BEACH ROCK FROM GOA COAST

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Beach rock is a common rock type in many parts of the southern hemisphere and also some areas north of the equator. Its distribution particularly in the Indian Ocean islands and atolls and coasts of India is reviewed. The mineralogic and faunal constituents of beach rock found along Goa coast is dealt with in detail.

While discussing the various views on its origin, it is emphasized that the process of cementation is chiefly controlled by ground water evaporation, inorganic precipitation and optimum temperature under the beach and inland. However, the thickness depends upon variabilities of precipitation, hinterland, water table fluctuations, temperature changes, composition and changes in sea level. Since the beach rock is formed in the tidal or spray zone its occurrence at higher or lower levels is suggestive of eustatic movement. The physical setting of this rock along the west coast of India indicates a post-middle Miocene to Pleistocene age.

Introduction

Beach rock is a common rock type in many parts of mainland and island beaches in the tropics and temperate regions of the world, particularly in the southern hemisphere. It is almost universally present in the warmer regions, even on tiny atoll sand cays of the Pacific and Indian Oceans, and also on arid coasts where there is no rainfall, and even in favoured but isolated regions. It is reported from as far north as England and as far south as New Zealand.

There have been several references to the occurrence of beach rock along the Indian coasts and the adjoining Andaman, Nicobar and Laccadive group of islands (Gardiner 1903, 1930; Sewell 1935; Ellis 1924). Fedden (1885) noticed white miliolite rock (beach rock) occurring in patches at 50–100 feet height on the sides of the hills and also recesses in the ravines along Kathiawar coast. In Malia district and Nawanagar regions, oyster beds are seen at elevated regions. Oldham (1885) found raised beaches and 'raised marine conglomerates' in Andaman, Nicobar, Rutland and Kachal islands. Raised coral reefs at 8 feet above sea level along the southern coast of India and beach rock between Mattupettai and Pamban, and also at Kiḷakarai were reported (Foote 1889; Thurston 1895). Raised oyster beds and beach sandstone were reported from the neighbourhood of Vizagapatam and Chilka lake

(Blanford 1872), Orissa coast, Calcutta on the east coast, and also Porbunder, Kathiawar, Sind (Pakistan) and Runn of Cutch (Wadia 1919). Beach sandstone appears to extend into the interior of all the islands in the Laccadive group and seems to be continuous with the conglomerate of the reef (Oldham 1896; Ellis 1924). Beach sandstone exposures at Rameswaram island near Pamban, and again at Mandapam spit, and along Tuticorin coast are extensively described by Sewell (1935). It is also noticed all along in Mandapam-Kilakara-Tuticorin region (Panikkar, personal communication). Revelle and Fair-bridge (1957) state that 'along southern coast of India there is an annual exploitation of newly formed beach rock for building stone'. In the opinion of the authors this beach rock mentioned is not real beach rock as described here. Fox (1922) recorded the occurrence of raised beach terraces along the west coast of the 'island of Bombay', and recently, presence of beach rock was noticed near Madh island, Bhandoli swarup area, near Bombay (Agrawal, personal communication).

NOMENCLATURE

Beach rock (also known as beach sandstone or beach conglomerate) is a friable to well-cemented rock consisting of mineral grains, rock fragments and calcareous debris, cemented by calcium carbonate. It is formed only in the intertidal zone or spray zone and occurs in thin beds, more often as patches, dipping seaward at 5–15 degree angles.

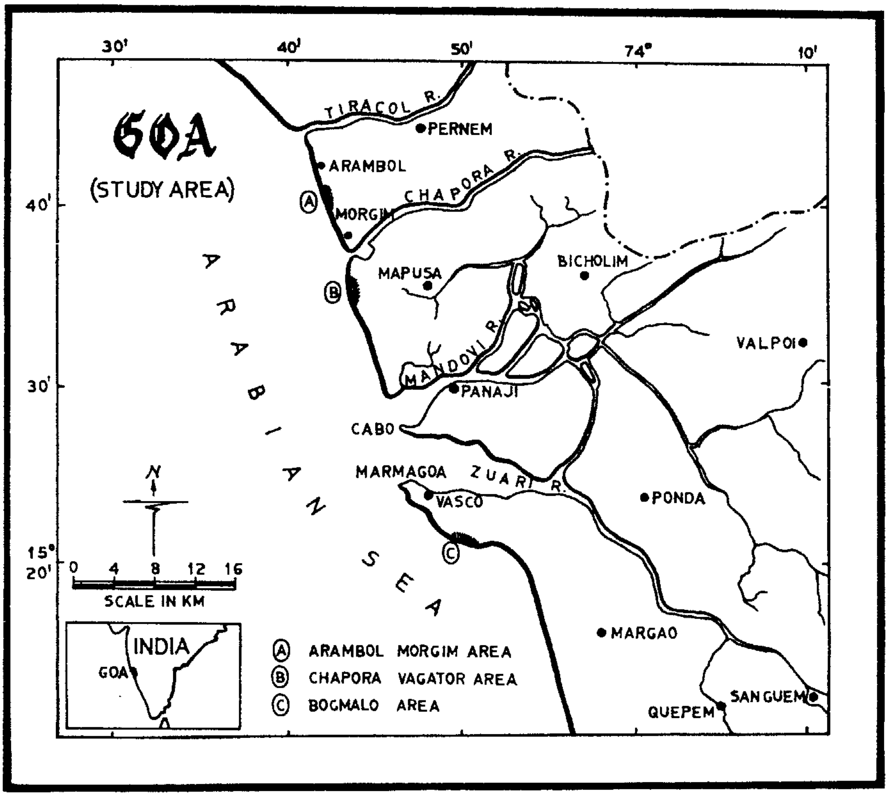
Beach rock is also described as a calcarenite composed dominantly of wave-worked shell debris, but in some places it is foraminiferal or oolitic, having mixed aragonite and calcite and inorganically cemented under conditions of intertidal exposure with an aragonite cement that rapidly inverts to calcite (Ginsberg 1953 *a*, 1953 *b*). According to Russell (1962) it is 'quartz sand, coral rubble, basalt boulders, bottle caps or something else'. but bonded exclusively by calcium carbonate and originated along the water table. Cay sandstone is synonymous with beach rock, but it differs from that in being formed from coral sand near the base of coral reefs and extending to above high tide.

PRESENT MATERIAL

The best exposures/patches of beach rock are found at Morgim-Arambol beach near Mandrem creek, Chapora-Vagator, and Bogmalo beaches along the Goa coast (*see* Map).

Morgim-Arambol area

Beach sandstone is exposed in the ravine (Mandrem river) cutting. It extends for about 125 feet having a width of 10 feet near the dunes. During high tide this area gets submerged as a result of inflow of sea water, thus alternately, it gets soaked with salt and fresh water. The weathered surface is whitish with crusts of Pelagosite. The beach rock here overlies the conglo-



Map of Goa showing the localities of beach rock exposures : A, Morgim-Arambol beach; B, Chapora-Vagator beach and; C, Bogmalo beach

merate which grades into pebbly sandstone, the pebbles look like phenocrysts. This sandstone is overlain by indurated brownish coloured eolianite and loose dune sand.

Lithology : The rock is composed primarily of very coarse grained sand (one type of quartz being white and transparent and the other less so, but coated with a thin film of iron oxide), with very few grains of laterite, tourmaline, quartzite, foraminifera and recrystallized tiny calcite crystals (dog tooth spar). The eolianite is composed of fine grained, angular to subangular to rounded, transparent quartz, and iron oxide stained subtransparent quartz both held together by highly ferruginous calcareous cement. The forminiferal content is very meagre but shelly material seems to be practically absent.

Chapora-Vagator area

A big slab of beach rock consisting of layered coquina and calcareous breccia is noticed at the beach level here (Pl. I, Fig. 1). At 50 feet southward, it is found to be overlying the quartzite. Another rock type, which is massive, blocky, shelly and unsorted with pebbles of laterite, coarse sand and large fragmented shells overlie the above at some places but independently also at others. This is 3 feet thick and is continuous though patchy, and is traceable along the beach for over half a kilometre. At places it is soft and friable while at some others it is very hard. It is overlain by a thin layer (about 1 foot) of sandy soil containing laterite pebbles. During monsoon period the sea water reaches this region and submerges the beach rock (Pl. I, Fig. 2).

Lithology—This is an indurated light brown, unsorted, massive rock type. It is chiefly composed of fragmented as well as whole embryonic gastropods and pelecypods, grains and pebbles of laterite, with subangular to subrounded quartz sand and heavy, minerals, fragments of echinoid spines, encrusted and recrystallized calcite and a very small percentage of foraminifera. It shows signs of transport and solution resulting in the destruction of considerable microfauna.

Bogmalo area

Here, the beach rock occurs as a thin ledge of about 1-2 feet thick overlying the conglomerate layer (comprising cobbles of laterite and dyke rock) which appears to be dipping towards the sea. The bed though patchy is found at 5-15 feet height above sea level and is overlain by a compact sandy soil. At places where there is excavation into the basement rock (chlorite schist dipping at 25°–40°) the ground water is seen trickling down along the joint planes (Pl. II, Figs. 3, 4)

The beach rock here is composed of water-worm sand, fragmented shells, foraminifera, ostracods, bryozoa and other minor types of faunal parts with laterite and limonite pebbles and traces of other minerals, all held together by a calcareous cement (Table I). Most of the quartz grains were stained pinkish due to iron oxide, while others are transparent, constituting about 65 per cent of the material. The grain size of the mineral and fragmentary shell constituents varies from very coarse to very fine sized sands. At places, calcified roots of palm trees are preserved only in single or clustered form without any woody matter present in it (Pl. II, Fig. 4). It is quite hard and compact; it can be broken only with the use of a hammer.

The beach rock from Bogmalo is the best developed and very characteristic in its lithology and fossil assemblage, hence a detailed investigation is undertaken and the result presented below.

Microfaunal assemblage

The foraminifera and other associated microfauna is separated in the usual manner and examined under the microscope. It is noticed that the major constituents of the foraminifera are rotalids and miliolids, any other forms present being very rare and secondary. In addition, there appears whole and fragmented ostracods, bits of corals, internodes of fragmented chielostomatous bryozoa, fish teeth, calcareous worm tubes and the like (Table II). However, the major component of the contained fauna is the fragmented shells of pelecypods and, to some extent, of gastropods.

FIGS. 1–2. Beach rock exposures at Chapora-Vagator and Bogmalo beaches: 1, beach sandstone at the beach, Chapora-Vagator beach; 2, shelly beach rock, Bogmalo beach.

Ammonia beccari and its variants, *Elphidium excavatum, E. crispum, Quinqueloculina seminulum, Miliammina fusca* are very characteristic of beach subfacies and turbulent zone in the littoral facies. They are also found in the estuarine shallow water (brackish water) regions.

FIGS. 3–4. Beach rock exposure at Chapora-Vagator and Bogmalo beaches:
3, beach sandstone exposed in a cliff at Bogmalo beach;
4, calcified tubes of palm roots, Bogmalo beach.

Ammonia beccari (Linné) is abundant in this material. It is characteristic of 5–60 fathom depth and it can tolerate a temperature range of 18–25°C but is sometimes capable of withstanding up to 31°C. Hence it is very commonly found in almost all the beach deposits of the tropical, subtropical, and even transitional waters of the world. Though it is common in saline waters it is tolerant to brackish and estuarine conditions also.

Quinqueloculina venusta, Spiroloculina excavata, Elphidium crispum and *E. advena* are all widely distributed, cosmopolitan, shallow water shelf species. *Ammonia papillosus, Spiroloculina excavata* are typical Indo-Pacific forms. *Amphistegina* sp. is fairly abundant in our sample which is indicative of shallow water or nearness up-slope of shallow water region. It is also lagoonal.

Eponides repandus and *Triloculina tricarinata* are also shallow water forms. *Spiroloculina indica* is a typical Arabian Sea species and was first described from the Karachi sands and again in the Juhu and Bhogat sands (Bhatia 1956). Similarly, *Elphidium indicum* which is described from the Bombay coast is also found here. However, it is rare in this material.

Ammonia beccari seems to be the most predominant species in the foraminiferal assemlage and, therefore, it may be deduced that the environmental conditions of deposition of this material presupposes beach and/or estuarine condition.

TABLE I

Mineralogic and faunal constituents of the beach rock

CONSTITUENTS	MORGIM-ARAMBOL AREA			CHAPORA-VAGATOR AREA			BOGMALO AREA		
	PERCENTAGE								
SAMPLES →	1	2	3	1	2	3	1	2	3
MINERALS									
QUARTZ	75	74	77	40	34	35	50	57	50
FELSPAR, PHLOGOPHITE, CHLORITE, EPIDOTE	2	5	3	2	5	4	3	2	3
TOURMALINE, TREMOLITE, ACTINOLITE, RUTILE	3	2	4	2	3	4	7	3	4
MAGNETITE, ILMENITE	3	4	2	8	2	6	2	3	2
LATERITE, LIMONITE	3	2	2	8	4	10	3	4	2
ROCK PIECES	4	2	3	5	3	4	2	2	3
FAUNA									
SHELL FRAGMENTS	5	3	4	27	36	28	20	15	20
FORAMINIFERA	3	5	3	4	8	6	10	8	10
OTHER MICROFOSSILS	2	3	2	4	5	3	3	6	6

DISCUSSION

Generally the beach sands and particularly the calcareous sands in the intertidal zone of the warmer seas tend to become cemented together very rapidly a few feet beneath the loose surface of the beach. The resultant beach rock is characterized by unsorted mixture of sand, pebbles, shell fragments, microfauna, and at times some wood fragments—all cemented together by calcium carbonate. It is an indicator of former coastline and its discovery in ancient rocks is very useful. It is very widespread in the warmer regions including tiny atolls. Jukes (Kent 1893) records the occurrence of nests of turtles' eggs in the beach rock of Raine's island in the Great Barrier Reef of Australia; similarly certain

TABLE II

Foraminifera and other microfauna in the faunal assemblage of the beach rock

MICROFAUNAL CONSTITUENTS ↓ SAMPLES →	BOGMALO AREA PERCENTAGE 1	2	3
AMMONIA BECCARI (LINNÉ) A. BECCARI AND VARIANTS A. PAPILLOSUS (BRADY)	62	60	67
ELPHIDIUM CRISPUM (LINNÉ) E. INDICUM CUSHMAN E. ADVENA (CUSHMAN) E. EXCAVATUM (TERQUEM)	9	8	12
QUINQUELOCULINA SEMINULUM (LINNÉ) Q. VENUSTA KARRER SPIROLOCULINA INDICA CUSHMAN AND TODD S. EXCAVATA D'ORBIGNY TRILOCULINA TRICARINATA D'ORBIGNY T. TERQUEMIANA (BRADY) MILLIAMMINA FUSCA (BRADY)	20	25	14
EPONIDES REPANDUS (FICHTEL AND MOLL)	3	2	4
AMPHISTEGINA SP.	6	5	3
HEMICYTHERE (?) CALIFORNIENSIS	6	5	3
CHILOSTOMATOUS BRYOZOAN FRAGMENTS (ERECT, JOINTED, ZOOARIUM INTERNODE FRAGMENT SHOWING POSITIONS OF OPESIA)	3	5	7
ECHINOID SPINE — FRAGMENTS FISH TOOTH CALCAREOUS WORM TUBES EMBRYONIC BARNACLE SHELLS	4	5	2
GASTROPOD (EMBRYONIC) FORMS & FRAGMENTS	12	15	8
PELECYPOD SHELL (FRAGMENTS)	75	70	80

mid-twentieth century 'artifacts' were found enclosed (Emery and Cox 1956) which suggests that it is formed rapidly.

A physical concentration of the contained fauna by waves and current action means their abundant presence in the beach sediment. Foraminifera dominate the microfaunal assemblage. The open sea species, if any, occur at low frequencies and their presence is the result of transport by waves, currents and spray. The open sea species are, however, absent in this material. Most of these species show signs of solution, wear and tear due to abrasion, transport, wave and current action (Table III). The calcareous cement is aragonite which rapidly inverts to calcite (Ginsberg 1953*b*). The cementing material is partly derived by supersaturated sea water soaking through every pore space and partially derived from the dissolution of some of the contained fauna (Russell and McIntire 1965), and finally exposed to heating and evaporation in the sun. This may perhaps be one of the reasons for the total absence of planktonic foraminifera. Nearly 40 per cent of even the thick-shelled, hardy foraminifera like *Ammonia beccari* and some miliolids, which are filled with iron oxide, act as solid grains and thin out and thus show the severe action of energy effects of transport and also solution. In fact, some of the porous limestones (Drewite) found in the intertidal zones of the warmer latitudes (in Red Sea, Crossland 1905 ; in Tahiti, Crossland 1928) are similarly formed.

TABLE III

Wear and tear effect in the transport and energy factor in Ammonia beccari *(Linné) and variants in a given fraction of the sample*

Ammonia Beccari (Linné) and variants ↓ Samples→	In one gram sediment								
	Morgim-arambol area			Chapora-vagator area			Bogmalo area		
	PERCENTAGE								
	1	2	3	1	2	3	1	2	3
In good condition	80	85	73	60	69	70	72	64	79
½ Broken	15	8	12	22	19	16	21	20	15
¾ Broken	3	4	11	7	5	4	4	8	4
in traces	2	3	4	11	7	10	3	8	2

It is very characteristic that, in the case of beach rock, the outer band is 'oldest' and occurs exposed at higher elevations and farther from the sea level while the 'younger' bands are underlaid and extend seaward.

ORIGIN

The process of cementation of beach rock is discussed from the time of Darwin (1889), Sewell (1935), Ginsberg (1953) Russell (1960), Russell and McIntire (1965).

Originally, it was proposed that the cementation of beach rock took place as a result of alternate moistening and drying through the action of recurring tides and waves along the shore and deposition of calcium carbonate in the pore spaces (Dana 1875). Branner (1904) proposed that the warm sea water aerated by wave action caused precipitation of calcium carbonate to form beach sandstone. However, Gardiner (1930) and Young (1930) advocated that precipitation of calcareous cement took place when sea water supersaturated with lime met fresh water (derived either from rain water, streams or ground water). During the process of precipitation of calcium carbonate in the formation of beach rock, the role played by bacteria like denitrifying *Pseudomonas caties* and ammonifying *Vibrios* are considered and referred to in the work of Drew (1914), Lipman (1924), Murray and Irvine (1905) and Vaughan (1924) ; however, Van Tuyl (1916) and Mawson (1929) believe that algae is responsible for the deposition of $CaCO_3$ (while utilizing the dissolved carbon dioxide and causing precipitation).

It is evident from several analyses (Russell and McIntire 1965), that cementation is the end product in the zone of water table migration and not of percolating sea water and critical control is the ground water evaporation, inorganic precipitation and optimum temperature under the beach and inland. The beach rock is not strictly a marine feature, hence the sea water temperature is not critical in its initial cementation. The process of cementation is chiefly inorganic and hence not related to bacterial, algal or other organic activities. It is further observed that the incipient beach rock after initial exposure to atmospheric and other marine agencies gets a second stage of bonding by calcite. Otherwise, under the powerful erosive action of waves, the thin bands break up, drift, and even get pulverised into original constituents and redeposited as beach material.

Eustatic Changes

The beach rock is formed more or less within the tidal range or the spray zone. Therefore, if it is found at higher or lower levels, it is deduced that some sort of a vertical movement must have taken place since its formation. In Madh island, near Bombay, and in Goa, the beach rock is found at a high elevation and shows signs of weathering. This indicates sea-level (eustatic) movement, and implies coastal uplift along the west coast of India.

According to Krishnan (1960) the Panvel flexure, and the presence of several hot springs along a straight line between Ratnagiri and Bombay, indicative of subsequent faulting, are of lower to middle Miocene age. Subsequent uplifts, if any, during the upper-Pleistocene to recent as evidenced by beach rock and other features are not recorded. However, radiometric dating of these beach rocks from different areas along the west coast may throw light on the exact date or age of these formations. However, for the present, it may be stated that the present physical setting on the west coast indicates post middle Miocene age. The authors believe that further investigations of more areas of similar exposures and other evidence on the west coast of India are required for proper understanding of eustatic movement along the west coast of India.

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