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Recent changes in coastal configuration of Henry's Island

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The swampy intertidal zone and part of the backshore of Henry's Island coast of 1969 have now been submerged. Topographic surveys, analysis of textural and palynological character of sediments coupled with time-series analysis of shoreline change show phase-wise erosion. This has resulted in ingression of sea. Modern sands, transported from near coastal seabed, are being deposited over the ancient clayey silt bed depending on retreat of high water line and relief. The shoreline has been retreated by about 450 m to 1 km. Pollen of *Liliceae*, *Pteris*, *Microthyriod*, *Excoecaria* and *Rhizophora* in the subsurface sediments indicate the swampy nature of the earlier coast.

Keywords: Erosion, palynology, relief, shoreline change, sedimentation.

THE coast of Henry's Island, West Bengal, extending from Saptamukhi River in the east to Bakkhali River in the west, is about 3 km along north-northeast to south-southwest trend. Both the Saptamukhi River and Bakkhali River are tidal creeks only and do not discharge considerable amount of freshwater and sediment. The Island is part of the Hugli estuarine system and characterized by semidiurnal meso- to macro-tidal environment. Numerous tidal creeks have dissected the land mass into many smaller islands. There existed a low energy, swampy intertidal zone in 1969 and there was dense forest in the backshore area (SOI toposheet) with clayey silt sediment cover. The present study reveals that the erstwhile coast as well as part of the backshore have now been submerged. Modern sands are being deposited over the ancient clayey silt sediment transforming the swampy intertidal zone into a sandy beach.

This area is almost unchartered. Not much information is available regarding the river discharge and sediment load. The sediments are being deposited on the coast from the near coastal seabed by tidal water after primarily being discharged by the Ganga River system into the Bay of Bengal[1]. There is no direct input on the coast from the river as such. The present study aims to understand the changes in coastal configuration pattern over the last 40 years.

Detailed field work and beach profiling have been carried out along the coast of Henry's Island during 2011–12 to study the geomorphic features and sediment character of the area. High water line (HWL) has been demarcated. Topographic survey and beach profiling have been done with the help of theodolite and auto level along nine transacts perpendicular to the coastline with an interval of about 300–500 m between the profiles. The interval of the profiles was drawn depending upon the geomorphic features. The survey was done from about 0.5 m water depth up to 1 km landward. In some sectors, surveying was restricted to less than 1 km due to inaccessibility. Profiling has been done connecting R.L. from the benchmark (2.6 m; toposheet no. 79C/6, 1969) of Irrigation Inspection Bungalow, Frasergunj. The beach profiling in 2011 has been done to measure the relief and slope of the present coast and also to delineate different units on the present coast vis-à-vis its relief. The topography of the coast has been visualized with the help of relief data. The topographic features along with sediment

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character were assessed to understand the distribution pattern of modern sandy sediments at greater depth. Locations determined by topographic survey are accurate, subject to human error.

LANDSAT images of 1975, 1989 and 2001 have been analysed to understand HWL of those periods. HWL of 2011, determined by field measurements, has been compared with that of SOI toposheet (1969) to calculate net shift of coastline over the last four decades. This was further compared with HWL delineated from LANDSAT images to understand the shoreline fluctuation pattern between periods. Pitting and coring have been done in sandy foreshore to determine the thickness of the sand column overlying the ancient clayey silt. Textural and palynological analyses of the sediment have been conducted in the laboratory. Grain-size parameters were analysed following Folk's classification[2,3]. The palynomorphs were identified following standard procedure given in the literature[4–6].

Study of topographic sheets of 1969 shows that the then intertidal zone was swampy in nature and there was vegetated backshore with clayey-silt sediment base. The erstwhile intertidal zone and part of the backshore have been eroded. The present intertidal zone is part of the then vegetated backshore. In general, the width of the present intertidal zone varies from about 36 to 450 m. In the central sector of the beach, the width is as narrow as 36 m. But at the bank of Bakkhali River confluence which is the westernmost sector of the Henry's Island coast, the width is about 1342 m (around profile E12), where sand spit is connected to the coastline. In general, slope of the beach ranges from 0.13° to 4.2° (Table 1). The widest part of the beach has very gentle slope (0.13°) and the narrowest part of the beach which is in the central part, shows steeper slope (2.53° to 4.2°). Backwash ripples (mostly asymmetric), cross ripple marks (wavelength 12–15 cm, average amplitude 5 cm), longshore bar and runnel have been found on the foreshore. Backwash ripples have been developed on fine sandy areas as a result of backwash of the waves setting up turbulent motion. These low-amplitude (about 2–3 cm) ripples extend parallel to the contours of the beach and usually have high concentration of mica in the troughs and black sands on the crests. There are clay balls in some sectors of the intertidal zone (around 21°34′27.9″N, 88°17′58.4″E and 21°34′31.9″N, 88°18′0.4″E). Average diameter of the clay balls ranges from 2.5 to 7 cm. These clay balls have been transported from a submerged erosion-prone zone in the near coastal water[7].

Table 1. Coastal parameters

Profile no.	Width of beach	Slope angle (degrees)	Highest relief (m)	Relief on HWL (m)
E12	1342	0.13	4.25	3.21
E13	682	0.2	3.79	3.23
E14	450	0.47	4.14	3.7
E15	150	0.9	4.02	2.36
E16	36	4.2	3.93	2.69
E17	–	–	4.29	–
E18	76	2.53	4.5	3.37
E19	203	0.96	4.46	3.41
E20	406	0.46	4.63	3.29

The foreshore has a mature sand dune belt of about 20–160 m width along the coast. The HWL is at the base of the dunes (Figure 1). The sand dunes, as a result of natural processes, are flattened at places and the relief ranges from 3 to 4.63 m (Figure 2). The water level during high tide occasionally crosses 4 m. During field visits, it was observed that water did not overtop or reach the upper part of the dune. Low relief neo-dune belt of about 40 m width has been developed in the western sector. At the confluence of the Saptamukhi River, small size shoals have been developed.

LANDSAT images of 1975, 1989 and 2001 and toposheet (1969) have been studied to delineate the HWL and this was compared with HWL demarcated during fieldworks in 2011 to understand the shoreline change pattern of the area over last 40 years. Details of the imageries are provided in Table 2.

All the images were taken during winter season when the tide remains within 2–3 m. The HWL drawn from the images of different periods are more or less comparable. The study indicated that HWL has shifted landward in different phases (Figure 3). The net landward shift of HWL in the western sector is about 450 m and in the eastern sector up to 1 km. Since 2001, the southwestern sector of the coast has been more or less stable in terms of erosion-accretion and HWL is at the same position. But, the northeastern sector shows substantial erosion. In the northeastern most sector of the Island, divergence of the littoral current caused by perpendicularly oriented shoreline and sand bars at the confluence of Saptamukhi River may have enhanced erosion[7]. Presence of ancient sticky clayey silt with tree stumps and rootlets on the present intertidal zone also signifies erosion in the area. There was substantial erosion in the western face of Bakkhali River confluence zone with deposition in the eastern face, i.e. Henry's Island side[7]. The coast has experienced erosion in different phases. Major part of the erosion was caused by catastrophic events in the seventies. High-amplitude waves of shorter duration during storms, cyclones or tidal surges are responsible for seasonal beach retreat[6]. Besides, other factors such as waves,

Table 2. Details of the imageries

Date	Sensor	Path/row	Spatial resolution (m)
1975/3/28	MSS L1T	148/45	60
1989/1/19	TM L1T	138/45	30
2001/1/4	ETM + L1T	138/45	30

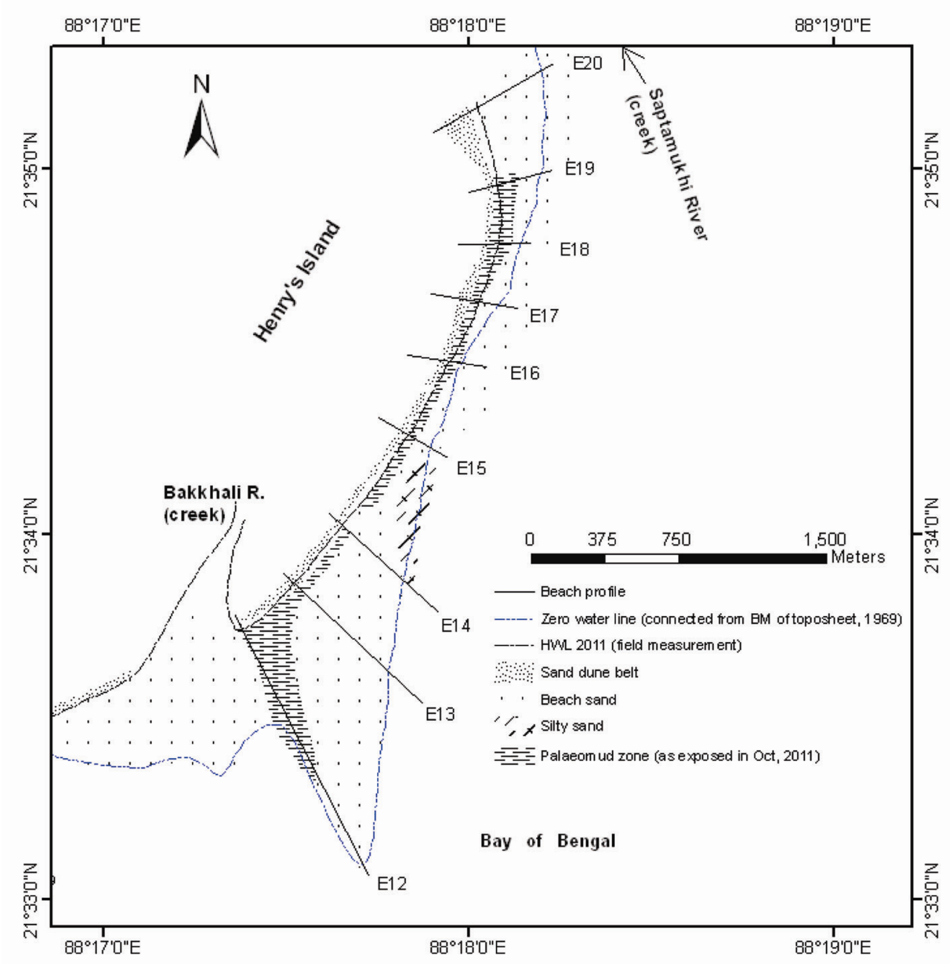

Figure 1. Geomorphological map of the coast.

tides, longshore current, littoral drift and the then relief of the area have also contributed towards the erosion and shoreline retreat in this area[1]. The landward shift of HWL due to erosion has resulted in inundation of ancient clayey silt bed during high water flooding. During flooding, sandy sediments, transported from the near coastal seabed have been deposited on the clayey-silt bed. Both the Bakkhali River and the Saptamukhi River are tidal creeks and they discharge negligible sediment and freshwater in the area. As HWL shifted in phases, the area close to the present coastline was exposed to sedimentation for greater time duration. But the areas of higher relief, still exposed as microcliff-like feature, could be inundated only during maximum flooding. As a result, very little or no sand could be deposited in these zones.

The present intertidal zone is veneered mostly by sandy sediments (sand content 77.9–97.6%). Fine sand is dominant (41.6–78.4%) along with substantial amount of very fine sand (9.1–44.8%). Silt and clay content in the sediments varies from about 2.5% to 10% (Table 3). These are modern sands, transported from near coastal seabed. The near coastal seabed is mostly veneered by fine to very fine sands[7]. Sediments of erstwhile forest and vegetated parts, exposed in some sectors, are mostly clayey silt (sand 11.1%, silt 64.07%, clay 24.7%). Some parts of the present backshore covered with dense vegetation are veneered by sand mixed silty sediments. Modern sand transported from the offshore by the tidal current and sand from the beach plain transported by aeolian action might have been admixed with the silty sediment, thereby resulting in sand-mixed silty sediment cover.

Graphic mean of the sandy sediments varies from 2.8217 to 3.8702φ (indicating dominance of fine to very fine sand) and mean of clayey silt is 6.8817φ (fine silt dominant). Standard deviation varies between 0.2954 and 1.6445, indicating very well to moderately well sorting. It appears that sorting decreases due to mixing of two populations, sand and silt. The standard deviation, on the other hand, of the clayey silt (2.516) indicates very poor sorting. Graphic skewness of the beach sediments (0.1836–0.6879) shows that all are fine skewed to strongly fine skewed, excluding one sediment sample which shows near symmetrical nature (graphic skewness 0.0755). Kurtosis values show that the sediments are mostly leptokurtic

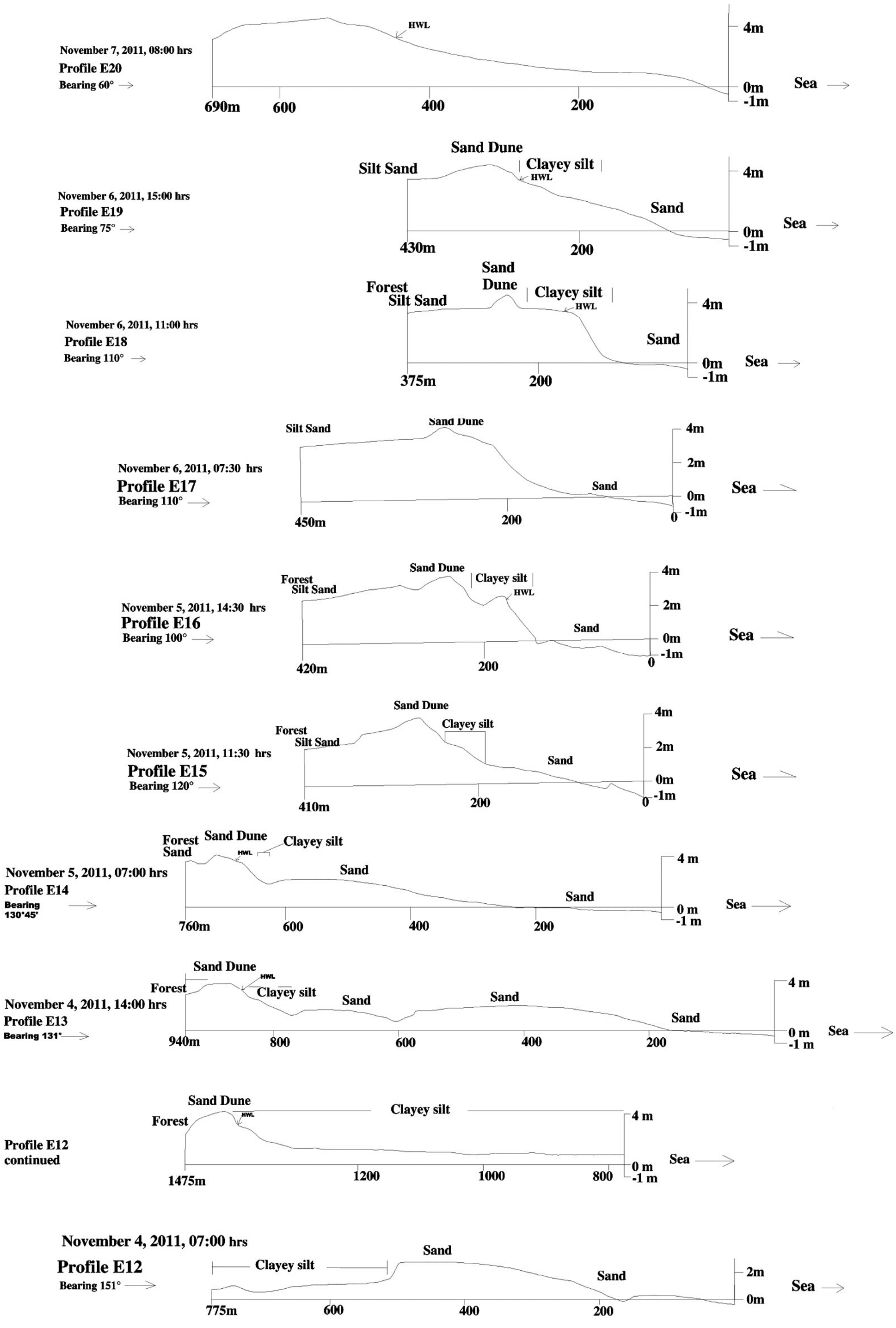

Figure 2. Beach profiles.

to very leptokurtic indicating unimodal/peaked nature of the curves, i.e. the central portion of the curves shows better sorting than the 'tails', though mesokurtic nature (1.0686–1.0196) is observed at places. The sandy sediments are mostly well-sorted, fine-skewed to strongly fine-skewed fine sand with substantial amount of very fine sand, with more or less strongly peaked curves. The dominance of the well-sorted fine to very fine sand indicates a more or less stable nature of the beach in terms of erosion-accretion. This is conformable with the observations

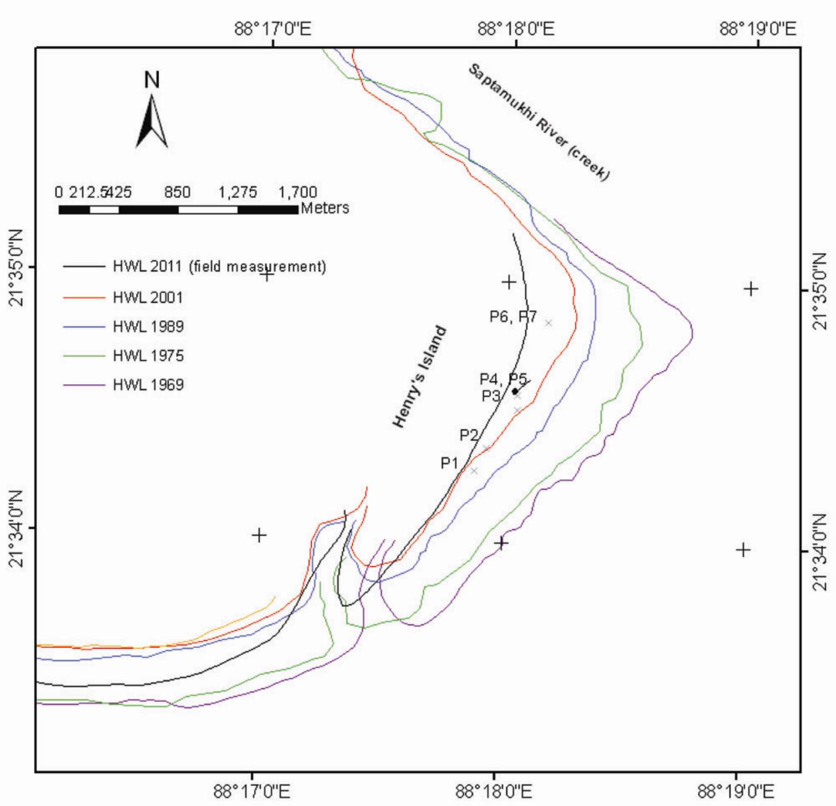

Figure 3. Shoreline fluctuation pattern.

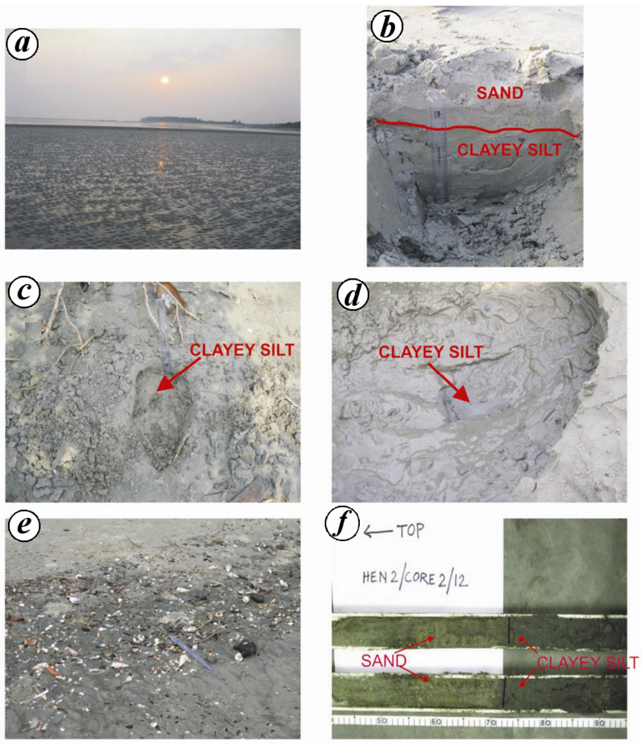

Figure 4. Different features of the intertidal zone in Henry's Island. ***a***, Wide and flat beach at the confluence of Saptamukhi River. ***b–d***, Subsurface clayey layer observed in pits. ***e***, Invertebrates on the intertidal zone. ***f***, Different sediment layers in cores.

from time-series analysis of HWL which also indicate that the southwestern sector of the coast having wide sandy beach is more or less stable since 2001.

The heavy minerals suite consists of mostly muscovite, biotite, pyroxene and amphibole. These heavy minerals are likely to have been transported from the offshore areas along with the sediments and accumulated on the present intertidal zone. The heavy mineral assemblage in the adjoining inner continental shelf shows dominant presence of amphibole and pyroxene[1].

An assemblage of bivalves and gastropods, such as *Telescopium telescopium*, *Thais* sp., *Natica tigrina*, *Oliva* sp., *Architectonica* sp., *Meritrix meritrix*, *Macra violetia*, *Glauconome sculpta*, *Telina* sp. and *Macra* sp. was found on the beach areas of Henry's Island (Figure 4). Most of the shells are fragmented. The biota assemblage indicates that some of them are *in situ* and some of them might have been transported from the near-shore (sublittoral) areas. In the coastal areas of Chandipur, parts of Sagar Island and Bakkhali where some sectors of the beach are muddy, occurrence of *G. sculpta* has been reported[8]. Possibly, the *in situ* biota which characteristically live in swampy areas, are the threatened taxa as they cannot survive in the sandy beaches. The coast is experiencing modern sedimentation and sands from the near-shore seabed are being transported and deposited on the beaches.

Table 3. Grain size and statistical parameters of sediments in the Henry's Island coast

Sample no.	Longitude	Latitude	Medium to coarse sand (%)	Fine sand (%)	Very fine sand (%)	Total sand (%)	Silt (%)	Clay (%)	Nomenclature	Graphic mean	Standard deviation	Graphic skewness	Graphic kurtosis
3/Hen	88.30503	21.58358	0.650175183	48.9474334	44.89295036	94.49055894			Sand	3.1562	0.4568	0.4145	1.0196
11/Hen	88.30089	21.57225	0.275622494	56.35820965	40.49834656	97.13217871			Sand	3.071	0.3564	0.4154	1.168
14/Hen	88.30011	21.57553	5.849739155	70.52934157	17.84201926	94.22109999			Sand	2.8533	0.5332	0.0755	2.3545
15/Hen	88.30147	21.57828	–	–	–	11.14766	64.0769	24.77545	Clayey-silt	6.8817	2.516	0.1836	1.3341
16/Hen	89.30147	22.57828	3.00062424	78.48506752	9.162860992	90.64855275			Sand	2.8217	0.7611	0.285	4.369
17/Hen	88.30489	21.58681	0.719833255	58.17913292	37.78132646	96.68029264			Sand	3.0449	0.3974	0.3235	1.2139
18/Hen	88.30519	21.59103	1.403919039	41.6526893	42.51632933	85.57293767			Sand	3.2747	0.5776	0.4585	1.5067
19/Hen	88.30394	21.58033	1.066348689	60.28507069	34.3339107	95.68533008			Sand	3.0442	0.4294	0.3298	1.2468
22/Hen	88.29544	21.56883	0.957271867	52.37924625	42.79060367	96.12712178			Sand	3.1075	0.4397	0.3718	1.0686
23/Hen	88.29617	21.56947	4.453314	48.36537964	25.0985803	77.91727393	18.4616	0.753534	Sand	3.8702	1.6445	0.6668	2.6234
28/Hen	88.29592	21.56381	0.407737343	72.24634771	24.98797856	97.64206362			Sand	2.9801	0.3288	0.2761	1.8905
29/Hen	88.29831	21.56189	0.470915901	62.40195922	32.96123187	95.83410699			Sand	3.0307	0.3676	0.3623	1.3886
31/Hen	88.30056	21.56994	0.607614498	51.67820379	27.20567575	79.49149404			Sand	3.3728	0.7942	0.6879	1.4004
33/Hen	88.29	21.56728	0.692545702	70.54067711	24.9136481	96.14687091			Sand	2.9993	0.349	0.3538	1.9156
34/Hen	88.28967	21.56769	0.210730644	59.30261674	37.88764135	97.40098873			Sand	3.0687	0.2954	0.4769	1.169

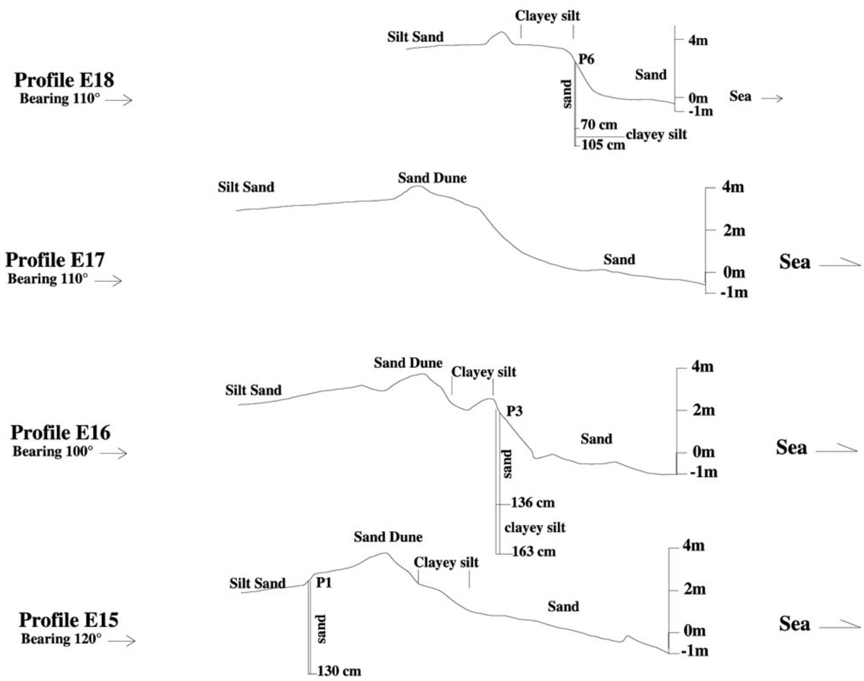

Figure 5. Few pitting/coring locations.

Table 4. Names of taxa found in cores

Taxon	Habitat indication
Excoecaria, *Rhizophora*, *Sonneratia*	Mangrove
Nymphaceae, *Liliceae* (monosulcate), *Pteris* (fern spore), fungal spore, fungal hyphae, *Typha*	Terrestrial plants of humid, swampy condition
Acritarch (spiny wall), micro-foraminifera (cf. *Ammonia*)	Marine influence

The relief of the ancient coast was very low; as low as 1.2 m at about 1 km landward from the then shoreline. The topography of the ancient backshore was undulating with highs still exposed as microcliff-like feature. The present relief of the area has been raised due to deposition of sand. The erstwhile relief has been determined by subtracting the sand column. Height of the ancient clayey silt bed, occurring at the surface as microcliff-like feature in some sectors of the present intertidal zone, is 3.67 m around profile E17 and 2.96 m around profile E12. Modern sands, mostly brought in by the tidal water, are being deposited over the ancient clayey silt bed of the present intertidal zone. Sand accumulation started only after tidal water could inundate the area during high tide. The highs were inundated only during peak high tide when water level reached its maximum. Further retreat of LWL might have caused the proximity of these highs close to seawater. Sand accumulation is not uniform along the coast as revealed from pitting and coring in seven locations in the foreshore. The lower relief areas were subject to inundation for a greater time period, accumulating more sand. Average wave height of the area[7] is about 1.2 m. Percolation of run-up water through clayey base into the intertidal zone is almost negligible. Consequently, there is almost as much of water in the backwash of this muddy zone as in the run-up resulting in the deposition of sand entirely over the muddy zone by the low-amplitude waves of longer duration.

In two of the seven pits (P1 and P2), ancient clayey silt layer underlying the sand layer could not be found even up to 130 cm depth and in the remaining five pits the thickness of the sand column overlying ancient clayey silt varied from pit to pit (136 cm at P3, 13 cm at P4, 30 cm at P5, 70 cm at P6 and 56 cm at P7). P1 and P2 were basically from an erstwhile small canal of forest area, which was favourable domain for accumulation of more sand resulting in the deposition of very thick sand column. HWL reached the zone around P3 in 2001 (Figure 5). Assuming a uniform shifting of HWL between two successive periods, it reached P6 about 4 years after P3, i.e. around 2005 (as calculated from shoreline fluctuation map). The domain around P4 and P5 is between 2001 and 2011 HWL. Assuming a uniform shifting over the last 10 years, the HWL might have reached this domain at around 2006. The then relief of surface of P3 was 1.2 m and that of P6 was 2.6 m. The relief of P6 was 1.4 cm higher than P3. Due to the deposition of sand over ancient clayey silt bed, the present relief of surface of P3 is 2.6 m and that of P6 is 3.3 m. There is more accumulation of sand at P6 than that of P3. Sand could be accumulated

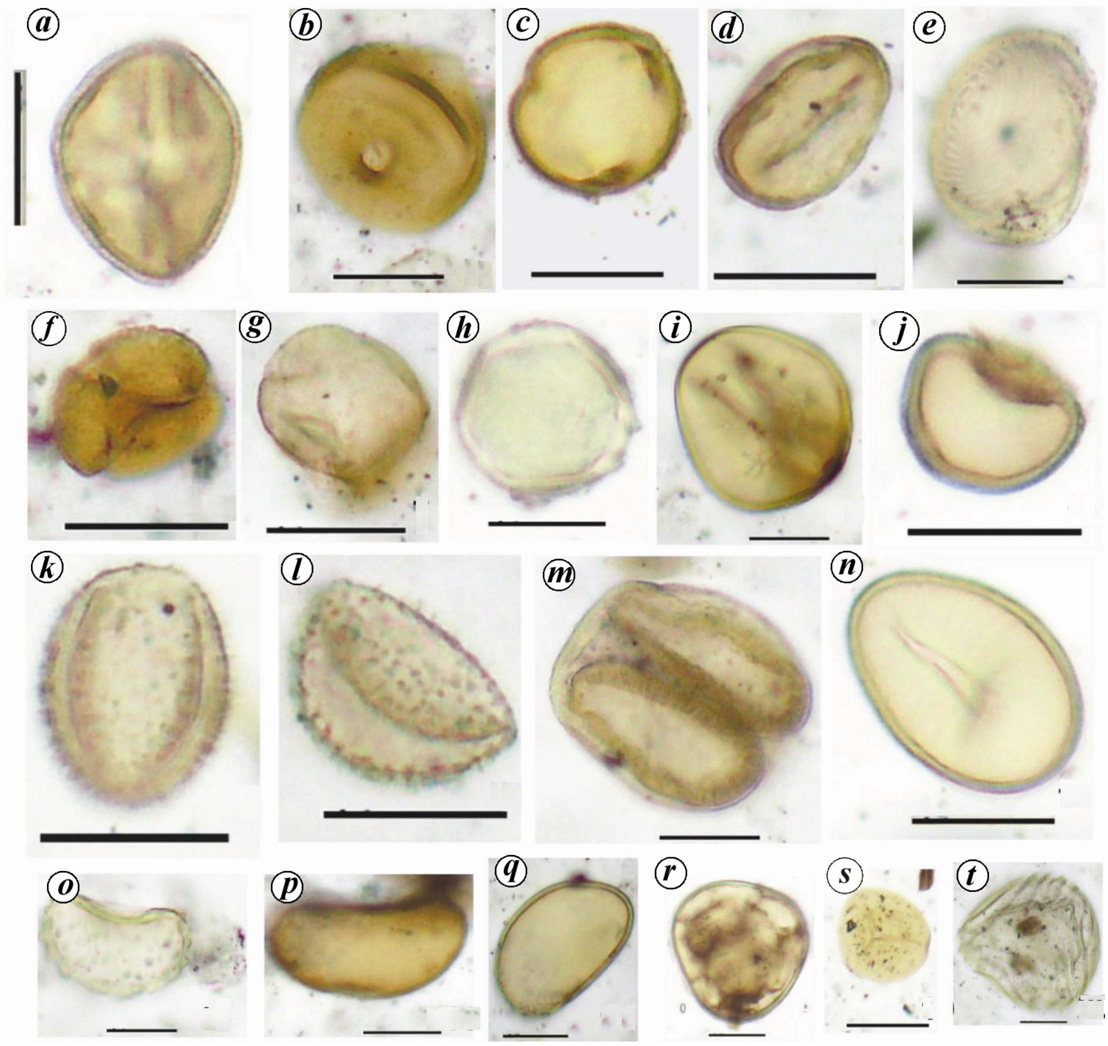

Figure 6. Pollen (***a–n***) and cryptogamic spores (***o–t***) under light microscope. ***a***, *Rhizophora*; ***b***, *Sonneratia*; ***c***, ***d***, *Excoecaria*; ***e***, *Bignoniaceae*; ***f***, *Shorea*; ***g–i***, Unidentified; ***j***, *Cyperaceae*; ***k***, ***l***, Nuphar; ***m***, *Pinus*; ***n***, Chlorophyton; ***o–q***, Monolete spore; ***r–t***, Trilete spore. Scale bar = 10 µm.

around P6 since about last 6–7 years (from 2005), whereas sands are getting deposited around P3 since more than last 10 years (from 2001). In addition, the relief of P6 was higher than P3. Because of higher relief and relatively less duration of inundation around P6, about 70 cm less thick sand layer could be accumulated there compared to P3. Relief of present surface of P4 and P5 location (ancient clayey silt layer at 13 and 30 cm subsurface respectively) is about 3.5 m and sand started accumulating since last 5–6 years (from 2006), resulting in a thin sand column compared to P3 and P6. Though the HWL reached the domain around P4, P5 and P6 during the same time-period, i.e. around 2005–06, accumulation of sand is more in P6 (70 cm) relative to P4 (13 cm) and P5 (30 cm), because the then relief of P6 was less by 2 m compared to P4 and P5 and the zone around P6 was inundated for greater duration. Moreover, the divergence of littoral current has resulted in deposition of more offshore sediments around P6. Besides, other factors like amplitude and period of waves of surf zone have also contributed towards onshore migration and accumulation of offshore sands during different phases and seasons to constitute a sandy beach.

Two cores (P3, up to 163 cm depth and P6, up to 105 cm depth) contained sand in the upper part and clayey silt in the lower part. The clayey-silt layers were sub-sampled at 5 cm intervals and processed for palynological studies at the Birbal Sahni Institute of Palaeobotany, Lucknow. The pollen content in all the samples was low.

The top surface of ancient clayey-silt layer is 136 cm below the present level in P3. The overall frequency of spores and pollen in the bottom-most sequence (160–163 cm) of P3 indicates less vegetation and an anoxic estuarine condition. Occurrence of genera like (Chlorophyton) *Liliceae*, *Pteris*, *Microthyriod*, *Excoecaria* and *Rhizophora* (Figure 6) indicates that the forest was covered by terrestrial herbs, fern and fungi, including mangroves (Table 4). In the upper part (151–154 cm below surface level) mangrove pollen reduced in number, indicating onset of erosion and disappearance of mangroves.

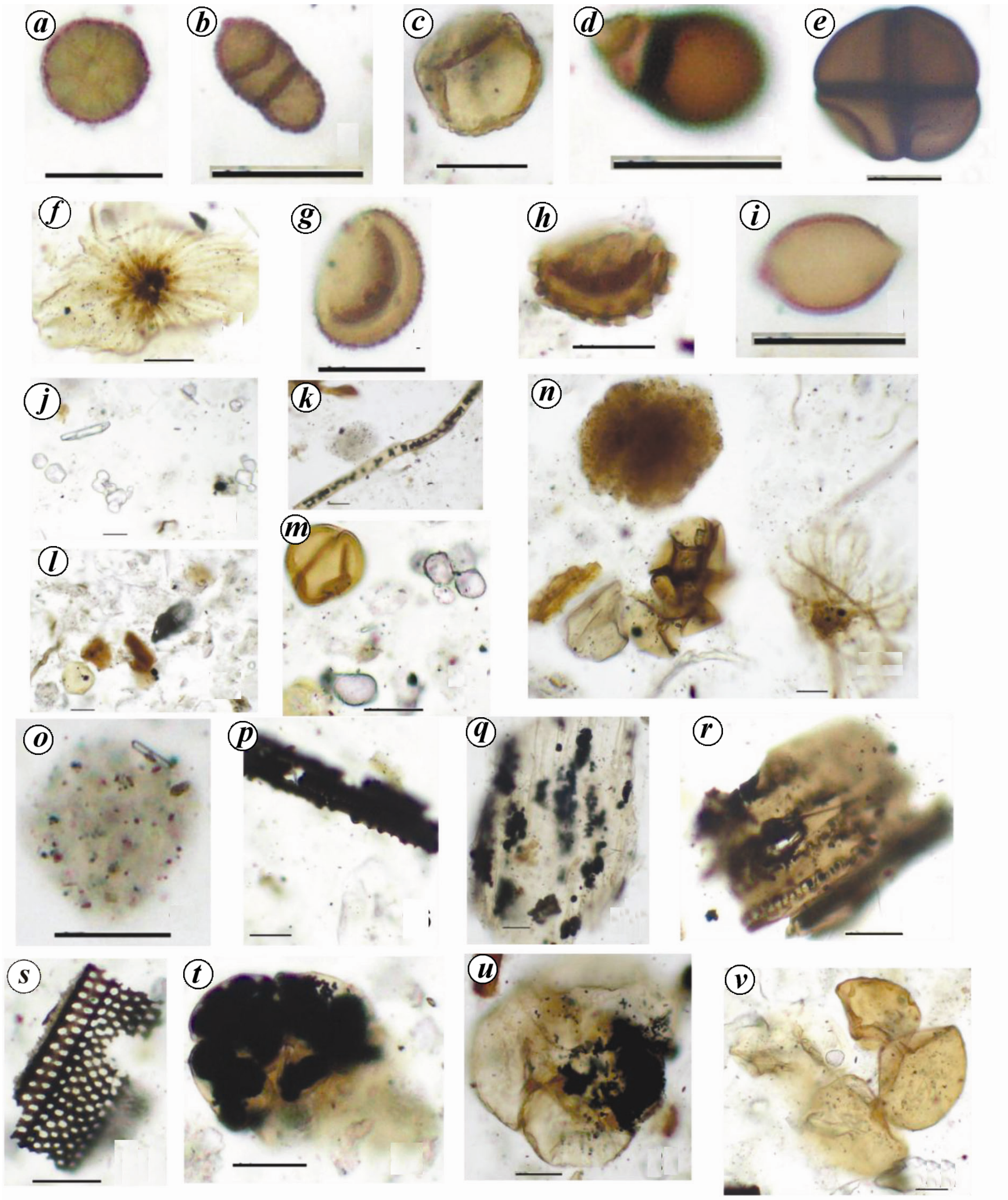

Figure 7. Algal/fungal spores (***a–i***) and other palynomorphs (***j–v***) under light microscope. ***a–e***, Fungal spore (ascospores); ***f***, *Microthyriod* fungal body; ***g***, ***h***, Algal spore; ***i***, Ascospore; ***j***, Rounded mineral debris; ***k***, Fungal filament with trapped pyrite crystals; ***l***, Heterogeneous debris; ***m***, *Excoecaria* pollen; ***n***, Ammonia foraminifera lining, *Microthyroid* body; ***o***, Rounded debris with inclusions; ***p–r***, Leaf epidermal fragments of grass with pyrite crystals; ***s***, Trachied (vascular fragment); ***t***, ***u***, Ammonia foraminifera lining with pyrite crystals; ***v***, Ammonia foraminifera lining. Scale bar = 10 μm.

Further upward (143–146 cm below surface level), vegetation decreased and swampy anoxic environment prevailed, as evident from occurrence of freshwater aquatic plant, fungi and ferns. The same environment continued up to 136 cm below surface level. After that accumulation of sand started. At 136 cm depth a marine form, acritarch, is observed. Few Nymphaceae in the sand indicate that there was stagnant water body in the nearby areas.

The entire clayey-silt sequence of P6 represents a low-energy, swampy deposit with cosmopolitan herbs and ferns. Traces of Cyperaceae, Thecamoeba, Poaceae, fungal spores, pyritized tissues (Figure 7) and algal cyst (at 102–105 cm depth) indicate presence of sparse vegetation in the area. Few cosmopolitan ferns, Brassicaceae, plant tissues were observed at 86–89 cm below surface. Here few marine forms such as foraminiferal shells were found. Seawater is likely to have reached the area during that time and the marine forms were transported from near-shore areas. It is also significant that here marine forms were observed at about 86 cm below surface, whereas at P3, marine forms were observed at about 136 cm below surface. The zone being closer to the coast than P6, was inundated much earlier than P6. Few low-salinity mangrove pollen (*Sonneratia*) in the next overlying sequence (at 78–81 cm below surface) of P6 indicate low-energy, brackish water condition that favoured growth of mangroves.

The present intertidal zone was a part of the mixed forest with clayey-silt bottom sediment. Mangroves as well as other freshwater aquatics, cosmopolitan ferns, herbs and tropical epiphytic fungi existed in a low-energy, swampy condition. These areas were very close to the then agricultural fields. Gradually HWL shifted landward inundating the lower areas first and a high-energy condition prevailed resulting in erosion and disappearance of the mangroves. After that, the obliteration of vegetation and accumulation of sand took place simultaneously.

The erstwhile intertidal zone and part of the backshore has been eroded sector-wise in different phases. Modern sands are being deposited on the present intertidal zone over ancient clayey-silt bed. The faunal assemblage, clay balls, heavy minerals and strays of foraminiferal shells indicate that the sands have been transported from near-coastal seabed. Thickness of deposited sand column varied depending on the time span of inundation and the then relief of the area. Sedimentation of modern sands on the present intertidal zone by marine processes has resulted in the development of a sandy beach, thereby changing the configuration and character of the Henry's Island coast.

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Kachchh Mesozoic domes, western India: study of morphotectono character and evolution

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Kachchh domes are recognized by the oval to elliptical-shaped outcrop patterns marked by outlines of bedding surfaces which invariably dip in the outward directions. The occurrence of domes in rows without having corresponding basin-like features implies that these are not superposed folds resulting due to constriction-type tectonic forces. Further, in spite of the close time–space relationship, the occurrence of domes is exclusively in the Mesozoic rocks on the uplifted block of the fault. The absence of any such rock formation on the other side of the fault rules out the possibility that these are 'drape folds' developed during the adjustment of the sedimentary blanket over the faulted-up edges of the basement blocks. Hinging on the evidence of intrusive plutonic (mafic) masses in the core of some of the domes, we suggest that the structures evolved through diapiric rise of magma bodies causing dome-shaped up-warping (bending) of the pre-existing (Mesozoic) flat-lying sedimentary formations. Linear disposition of domes is explained as due to channellization of magma along the fractures that developed around large-scale crustal doming during the early phase of the Reunion Plume impingement under the Indian Lithosphere.

Keywords: Diapiric folds, domes, evolutionary history, magma bodies.

AMONGST several features that make Kachchh a geomorpho-tectonically unique terrain in western India, the series of blister-like domes amidst virtually undeformed, flat-lying bedded sequences is considered significant. Reference to the dome-like structures exposing Mesozoic sedimentary sequences endowed with records of rich marine and fluvio-marine fossils are found in early literature on Kachchh geology[1–4]. Geological maps showing closed outcrop patterns with outward dipping (quaquaversal) beds have been prepared by some authors[5,6], which help identify these as 'structural domes' and not as mere topographical features. Occurrence of structural domes in Mesozoic sediments and that too in a 'Stable Continental Region' calls for explanation. The present communication is aimed at finding the evolutionary history of the Kachchh domes.

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