindhudurg and South Ratnagiri district tidal range is less than 2 m. On Raigad district coast the tidal range is between 2 and 4m and along Thane district coast it is more than 4m. (Karlekar 2009): Within 24 hours 2 high and 2 low tides are commonly observed. The time interval between High tide and low tide is of 6 hours.

Water layer leveling and rock platforms

The lowering, smoothing and leveling of inter tidal rock platforms associated with pools of standing water is usually termed as Water layer leveling. This type of leveling is caused where spray and splash accumulate. The horizontal platforms produced by this action are mainly formed on rocks with high proportion of siliceous material and low angles of dip. Water layer leveling is most active at lowest elevations. The process is induced by alternate wetting and drying. The process of leveling cuts into the divides between the rock pools, enlarging them and eventually causing them to merge. Alternate wetting and drying, salt crystallization, chemical weathering and movement of water through the rock capillaries are the processes most active on intertidal rock platforms.

Case hardening often accompanies rock platform surfaces. It occurs along joint planes forming frame like patterns. Several types of weathering pits, joint blocks, ridges and furrows are found on such surfaces. Most pronounced forms stand out in relief above the general surface, especially on the slightly higher back side of the platform. Large depressions are found on seaward margins of such platforms.

The process operates best on rocks with low angles of dip and makes platforms more irregular. Several ridges or 'ramparts' often rising a meter or more above the general platform surface have been attributed to water layer leveling. The margins of platforms are frequently kept moist by spray and splash (Hills 1971). Ramparts are the characteristic features of volcanic rock coast, particularly in low latitudes.

Water layer weathering appears to be active at all elevations between low tide and upper limit of spray and splash (Trenhaile 1987*)*. The process smoothes levels and lowers the rugged wave cut surfaces where rocks are suitable for levelling.

Study Area

Along Dahanu Coast of Maharashtra between Zai (20.13 N /72.73 E) and Tarapur (19.86 N / 72.68 E) there are very striking rock platforms with sharp surface relief in the inter-tidal zone. They are backed by silt clay deposits, sandy beaches, dunes, dune systems and wide littoral terraces slightly above the high tide level.

All the platforms in question are developed at the level of low tide. The platforms are 'non structural' benches, which cut across the local structure of coastal rock formation at the height of 2-3 m above mean sea level. Research on such platforms has been rarely published to date. More studies on various aspects of such platforms are needed. The platforms near the coast and at the foot of the cliff are often termed shore platforms. It is not always appropriate to use such a term without clear understanding of their formation. The purely descriptive term 'intertidal rock platform' is preferred here.

The shoreline under study is slightly indented with embayment where consequent streams flow into sea. The distribution of rock platforms in intertidal zone and the features on the coast are shown in Fig.1. The coast is characterized by beaches (Bordi, Narpad, Vadhavan, Chichani) and low dunes, scattered dune mounds, tidal inlets (Khonda (Dahanu) creek, Tarapur-Chinchani creek) that are influenced by tidal inundation, and wide littoral terraces. The coast enjoys a macro tidal environment where maximum tidal range is 6.5 m. In many sections, the coastal strip shows old sand bars and spits as well as Holocene fossil beach dune deposits (Karlekar et al 2012). The shore proper presents a succession of alternating headlands and bays.

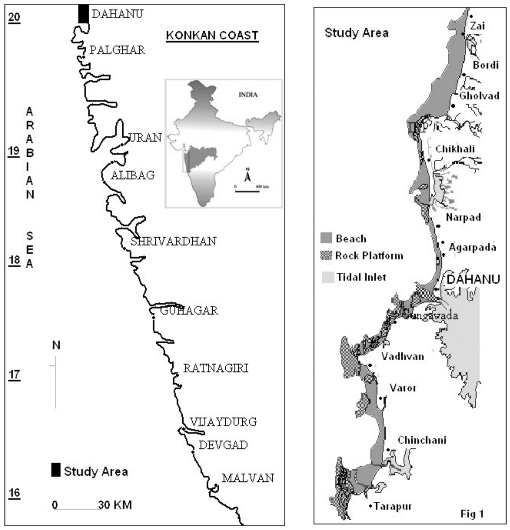


Fig. 1:

The climate of the area shows a regular variation on account of the alternating southwest and northeast monsoon. The weather on the coast is therefore more seasonal in nature. December to March is a relatively cool season with northeast winds. The weather is dry and the cloud cover is very little. April and May are hot months. In this period the winds are light and variable with sea breezes on the coasts. June to September is the season of southeasterly and easterly winds. The period from the end of southwest monsoon to its recommencement is usually identified as a fair weather season

Considering the specific environment, February to May is treated as Pre-monsoon, June to September as monsoon and October to January as Post monsoon period on the coast. Rough or very rough seas occur during south-west monsoon. Moderate to heavy swell waves also persist along the coast in this season. Winds on open sea are modified when they approach the coast mainly due to the effects of coastal configuration.

Being a coastal region Dahanu experiences less variation of temperature during the day and the seasons. From February, temperatures progressively increase till May which the hottest month having 30°C as mean daily temperature. In summer season and in June before the onset of the monsoon day temperatures may sometimes go above 37°C on the coast.

Predominant wave and wind direction in the area is from south west - west in monsoon and west – northwest in fair weather. The wave period ranges from 3 -6 seconds in monsoon and 10 second in winter. The average wave height changes from 1 to 1.5 meters in winter to slightly above 4 to 6 meters in monsoon. Table 1 gives the parameters of wave climate on Dahanu coast in monsoon and fair weather. (Karlekar 2009)

Table 1: Wave climate at Dahanu

		Monsoon	**Fair weather**
Wave	A) Direction B) Period C) Height	SW – W 3 to 6 sec 4 to 6 m	W – NW 10 sec 1 to 1.5 m
Wind	A) Direction B) Speed	SW –W 10 to 14 knots	W – NW 5 to 11 knots
Tidal current	Velocity	< 10 cm/s	< 10 cm/s
Longshore current	A) Direction B) Velocity	S – SE ly 30 to 40 cm/s (Powerful in July)	N – NW ly 8 to 20 cm/s (Powerful in Oct.)

(Source, Karlekar 2009)

The long shore current direction on the coast is variable. Dominant current direction in monsoon is south south easterly and the velocity of the longshore current varies from 30 cm/s to 40 cm/s. The longshore current in fair weather is north to northwesterly. The velocity of longshore current in this period varies from 8 cm/s to 10 cm /s. The velocity of the tidal current on Dahanu coast was found to be less than 10 cm/s throughout the year. (Karlekar 2009).

Methodology

In order to study the morphology of rock platforms, the surface relief forms, furrows, ramparts, pools, sediments and mangroves, detailed field measurements and observations were undertaken. All the work was carried out in the period of ebbing tide when optimum exposure conditions were available. The sediment samples were also collected simultaneously. The total height of mangrove trees was measured in mid tide and low tide periods.

On the platform at Narpad which is a typical intertidal rock platform, at 15 different locations thickness of silt clay deposits was measured. The level of submergence of mangrove trees was ascertained with the help of arrested floating material such as plastic bags, twigs etc. The exact locations of sediment deposits and mangroves were fixed by using GPS.

GIS software namely SURFER, and GLOBAL MAPPER were used for mapping. The Goggle images of the area for the years between 2003 and 2012 were used for geomorphic mapping of major rock platforms on the coast.

The Inter Tidal Rock Platforms

Development of rock platforms requires a delicate balance between rock resistance and intensity of wave attack. For the development of wide platforms on this coast, the less resistant lithology plays more important role. The waves lose their energy expeditiously when they traverse over the wide platforms.

The features on the shore platforms are evidently different than those seen on high tide shore platforms. (Pethick, 1984). The principal agency for the planation of the platform is not so much the abrasion as

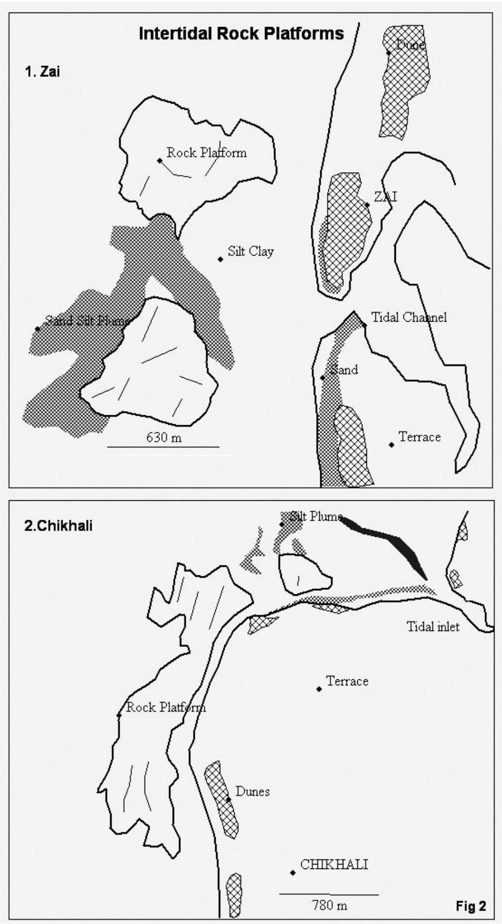


Fig. 2:

the weathering (water-level weathering of Wentworth, 1938, or water-layer weathering of Hills, 1971) and the wave action merely supports the transportation of loose material on the platform. Therefore, the rock platforms which are less resistant against weathering caused by alternate wetting and drying, are comparatively broad. The platforms are developed in a macro tidal semi diurnal environment where tidal range is as high as 6.5 m (Indian Tide Tables 2011).

In all six prominent rock platforms were investigated from the study area (Fig 2,2a,2b).

The morphological details are given in table 2. The platform at Vadhavan is relatively bigger and wider and has a gradient of 0.83 degrees. Most of the platforms are backed by beaches but are separated from the beaches by a shallow area filled with sand silt sediments. November onwards one can invariably see plumes of silt clay brought from the terrain in monsoon scattered in the vicinity of platforms. The surface of the platforms is characterized by many furrows running in various directions (Plate1: see page 237). The average length of furrows is about 300 m with a frequent orientation ranging from 83 deg to 200 deg. The furrows on the seaward part are as deep as 1.5 m. The surface is also pitted by pools and pot holes. It is covered by frequent rounded gravels, and regions of sand silt and clay deposits. There are sharp honeycomb structures and micro ridges of unweathered hard basalt.

Table 2: Morphology of rock platforms

Rock Platform at	Location	Area (sq km)	Max Width (m)	Gradient (Deg)
1. zai	20.13 N/ 72.73 E	0.40	820	0.06
2. Chikhali	20.13 N/ 72.73 E	0.62	980	0.13
3. Narpad	20.13 N/ 72.73 E	0.75	1450	0.07
4. Gungawada	20.13 N/ 72.73 E	0.77	1640	0.06
5. Vadhavan	20.13 N/ 72.73 E	0.78	2450	0.83
6. Varor	20.13 N/ 72.73 E	0.65	1320	0.08
Average		**0.66**	**1443.3**	**0.21**

Source: Authors

The average area of the platforms on this coast is 0.66 sq km with an average maximum width of 1443 m and gradient of only 0.21 degrees indicating the fact that they are moderately wide, almost flat and horizontal platforms.

The relief contours on the Narpad platform (Fig 3) show that the surface is not smooth and is characterized by big depressions at two places. Here the water layer weathering is very effective due to the less resistant rock. The platform surface is covered by frequent rounded gravels, and regions of sand silt and clay deposits. The variation in the thickness of such fine grained deposits is due to the surface irregularities. The maximum thickness of sand silt clay

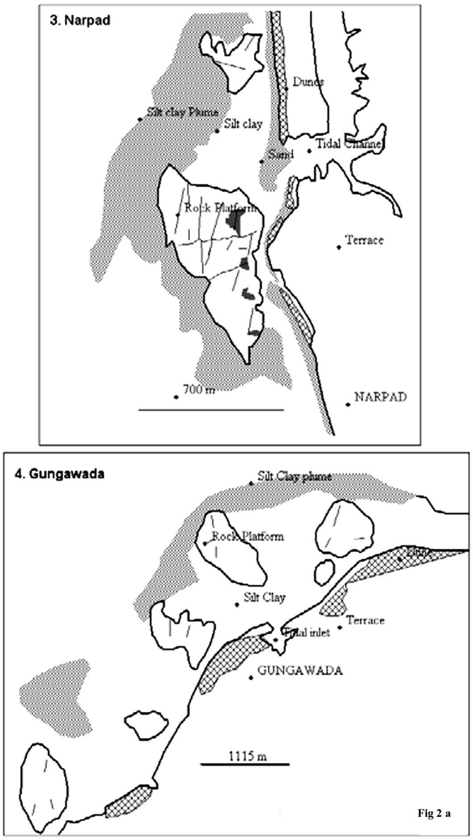


Fig 2 a

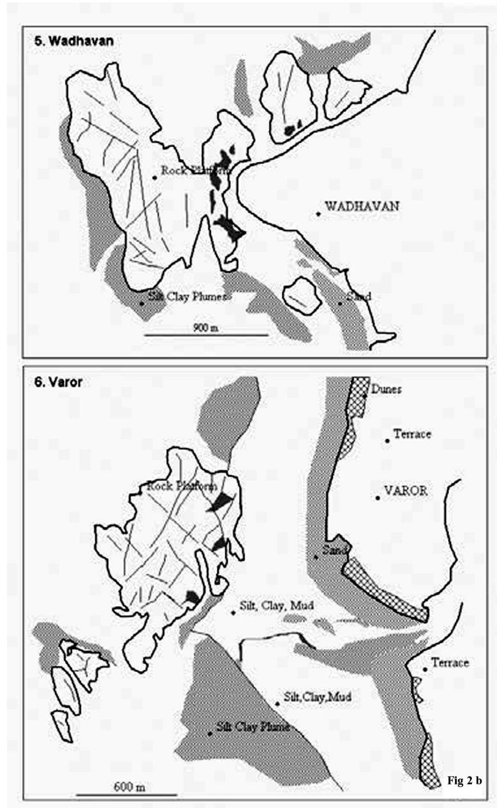


Fig 2 b

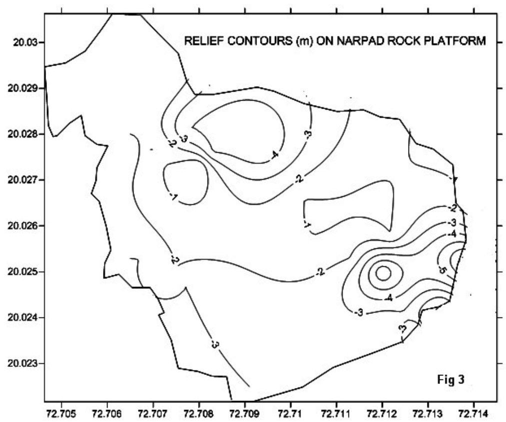
deposits is to the tune of 11 cm and is observed in pools and depressions (Fig 4). Elsewhere on the platform the thickness of such deposits is between 2.5 cm and 9.5 cm. Mangroves are found scattered where conducive substratum conditions (silt clay deposits) exist. Such conditions are found on the shoreward side of the platforms. The platform at Vadhavan shows mangroves 30 cm to 1.5 cm tall occupying a narrow elongated area on the back of the platform (Plate 2: see page 237). The interpolated levels of high tide submergence obtained by measuring the height of arrested floating material such as plastic bags, twigs etc on Narpad platform is shown in **Fig 5**. The levels are helpful in knowing the surface topography as well as the areas of longer inundation.

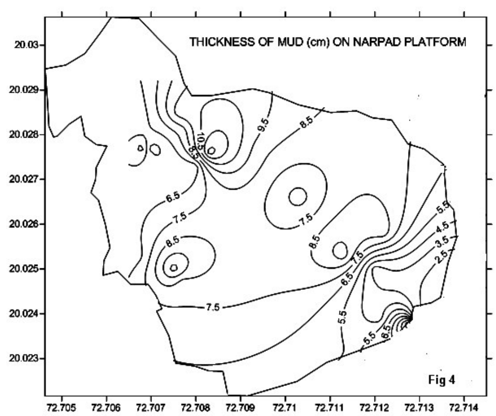
Summary and Conclusion

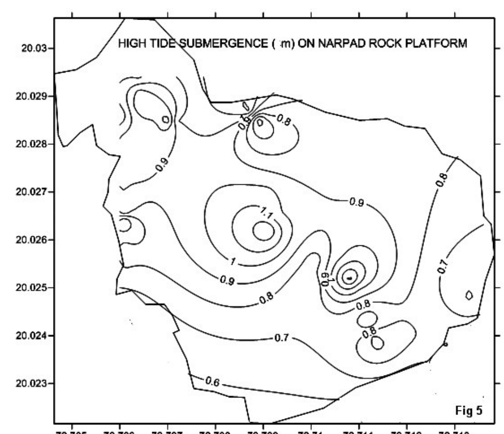
The features of rock platforms on Dahanu coast can be summarized as follows: (1) They have a width that ranges between 800 and 2450 m (2) The surface of the platforms is leveled in intertidal zone and especially between the mean sea level and mean high tide level, except seaward margins (3) They are developed on basalts with strike nearly parallel to the general direction of the shoreline and dip of 1in 250 toward sea; (4) Their surfaces show very sharp relief lines, furrows and pools (Plate 3: see page 238) (5) The surface inclines slightly towards sea with an inclination of 0.06° to 0.83° especially in the middle sectors. of the platforms. (6) Along the rim of a few platforms there are slight breakwater like ramparts (7) On the surface there are frequent rounded gravels and micro regions of silt sand deposits.(8) All the platforms have been carved with deep wave furrows (9) There are no cliffs at the rear of the platforms. They are separated from but backed by beaches. (10) On the surface, honeycomb structures, solution pools, potholes filled with sediments and mangrove bushes on silt clay deposits are found. (11) The platforms are carved by wave furrows which are regulated with joints.

It is difficult to explain that so broad and almost horizontal platforms are shaped merely by wave abrasion. The waves armed with rock fragments are powerful agents of abrasion and the waves without such fragments are capable of only limited abrasion. But on the surface of platforms on this coast there are clear evidences of the potency of waves armed with abrasive debris, such as smooth and rounded gravels, excavated potholes and wave furrows with the direction that coincides with the wave approach. It however appears that the principal agency for planation of these platforms is not so much abrasion as water level weathering.

The platform surfaces that are leveled approximately in inter-tidal zone may correspond with the lower limit of sea-level weathering. The weathered rock is easily loosened as it is made less resistant due to alternate wetting and drying in inter-tidal zone. The weathered material is quickly carried away even by calm waves at usual high tide. The prominent crests of weathered rocks break easily into the fragments along the joint-surface due to wave attack. Thus the platforms are flattened nearly horizontally in inter-tidal zone. For the development of these broad platforms the less resistant lithology rather than the intensity of wave attack has played a more important role. The water level weathering caused by alternate wetting and drying in the inter-tidal zone seems to be a controlling factor in their planation.







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Dr. Shrikant Karlekar,
Professor and Head,
Dept.of Geography, S.P.College,
Tilak road, Pune

Dr. Tushar Shitole,
Head, Dept.of Geography,
R.M.A.C.S. College, Akurdi, Pune