

Geomorphology of the Goa Coast

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Abstract. This paper is based on the observations and interpretations of aerial photographs (1 : 25,000 and 1 : 15,000) of the Goa Coast. Aerial photocharacters like tonal differences, texture, shape, size, form, pattern, vegetation, soil characteristics and associated features were useful in identifying fluvial, marine and aeolian features such as tidal flats, river terraces, mesas, wave-cut platforms, old beach ridges, dunes, etc. The drainage network is predominantly in two directions coinciding with the regional trend, major faults and fractures and represents a fine example of a structurally controlled drainage pattern. The islands near the coast are parts of coastal headlands now isolated from the retrograding coast. Some islands are merged with the mainland by tombolos or alluvial plains. The presence of laterite beds at a depth of 27 to 35 m below the present sea level along the estuaries indicates the drowned valleys. Geomorphological evidences show that the coastal tract of Goa has undergone the following stages after the outpouring of Deccan Traps : epirogenic movement ; headward erosion ; recession of scarps ; superposition of the streams ; lateritization ; submergence ; emergence ; progradation and retrogression. Based on the disposition of the landforms it is surmised that the coast is prograding along the sandy stretches and retrograding along the hilly portions.

Keywords. Aerial photographs ; geomorphology ; Goa Coast ; fluvial forms.

1. Introduction

The National Institute of Oceanography is carrying out a comprehensive geological and geophysical survey of the continental margin of India. As a part of this project a geomorphological study of the coastal area is being carried to understand the quaternary history of the coastal areas and its relationship with the history and sedimentation on the shelf. Aerial photographs of the coastal areas provide a valuable, rapid and accurate tool for the study of coastal geomorphology. Generally greater details of the coastal configuration and nearshore features are discernible on the photographs than can be observed in a comparable short time by painstaking field studies. As a part of this programme a study of the coastal areas of Goa was initiated. The beaches in Goa are attracting increasingly large number of tourists because of its scenic beauty. A number of beach resorts are being developed and tourism is making an important contribution to the economy of Goa. A study of the geomorphology and quaternary history of the

area will be of considerable importance for the planned development of coastal area. The present paper is based on the study of aerial photographs of coastal areas of Goa (figure 1) followed by selected field checks.

2. Geological background

The pre-Cambrian Dharwar and Cuddapah rocks occupy a large area in Goa. The Dharwars are represented by quartzites, phyllites, chlorite-schists, gneisses, granites, metabasalt, metagraywackes and banded hematite quartzite. Strata of Cuddapah age occur along the northern coast of Goa from the Terekhol river to the Marmugao headland. These unfossiliferous metasediments are profusely intruded by basic dykes (Oertel 1958). The regional trend of the pre-Cambrian rocks is NNW-SSE in the north and veers to E-W in the south (Wagle and Misra 1975). In a small area in the north-east the Deccan Traps cover the ancient crystalline formations. The pre-Cambrian rocks and the traps are covered by about 30-40 m thick laterite on the coast which thins to the interior. Laterite beds are also reported in the estuaries of Chapora, Mandavi and Zuari at 20, 27 and 34 m below the hydrographic zero (Feio 1956). The older formations are covered by recent, sub-recent sediments, *i.e.*, alluvium and dunes along the river valleys and the coast.

3. Method of study

An uncontrolled mosaic of photographs (1960 1:15,000 approx. and 1973 1:25,000 approx.) of the coastal area of Goa (figure 1) covering survey of India toposheets 48 E/10, 14, 15, E/16, I/4, J/1 were prepared and studied. This was followed by a study of the area runwise (N-S strips) under the mirror stereoscope and the geomorphic details were transferred on kodatrace and later compiled in a map.

4. Geomorphology

The territory of Goa (N 14° 48' to N 15° 48' lat. and E 75° 40' to E 74° 20' long.) mid-way along the west coast of India occupies a 100 km long and 40 km wide strip (in the widest area) between the Western Ghats and the Arabian Sea. Physiographically the region is divided (De Souza 1965) into : (i) the coastal tract consisting of recent broad alluvial plains, vast estuaries, beaches and dunes, (ii) the tract between the coast and the Ghats, the "sub-ghats" region and (iii) the Western Ghats. The coast trends NNW-SSE more or less in a straight line. The coastline consists of sandy beaches separated by rocky headlands, cliffs, river mouths and broad estuaries.

The paper describes the area under the first category, *i.e.*, the coastal tract of Goa, extending from the Terekhol river to Kalinadi Creek. Photo-elements analyses such as tone, texture, shape, size, form, pattern and associated features aided considerably in identifying and describing the following geomorphic units,

5. Geomorphological features

<i>Fluvial</i>	<i>Marine</i>	<i>Aeolian</i>
Drainage	Mesas	
River terraces	Cliffs	Dunes (recent and old)
Channel bars	Wave-cut platforms	
	Offshore islands	
	Tidal flats	
	Beaches and old beach ridges	
	Waves	
	Turbidity flow	

5.1. Fluvial forms

5.1a. *Drainage and drainage pattern* : The drainage pattern in Goa is dendritic and the network dense ; this may be because of the heavy monsoonic precipitation on the windward (western) side of the Ghats and also due to the fact that there are closely-spaced network of fractures running NW-SE and NE-SW and the drainage lines could easily entrench themselves because of highly weathered mantle over the rocks. Most of the rivers are straight with sharp bends and meandering is a rare phenomenon. The drainage network is predominantly in two directions: one, *i.e.*, NW or NNW which follows the regional trend and the other E-W which coincides with major faults, fractures or joints. The exception is river Sal which runs parallel to the coast and finally opens into the sea after touching the hard rocky exposures.

5.1b. *River terraces* : These are topographic surfaces marking the former flood plain levels. Field checks reveal that the horizontal or nearly horizontal alluvial terraces on either sides of the rivers are about 1 to 2 m above the present high water level and are covered with alluvial deposits.

5.1c. *Channel bars* : The deposits of sand and gravel along the river channel are designated as channel or meander bars, depending on the position and origin. Such deposits are found along the channels of Terekhol, Chapora, Sal, Talpona and Kalinadi (figure 1). On air photos these sand bars are seen as streaky multiple channels while under stereomodels these appear to have some relief, the intervening low-lying portion being filled with silty clays. The presence of meander bars on the convex side of the channels indicates the migration of the river towards the convex end.

5.2. Marine forms

5.2a. *Mesas* : Laterite mesas are recognised on air photos by their light to medium tone, relatively flat tops and negligible to gentle slope. The surface has a pitted appearance ; sparse to thin vegetation but the slopes are marked by dark tone due to dense vegetation. The height of mesas varies from 40 to 100 m from m.s.l. The ground checks made around the important mesas indicate that

they occupy mainly three levels, *i.e.*, between 40–60 m, 60–80 m and 80–100 m. The tops are covered with massive laterite ranging in thickness from 20 to 40 m. Some of the laterites show relict joints and foliations indicating *in situ* weathering of metamorphic rocks. The coastal plateaus are generally separated by alluvial or sandy stretches, while in the interior the lowlands are also lateritic and at times a plateau of laterite may be followed by another lower level plateau.

5.2b. *Cliffs and wave-cut platforms* : The most prominent features of marine erosion seen in aerial photographs are cliffs, sea stacks and nearly horizontal abrasion platforms. Abrasion platforms are better seen in low tide photographs.

Field checks indicate that the cliffs range in height from 5 to 40 m and have been formed by under-cutting and subsequent fall of large rock masses (figure 2c). A typical cliff may be divided into two parts: the lower vertical one, which is presumably barren of soil and the upper one with a thin veneer of soil (1–2 m). Cavernous weathering and beach rock are seen just above the present sea level and beyond the highest limit of wave spray in a number of places (figures 2a, 3c). The sea arches are not common but their surviving pillars or stacks are seen. At some places the sea stacks have been worn down and are exposed only at low tides. These isolated stacks show lithologic and structural relation with the rocks, a little inland along the coast. Sea caves are common along the hilly part of the coast.

Marine abrasion platforms are found at the base of the cliffs and headlands (figure 3b), whereas there may be another lower level platform submerged under the water. Along the northern part of the coast the platforms are cut in quartzites and laterite, while in the southern part these are in metabasalt and gneissic granite. Along some beaches of the northern sector of Goa conglomeratic laterite is exposed forming the wave-cut terraces. Some of the terraces are in the intertidal zone but others are above the present high water line (figure 2b) and may indicate earlier higher sea level. The laterite mainly consists of rolled gravels, pebbles and cobbles of laterite with some other rock types cemented by hydrated iron oxides (figure 3a). It is possible that some of these may represent earlier shingle beach, the material having been lateritised later; also they may be colluvium, accumulations at the footslope of hills, later lateritised. The detailed study of the material (composition, roundness, sphericity, etc.) may throw some light on this. Borges (1948) referred to this laterite as “secondary” or “coastal laterites” due to the presence of shells alongwith rolled rock fragments. De Souza (1968) has also recognised “conglomeratic type of laterite” but restricted the occurrence to the lower slopes of hills in Goa. However, Prudvi Raju and Vaidyanadhan (1978) have referred to similar laterite in the East coast in Visakhapatnam area as “colluvial laterite or lateritised colluvium”.

5.2c. *Offshore islands*: The important islands off the coast of Goa are Pikene, Grande, Kambariam, St. Jacinto, St. George and Kanko. These appear to be the detached portions of coastal headlands now isolated from the retrograding coast due to wave action or due to rise of sea level. According to Feio (1956) the present Marmugao headland was also an island now connected with the mainland by a tombolo over which stands the city of Vasco-da-Gama. Aerial photographs indicate that the tombolos are under formation connecting the St. Jacinto and Kurmagad islands to the main land.

5.2d. *Tidal flats* : The lower reaches of all the rivers are tidal, sea water encroaches during high tide and submerges the low-lying areas adjacent to rivers, forming tidal flats (figure 1). On air photos, the tidal flats show dark tonal contrast to the lighter channels, bordering the present river. But old tidal flats are marked by light tone with cultivated fields adjacent to the present tidal flat. The old tidal flats are situated 2-3 m above the present sea level. Some of these are not necessarily tidal flats, but barrier flats. The latter form behind a barrier (which was earlier a bar) and almost look like a tidal flat. It is the nature of the material and relief of the neighbouring forms that aid in distinguishing them. Barrier flat is usually due to emergence of a coast (58 c/5 & c/1). The material filling in can be eolian, fluvial or marine. But in tidal flat, it is essentially brought in by the tides. These tidal flats cover wide stretches along Terekhol, Chapora, Mandavi and Zuari rivers. The agricultural lowlands, in the coastal tract are old tidal flats formed by sediments deposited along the principal rivers. Field checks reveal that soil of the tidal flats consists of silty sand or silty clay with abundant organic matter.

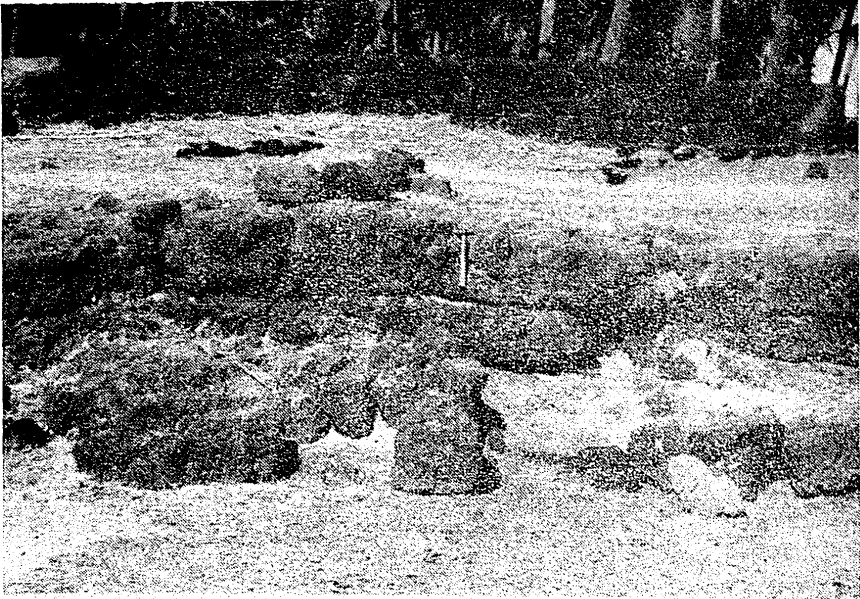
5.2e *Beach* : This unit is restricted to a narrow belt ranging from a few metres to about 100 m along the coast. A greater part of the zone forms the intertidal region. Aerial photographs taken at the low tide display different features in detail and in some, submerged portions are also seen. From the aerial photographs it is seen that the unprotected areas facing the seas are marked by long stretches of straight sandy beaches. On the other hand, the semicircular bays are marked by invariably crescent-shaped beaches due to waves.

Old beach ridges have also been noted along the coast, these are 1-3 m high and roughly parallel to the present shoreline. The beach ridges can be distinguished from dunes because of their continuous linear forms. Each ridge perhaps marks the position of an old shoreline.

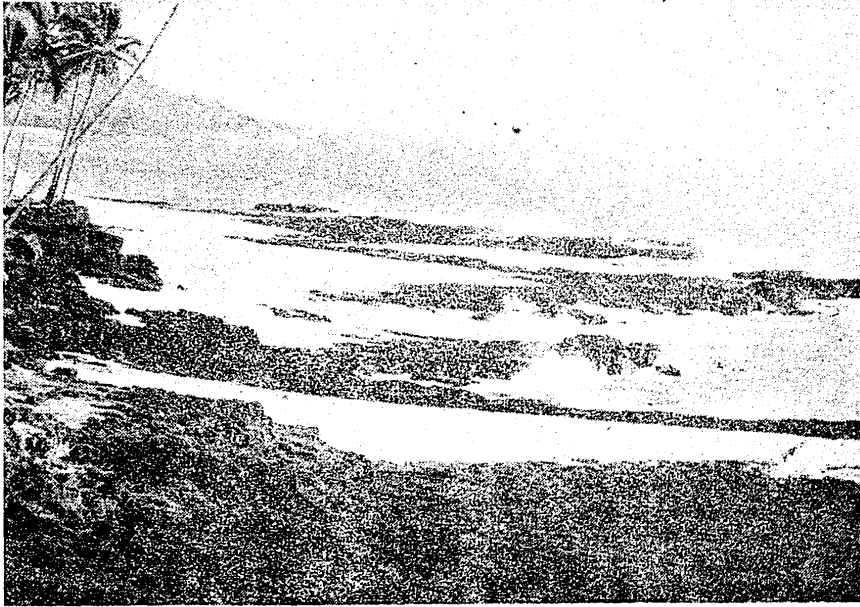
5.2f. *Waves* : During the period of photography, *i.e.*, January-February, 1960 and 1973, two trains of waves are recognised in the near shore area: (i) from WSW which is dominant and (ii) from WNW which seems to be subsidiary. Though in these months (January-February) deep water waves are from N and NW (daily weather reports of IMD 1971-73), when approaching the shore at an angle, the waves may undergo refraction due to shoaling and shore configuration.

The direction of the deep water wave approach, wave periods, bottom topography and shore configuration determine the pattern of the wave front in shallow water. The photos show that along the sides of the islands wave refraction causes the waves to bend and approach parallel to the shore while at the river mouths the line of breakers is pressed seaward (figure 1). This seaward shift of breakers may perhaps be due to the waves moving in a direction opposite to that of the ebb current and having a damping effect of sediment laden waters, or may be due to the sediment accumulation at the mouth of the rivers.

5.2g. *Turbidity* : Aerial photographs of the area also provide a synoptic view of discrete water masses that can be differentiated by suspended sediment load. In addition to the coastal turbid water zones, a pronounced plume of high turbidity brown water can be observed entering the Arabian Sea from the Terekhol,



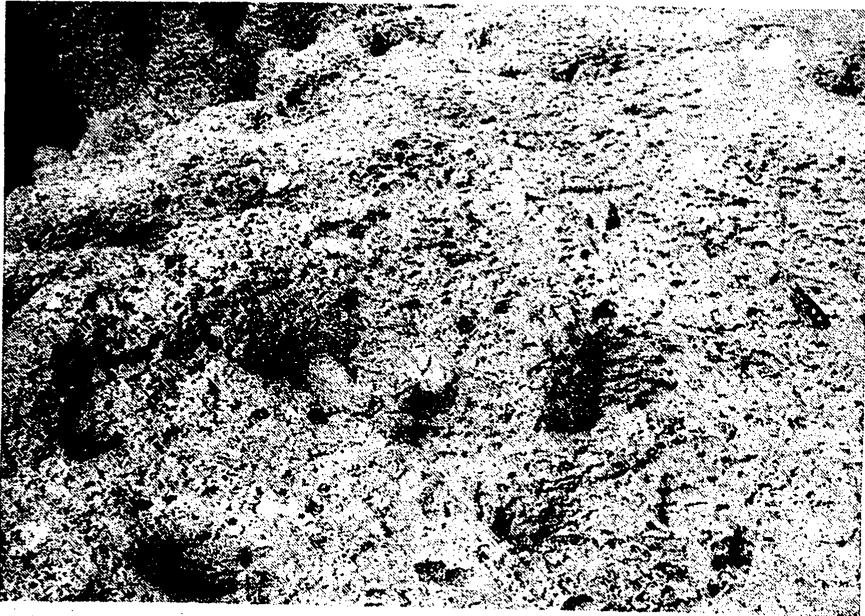
2 a



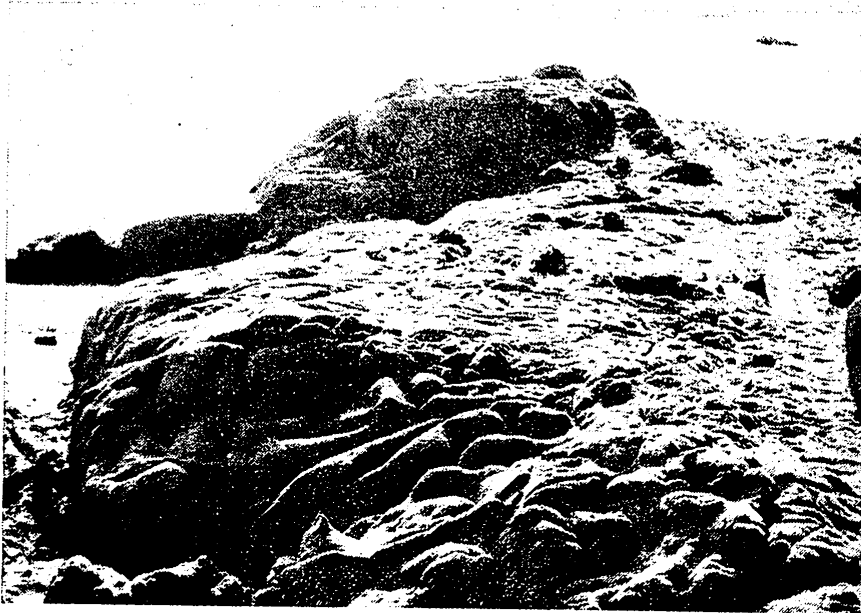
2 b



Figure 2. a. Beach rock just above the present day sea level. b. Wave-cut terraces in the intertidal zone and above the present high water line. c. Laterite cliffs showing the undercutting and subsidence.



3 a



3 b



Figure 3. a. Conglomeratic laterite. b. Marine abrasion platforms at the base of the cliffs. c. Cavernous weathering just above the present day sea level.

Chapora and Sal estuaries. The sediment plume at the mouth of these rivers shows a deflection towards the south indicating a weak southerly current.

5.3 Aeolian forms

5.3a. *Coastal dunes* : A series of sand-dunes occur parallel to the coast in many areas. Within these dunes a set of old and recent or active dunes can be distinguished. The recent or active sand-dunes exhibit a very light tone in airphotos. These are located close to the beaches and rise to height of about 15 m. The dunes are generally devoid of vegetation or have only a very thin veneer of vegetation. The older dunes are marked by a very dark tone and this tonal contrast enables their clear distinction from the recent dunes. The older dunes landscape depicts a series of low ridges more or less parallel to the coast separated by swampy depressions. The old dunes in the interior are now stabilized by growth of thick vegetation. These dunes extend to about one or two kilometres inland and indicate the accretion to the shoreline.

6. Discussion and origin

The landforms in an area are the result of interaction between structure and lithology of the rocks of the area and the processes operating in the area. The Central west Coast of India which includes Goa is marked by large hills bordered by narrow alluvial plains followed by an indented coastline with arcuate bays, estuaries and few sandy stretches. In the Goa area the maximum distance between the Ghats and the sea is about 40 km, but several isolated hills rise in the coastal tract between the Ghats and the sea. The Western Ghats on the east form a long unbroken escarpment. The Ghats comprise many geological formations of differing physical and structural characteristics. The northern half of the Ghats from Tapti valley southwards to Goa is formed of horizontal beds of massive Deccan Traps. South of Goa, the horizontal bedded traps give place to steeply dipping gneisses and schists.

The present study provides some information about the geomorphological development of the area after the outpouring of Deccan Traps and as elsewhere in the country particularly on the west coast the pre-Deccan Trap geomorphological history of the area is obscure. The geomorphological evidences show that the ancient Dharwarian rocks were peneplained before the outpouring of the Deccan Traps. After the outpouring of the Traps the coastal tracts witnessed epirogenic movement ; headward erosion ; recession of scarps ; superposition of the streams ; lateritization ; submergence ; emergence ; progradation and retrogression. The landforms of the coastal tract of Goa have therefore undergone through the above stages since the outpouring of the basalts.

The prominent landforms in the coastal region are the laterite capped table-lands with a gentle seaward slope and there is usually an abrupt fall along the coast presenting a cliffed coastline. These mesas mark distinct levels at 40 to 100 m which are significant in interpreting the geomorphic evolution of the area. The levels particularly the one at 100 m and above are very high and without any evidence of marine abrasion or marine deposition, it is therefore difficult to explain

their origin by eustatic change. It is also difficult to date these surfaces as these are carved out in unfossiliferous crystalline rocks. The origin of these laterite mesas can be explained in the following stages: (i) the coastal tract was peneplaned before the outpouring of the Deccan Traps, (ii) the Deccan Traps covered the peneplaned surface, (iii) later due to tectonic disturbance, *i.e.*, subsidence along faults parallel to the coast a broad step-like topography was formed, (iv) fluvial and marine erosion initiated the removal of the trap blanket from west to east leaving behind plateau-like surfaces at different heights (cf. 40 to 100 m) which form the present mesas. The retreat of the Deccan Trap is confirmed by the west flowing rivers which are rapidly eroding headwards and capturing the well-established drainage on the older plateau surface. The best example of river capture is the Dudh Sagar Fall.

Due to the removal of the basaltic cap the streams flowing on the basalt started following the structural weaknesses and trends of the earlier peneplaned pre-Cambrian surface. Most of the streams have subsequently followed faults, fracture lines and the synclinal axis giving a fine example of structurally controlled drainage. At the same time due to the retreat of the lava flows from west to east the Dharwarian rocks were again peneplaned and when the topography and climatic conditions were favourable, extensive lateritization took place. The thicker laterite cap towards the west and a thinner one or its absence in the east indicates the gradual retreat of the Traps from west to east. *In situ* formation of laterite is also evidenced by the clear transition from parent rock to laterite and the presence of relict features of the parent rock in the laterite.

The presence of laterite beds forming the abrasion platforms in the intertidal zone as well as at a depth of 27 to 35 m below the present sea level along the estuaries can be attributed to the quaternary rise of the sea level giving rise to drowned valleys. Similar drowned valleys have also been reported along the west coast in adjacent areas (Vaidyanadhan 1968). The islands (St. Estevan, Chora, Divar, etc.) along the coast were possibly earlier inselbergs and they also support the evidence for submergence. At the same time the presence of vast alluvial plains adjacent to river beds as well as surrounding the hillocks which were once islands; presence of marine sediments 2-7 km inland; abrasion platforms well above the present sea level and the beach rock (Setty and Wagle 1972) along the coast are the strong evidences of emergence. Therefore it can be concluded that the coast is subjected to submergence in quaternary period followed by partial emergence during recent times. The present sea level is neither higher nor lower but represents an intermediate level.

The coast with broad beaches, old and recent dunes and the old beach ridges indicates the progradation of the coast specially along the beaches. At the same time the portions of the coast with cliffs and wave-cut terraces under formation indicate that the hilly region of the coast (headlands) is under constant attack of the waves causing the erosion and as a consequence of retrogression of the coast. It may, therefore, be concluded that the coast is prograding along the beaches while retreating along the cliffs and headlands.

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