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Geoarchaeological Investigations in and Around the Ancient Port Site of Nalasopara: A Preliminary Study

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Abstract: *Western Indian ports have played a vital role in regional and maritime trade right from the ancient period. The present study focuses on the geomorphological investigations carried out at the site of Nalasopara (district Palgarh, Maharashtra) in January 2020 in collaboration with INHCRF, Nashik, and the Institute of Archaeology, University of Warsaw. An auger survey was done across the site in addition to an archaeological survey, metal detector survey, GIS analysis, and UAV mapping. The aim was to assess the nature of subsurface sediments as well as surface features in order to understand paleo-landscape and coastal histories besides knowing the extent of archaeological deposits on which human habitation survived from the Mesolithic to the present period.*

The data presented here points to the destruction of ancient habitation site due to sea level rise as well as the siltation of large depressions. The results also contribute to a preliminary understanding of the paleo coastal environments and coastal histories. The analysis of auger samples of certain key locations helps us to understand long-term site formation processes and hints at sea-level changes that not only destroyed the past records of human occupation of the coastal areas but also acted as a driving force behind settlement abandonment as well as in the formation of newly created coastal hot spots throughout ancient and medieval period.

Keywords: *Nalasopara, Geoarchaeology, costal geomorphology, ancient ports, phytoliths, siltation, micro fossil, particle size analysis, bore hole data, palaeoenvironment*

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Introduction

Western Indian sea ports played a vital role in Early Historic trade and commerce. The ports of Sopara, Kalyan, Chaul, Mandad, etc. are mentioned not only in the Periplus of the Erythraean Sea but also in various cave inscriptions of Maharashtra. The ancient port site of Nalasopara, is located in Vasai taluka, Palghar district, it is one among the chief ports of the Western coast and was known as Suparaka or Supparak (Tripathi and Gaur 1997). It is mentioned in Mahabharata as one of the important places in the Aparanta Region (Bhoir 1990). The ancient port town was situated on a sub-creek that touched the Vasai creek on the south near Nagapura or Naigaon and continued to flow to the north up to the Vaitarana creek at Agashi near Arnala. The sub-creek slowly got silted and consequently, the most ancient port of Konkan became land-locked and defunct (Thosar 2005). Sopara is the only port in Western India from where two major Asokan rock edicts 8th and 9th versions have been found. This indicates that this port was an important link between the coastal area and the plateau area, possibly to trap the resources of the plateau hinterland. This port might have also acted as a center for long-distance trade between Sopara and Southern Arabia, Red Sea, Egypt, and hence it probably became an important trade center at least from the Mauryan Period (Thapar 1996). According to Bhandarkar, Sopara was the headquarters of Sunaparanta (Law 1941). It was also one of the administrative units under the Satavahanas and is mentioned in the inscriptions of Karle, Nashik, Naneghat, and Kanheri (Ray 1994). The Buddhist text (Mahavamsa) mentions this site as a prominent Buddhist Centre (Moray 2007). Archaeological excavations at the stupa site of Sopara that is locally known as Baruda Raja cha Killa were conducted by Bhagwanlal Indraji. The excavations yielded a large stone coffer, jewelry, numerous gold flowers and fragments of a begging bowl, a copper casket, and seven Buddha images and a Maitreya image which belong to the 8th-9th century A.D. A silver coin of Gautamiputra Satakarni was also found from the mound. The VIII rock edict of Asoka was also discovered near Bhatela Lake in Sopara (Indraji 1882). From the nearby Bhuigaon Khurd, fragments of the IX edict were discovered as well (Chakravarti 1956-7). The site was re-excavated by M. M. Qureshi of the Archaeological Survey of India in 1939-40 when several stone lintels and two small stupas were found on the south side of the main stupa in addition to a few sherds of plain glazed ware of the Islamic period (Desai 1981-84). Anwar Munshi (1972) found a number of Satavahana lead coins at Sopara. In 1993, Howell and Sinha (1994) laid four trenches out of which three trenches viz., SPR-1, SPR-3 and SPR-4 were located in Sopara Bhander area and SPR-2 at Kumeti area. The excavations yielded a good repository of cultural material such as lead and copper coins, beads, bone points, and several body sherds of amphora, Black and Red ware, RPW, NBPW, Islamic blue glazed ceramic pieces, brickbats, stone fragments, walls, clay objects, Iron nails, and remains of a Jaina temple. An earthen wall and a fourteen-course stone wall with varying sizes of stone blocks were also encountered during this excavation (*IAR* 1994-95:108).

A copper plate inscription of the Chalukyas of Badami was discovered from the village of Nalasopara. The charter is written in Sanskrit language in southern characters. The record belongs to the reign of Pulakesi II. Dated in Saka 554 (AD 632), it records the grant of the village (Puduka) in Nasika-vishaya to a certain Brahmana (name not clear) belonging to Pingala-sagotra, to defray the expenses for performing the ritual panchamahayajna (*IAR* 2002-03:181-82). Various Arab travelers and geographers make reference to the port of Sopara (Ducène 2016). A Kutchi sea manual belonging to 17th-century talks of a regular cargo trade route through the Bolinj-Sopara creek from Gujarat to Mumbai and Thane. In this century itself, the port stopped functioning due to active siltation that consequently resulted in islands getting fused with the mainland (Arunachalam 2002).

It is clearly evident from the archaeological and literary sources that Sopara remained an important cultural, religious, and economic center for centuries dating from the pre-Asokan period up to the 3rd century A.D. and again from 6th to 13th century A.D., as well as thereafter till 17th Century when Portuguese traded with India (Manvungh 1990, Swamy 2000, Hebalkar 2001, Toshar

2005, Arunachalam 2002, Khandpekar 2006 and Moray 2007). The main cause for the decline of the ancient port of Sopara is not clearly known, however experts think that siltation of the area could be an important factor in its decline (Ghate 1990, Ghate 2007, Tripathi and Gaur 1997 and Arunachalam 2002).

The Site

Nalasopara is located on the Western Indian coast at Vasai Taluka of Palghar district, Maharashtra. The region is of humid zone with summer monsoonal rainfall varying from 1500 to 2500 mm per year, and is frequently affected by monsoonal floods.

Presently, Nalasopara, Gas, and Nirmal lies between the rivers Ulhas and Vaitarna in a fertile deltaic region bounded by tidal flats on the south-east and a flat landscape of fluvial, lacustrine and marine origin on the west (Figure 1). The site is dotted with numerous lakes that are remnants of an active paleo channels that once dissected the landscape in the form of meandering streams flowing with a NE-SW course. These palaeochannels show several episodes of deposition and represent meandering streams separated by in-filled channel deposit. The fertile landscape formed in and around the villages of Sopara, Gas and Nirmal has mixed soil types such as silt, clayey silt, silty clays, and clays. The present landforms have formed over the beach ridges and on the beach rock that has possibly formed during the Holocene period (Abbas 2020, Abbas et al. 2020, Abbas et al. 2021 and Smagur et al. 2020). At several places small patches of black fissured clays are visible. These possibly owe their origin to ponding environments which seem to have resulted from minor avulsion due to sea-level changes or subsidence of delta (Bryant et al. 1995 and Mohrig et al. 2000). Sediments, which were probably deposited by the paleo-channel or by the network of tributaries, form a very fertile land and are considered to be highly suitable for the cultivation of leafy vegetables as well as paddy and certain other crops. At present the tidal flat located towards the south eastern side of the site has a few creeks of 1-2 km length and is engulfing the agricultural land. Studies conducted by Space Applications Centre (ISRO), Ahmedabad, and by Coastal Erosion Directorate, Central Water Commission in 2014 show that the coast near the study area is eroding to stable in nature which is evident from the uprooting of Casuarina trees. Accretion is also observed along with small segments either due to constructional activities or due to bar formations at river/creek opening. Significant depositional bars are found near Nalasopara and around small creeks north of the Vasai creek.

Studies on the western Indian coast reveal that during the Holocene period development of extensive coastal plain took place along the coast possibly in response to a slight lowering of the sea level and the coastal features reveal that during the late Holocene, the Konkan coast was characterized by littoral terraces at different levels and their distribution points towards raised shorelines that could be linked to Holocene sea levels in the area. It lies above the current sea level and occupies a back beach area bordering beaches or banks of the shoreline sectors of tidal inlets and their evolution during the late Holocene Period can be inferred from the relative locations and elevations on the coast (Karlekar 2019). Sea-level fluctuations on the Konkan coast are more or less of a general character as indicated by two/three generations of dune ridges that provide convincing evidence of former shorelines. The farthest dune ridges suggest an early to mid-Holocene period and these terraces are found within the elevation range of 4 to 6 m. Fossil beach ridges are found to occur invariably in front of tidal basins on the Western coast (Karlekar 2001). These sea-level changes were formed mainly due to the configurational changes in the sea and during the late Holocene period this coast was characterized by barrier spits, open inlets and estuaries as well as wide dune systems (fore and back dunes), mangrove swamps, abandoned and rearranged spit bars and littoral terraces. These are found almost everywhere on this coast and are indicative of some degree of reorientation and configurational change in the sea during the late Holocene period. Studies conducted on the western coast also point towards the maturity of estuarine systems during the late Holocene (Karlekar and Rajaguru 2012).

Aims of the Study

The geomorphological study at Sopara was conducted with a hypothesis that the ancient coastal settlements were situated on the most elevated areas of the dynamic landscapes such as levees of paleo-channel, near large and small tanks/lakes (that are actually remnants of paleo-channel network) and on the relict beach dune ridges. Hence the aim was to see the spatial distribution of archaeological site and prepare a detailed map of the archaeological landscape in and around Sopara. The other aim was to investigate the palaeo-geographic conditions and geomorphic development of the site and deduce the relationships between various geomorphic elements and processes and its impact on the ancient settlement pattern. It was also aimed to understand the environmental conditions on the basis of microfossil analysis of sediments.

Methods

Being an ancient port site, most of the archaeological features are buried under thick deposits of silt, sand, and clay, thereby creating encumbrance for a thorough understanding of the archaeological nature of the site. It was therefore necessary to employ various methods for a better understanding of the site. For survey and mapping, advance satellite imageries, aerial photos of the site were obtained by UAV, topographical sheets, geological maps, district resource maps, and Central Ground Water Board Maps, old colonial maps (both British and Portuguese maps) as well as geo-referencing instruments and software were used.

Drone survey was employed at the site as a remote sensing tool. DEM, DSM, Ortho Images, multispectral 5 band images, contour map, etc. acquired during the UAV survey were used for site documentation, mapping, photogrammetry and to detect buried archaeological features. For this survey, fixed-wing UAV was used with a 24 megapixel Sony camera for RGB photography and 5 bands multispectral sensor (Micasense Red Edge Sensor) to acquire multispectral images (Figure 2) green, red, red edge and near-infrared, a blue band for deeper insights into specific issues and composite RGB imagery. The collected data was integrated into QGIS database for analysis.

A manual auger was used at selected points across the ancient site for the collection of environmental and geomorphological samples to understand the stratigraphic sequence of the site, and to map the ancient palaeo-channels/palaeo-creeks at various locations of the site. The aim was to assess the nature of subsurface sediments as well as existing surface features for a better understanding of the formation of palaeo-landscape and coastal histories besides knowing the extent of archaeological deposits of the ancient port site of Nalasopara on which human habitation survived from Mesolithic to the present period. A 30 cm Adelman corer head was used with a 5m shaft for this purpose. About 12 bores were taken (Figure 4) and each coring spot was recorded, described, and mapped in QField, which was then processed in QGIS. Auger samples were collected up to a depth of 3m at regular interval of 20cm-30cm. The retrieved material from each sieve size was weighed and then the specific characteristic of the individual sample such as sediment texture, composition, colour, presence or absence of cultural material was noted. The individual samples were passed through sieves of various sizes, namely, 4.75mm, 2mm, 1mm, 500mic, 250mic, 125mic, 64mic, 31mic at INHCRF Lab. On the basis of characteristic features of the samples retrieved from different depths, were assigned to respective litho units, which were then described and compared with the data of other bore holes. Particle size analysis was conducted at IISc Bangalore (Department of Material Sciences).

Core samples from bore hole location SPR-C and SPR-I were sent to Phytolythic Research Centre, Pune for microfossil analysis to reconstruct the paleo-environment of the site. The sediments were analyzed in the laboratory by using standard methods with removal of carbonates and nitrates followed by heavy density separation (Piperno 1988). Simultaneous extraction of Phytoliths, Diatoms and Sponge spicules was undertaken. Up to 200 Phytoliths; inclusive of other microfossils from each sample were observed and counted so as to generate a quantifiable data. Observations were also made on the physical character of phytoliths at times so as to get an idea about its general preservation condition. The classification used for phytolith analysis is a combination of – phytolith shape, anatomical origin and classification based on grass families. The phytoliths were observed under Olympus research microscope and photomicrographs were taken under 45 x magnifications. These samples were also subjected to calculation of phytolith morphotypes for Climate Index (Ic), Phytolith index (Iph) and Cold / warm ratio (C/W). The various grasses of different subfamilies produce unique shapes, such as Panicoidea produces dumbbell (bilobate) and cross shape phytoliths which represents a warm moist climate. Similarly cold dry climate can be revealed from the trapezoid and rondel phytoliths produced from Festucoidea. While warm dry habitat was represented by the short-saddle shape formed from Chloridoideae. The high Ip index in modern soil represents aridity.

Geomorphological Evolution and Paleo-climate in the Coastal Zones of India- An Overview

Earlier studies on Holocene Sea-level Highs and lows by Agrawal and Kusumgar (1967), Prudhvi Raju et al., (1993) and Banerjee (1993), Achyuthan (1997), Farooqui and Vaz (2000) indicate towards high sea level condition at different points of time in coastal areas. Similarly, different transgressive and regressive phases were documented by Kale and Rajguru (1985), Faroqui and Vaz (2000), Achyuthan and Baker (2002), Gupta (1981), Banerjee and Sen (1987), Sen and Banerjee (1988, 1990 & 2016). Gupta (1977) and Somayajulu et al. (1985) evaluated a transgression phase at 6,000 years on the Saurashtra coast. Bruckner (1989) and Guzder (1975) have concluded that in Konkan the sea level was 1m higher than the present level during 2500 BP. On the basis of dating conducted on gastropod shells, Mathur et al. (2004) concluded an overall regressing trend along the northwest coast from 6000 to 2000 BP, similarly, Rajendran et al., (1989) report transgression between 8000 and 6000 years BP and regression between 5000 to 3000 BP along Kerala coast. Along the southern Tamil Nadu coast, 4 to 5 major transgressions were reported during the Holocene period (Loveson and Rajamanickam, 1988; 2001). Evidence in the form of paleo delta along the East Coast of India shows transgressions events (Vaidyanadhan 1971; Sambasiva Rao, et.al., 1978; Loveson, et al., 1990; Ramasamy, et al., 2006). Recent findings of Holocene sea level curve that has been generated for the East Coast of India by Loveson and Nigam (2019) indicates that the magnitude of high stands is considerably coming down gradually from a high of ~4.0m during 6050 BP to 1.5m at 500 BP respectively.

Evidence related to Holocene sea-level fluctuations along the western Indian coast clearly indicates that around 14,500 years BP the sea was low at 100m depth and rouse to 80 m depth around 12000 years BP showing a rate of approx. 10 m/1000 years which was followed by a still stand for about 2,000 years. From 10000 to 7000 years it rose at a very high rate (approx. 20 m/1000 years) and from 7000 years BP onwards showed minor fluctuations (Nigam et al., 1992; Hashmi et al., 1995). Detailed studies on the western continental shelf of India have revealed a series of submarine terraces at different depths between the outer fringe of the inner shelf and the shelf break, being more common between 11° and 20°N. The terraces are prominent between water depths of 50 and 115 m and occur at six distinct levels. These well-defined, broad, symmetrical submerged sand ridges were found on the middle and the outer shelf 100-200 km offshore and between 75 and 100 m water depth. These ridges are 0.5 to 10 km wide, 1.5 to 18 m high and several tens of km long, with a few kilometers spacing and a trend of NNW-SSE parallel to the shelf edge (Wagle et al., 1994; Wagle and Veerayya 1996). Analysis of feldspars and quartz contents of sand and silt fractions from the western continental shelf indicate that the climate during the Late Pleistocene and early Holocene was arid (Hashmi and Nair 1986). Carbonate content and faunal remains from the coastal Arabian sea also provide evidence of a major environmental change about 13000 yr B.P (Borole et al 1982). Studies have also shown that the Holocene transgression reached its maximum (c. 1m higher) around 2000-2800 BP and deposited beach ridges in the Konkan Coast between Bombay and Goa (Brückner 1989).

In Saurashtra, abandoned cliffs, marine terraces, shore platforms and marine notches along the southern Saurashtra coast have been used to ascertain the magnitude of sea-level changes during the Late Quaternary. The study shows a 6 to 9 m uplift of the coastal fringe which is attributed to the last interglacial corresponding to the Marine Isotopic Stage 5 (MIS-5), whereas a 2m rise is identified during the mid-Holocene (Bhatt and Bhonde 2006). Studies on the Miliolite deposit in the Kathiawar Peninsula show that miliolites that were deposited by the sea during the last interglacial transgression are found up to +4 m above mean sea level. This is confirmed by the dating of other marine accumulation terraces up to this altitude which is also of stage 5e of the oxygen isotope record (c. 125 ka), whereas the dating of marshy soils and marine sands indicates that the Holocene transgression reached its maximum around 5000-6000 BP when sea level was about one meter higher (Brückner 1989). Pollen signatures, paleo-botanical data, and offshore peat deposits on the west coast of India indicate that the mangroves of the southwest coast are essential of the Middle Holocene age (7220-880 yrs BP); this has been well recorded elsewhere, when sea level stabilized. The stability of mangrove development coincides with the Holocene climate optimum (HCO) when Monsoon Asia witnessed heavy precipitation. Since 3500 yrs BP decline of mangroves is witnessed and further degradation at many sites have been attributed to the prevailing arid climate and weakening of monsoon until 1500 yrs BP (Limaye et al., 2013).

Studies indicate that during the last glacial maximum at c. 18000 BP much of the western continental shelf of India was aerially exposed and the coast extended up to the present shelf edge. However, by the beginning of the Holocene, the sea started transgressing the shelf region, interrupted by still stands until it reached the present stage. The radiocarbon dates from the region indicate a major transgression during 8000-9000 BP, which impacted the then-existing luxuriant coastal mangrove vegetation. This transgression event coincided with a strong monsoonal regime, helping deciduous evergreen vegetation to flourish in the mountainous region of the Western Ghats. The strong monsoon lasted until 6000 BP, ending in a cycle of a weak summer monsoon around 3500 BP causing aridity that resulted in the destruction of the coastal mangrove vegetation. The arid climatic conditions were succeeded by a stronger spell of monsoon that also coincided with a phase of marine transgression (4000-2500 BP) that got stabilized during this phase until the present (Rajendran 2013). Similarly, sediment texture, $\delta^{13}C$ values from a core section recovered from the core monsoon zone (CMZ) of central India indicates that from ~11.4 to 9.5 ka BP the region witnessed enhanced Indian Summer Monsoon (ISM) intensity than a gradual stepwise expansion of C_4 plants during ~8.1 and 6.3 ka BP, ~6.3 to 4.7 ka BP, and ~3.0 to 2.0 ka BP suggests a gradual weakening of ISM. The highest $\delta^{13}C$ values (–18.7‰) recorded at ~2.0 ka BP indicates the dominance of C_4 plants suggesting the weakest phase of ISM in the study area. From ~2.0 to 1.6 ka BP expansion of C_3 plants indicates a sudden increase in ISM intensity and subsequently, three different stages of enhanced ISM indicating a more humid phase between ~1.6 and 0.93 ka BP, ~0.76 and 0.42 ka BP, and ~0.28 ka BP to present (Kumar et al 2018). A recent Holocene sea-level curve for the east coast of India shows that from 14800 BP, the sea level rose to the present-day level with significant stages of oscillations including two steep rises that are observed with the rate of 2.06m/100 years and 2.22m/100 years from 14800 to 7200 BP which is intercepted by a standstill period noticed from 9200 to 8100 BP. After 7200 BP, 5 minor fluctuations represented by various magnitudes of transgressions and complimentary regressions up to the recent time have been observed. During the Holocene 0 MSL is recorded around 6850, 3900, 2500, 1500 and 900 BP along the east coast of India (Loveson and Nigam 2019).

Geomorphological Evolution of Nalasopara

In order to assess the geomorphological potential of the site of Sopara, Ghate (1988) conducted a multidisciplinary study and postulated that configurational changes played an important role in changing the coastal landscape of North Konkan. Further, this study also suggested that during 8000 BP the sea level was lower by about 2m than at present and it reached the present level by about 5500 BP; since 5000 BP the sea level has fluctuated within the range of 1-1.5m. The survey conducted by INHCRF and University of Warsaw in the Nalasopara area brought to light about 8 rows of well-defined relict sand dune ridges ranging between 300m wide and 10m high and the 50m wide and 7m high (Figure 3. These ridges are more prominent towards the south-eastern side of the site and run parallel to the present coastline for about 2-3 km. Some of them are occupied by modern settlements and others are being used for agricultural activities. Within these ridges, several undulations are visible towards the stoss side that indicate dune development initiated by wind-blown sand. The longitudinal profile of the Nalasopara area along the shore shows the development of parabolic dunes due to continued transport of sand through blowouts or alternatively, this may be a result of barchanoid relic ridge formation. These relict ridges formed possibly due to active configurational changes, orogenic events/glaciation, and deglaciation or due to isostatic adjustments in the Arabian Sea. The direct evidence of shifting of shoreline is evident in the form of beach ridges as well as sand dune ridges present in the peripheral areas of the site. Several inter-ridge depressions about 100 m to 300m wide are also visible. Some of them are still visible as lakes (possibly remnants of paleo-channels) in the study area. These lakes were modified during the Historical period either for religious purposes or for subsistence. It is quite possible that during the early or mid-Holocene phase these lakes were palaeochannels and were active as western India experienced a wet climate during this period (Singhvi and Kale 2009). During this period the sea level was also higher than the present level (Maurya et al., 2008) and the Little Rann of Kachchh was covered by 2-5 m deep water from 6 ka BP to about 2 ka BP (Gupta 1975).

The explorations conducted by the present team indicate that the ancient settlements were formed on sand dunes, mudflats, on the abandoned channels and levees as well as on relict beach ridges (Figure 11). Ghate (1990) noticed that the paleo-channel is represented by calcareous sandstone of fluvio-marine origin, overlain by about 2 m thick unconsolidated sands, clays, and silt beds which have preserved microliths, weathered potsherds, marine as well as freshwater shells. Sands and silts are affected by post-depositional development of carbonate rhizoconcretions suggesting lowering of sea level after the deposition of silt and clays.

To understand the geomorphological development caused by sea level changes, and the distribution of various geomorphic units in and around Nalasopara, sediment coring was done at the site. This was also done to perceive the nature of subsurface sediments as they would throw light on paleo-landscapes. Coring not only served as an ideal method for collecting the environmental samples but also proved useful in detecting buried habitation soil/archaeological mounds without recourse to geophysical prospection methods. It aided in estimating the thickness of habitation deposit at many places. For sediment coring, a manual sediment corer was employed to collect the geomorphological and Paleo- environmental samples.

The core samples retrieved from twelve different localities in and around Nalasopara suggest that several factors such as transgression and regression of sea level, Aeolian-lacustral-fluvial processes as well as anthropogenic activities have contributed to the geomorphological evolution of this landscape. The data further suggests that most of the ancient occupation is located on the ancient dunes (dunal ridges), whereas the interdunal slacks were used for agricultural activities or have palaeochannels/ creeks filled up with fresh water. The presence of alternating layers of silty sand, sandy silt, clay lenses, beach rock, sandy lenses sometimes cemented/loose/with or without marine shells or with freshwater shells throughout the landscape is indicative of a dynamic landscape that developed during the Holocene Period (Figure 5).

Analysis of the borehole data (Table 1) suggests that marine sediments are present at around 4 m AMSL below the habitation soil/natural soil. The highest point where the bore was taken lies on both sides of the Gass lake (SPR-K and SPR-L, 5-6m AMSL). At point SPR-K, beach rock was encountered at a depth of 3.90m AMSL. All these sediments are indicative of several episodes of the transgression of the sea up to about 4 m AMSL in the past. Alternating marine, anthropogenic and tidal sediments in the samples are indicative of sea engulfing the habitation areas and reoccupation of those areas after the regression of sea. Many a times pottery was found in the Palaeo tidal zones, indicating some of the habitation zones being converted into tidal zones (presence of marine and freshwater shells in silty sediments) in the peripheral areas of the habitation. A similar pattern was also seen at Sanjan (Deo et al. 2011, Rajaguru et al. 2013).

The analysis of the samples indicates that the past environment in and around the study area was very dynamic and continuous sea-level changes have caused lateral transgression and regression phases as well as the development of tidal zones and estuarine environment possibly due to configuration changes in the Mid to Late Holocene Period. These factors were decisive in shaping the development of human cultures at the site. In this context, a study conducted by Nigam (2006) for the western Indian coast shows that by about 10 ka to 9.5 ka BP the sea level was 30-35 m below the present sea level and reached the present level around 5 ka BP, and it continued higher from 4.5 ka BP to 1 ka B.P. This rise in sea level is well represented at the site of Sopara, where the borehole data shows that most of the early Historical habitations formed either on the beach sediments or on the coastal dunes that are located above the present sea level. The samples also indicate pre-early historical sediments show continuous regime change. Data from SPR-H shows that early Historical occupation was formed near the inter-tidal zones. These clayey sediments contain both terrestrial and marine shells along with pottery (Unit VIIb) and lies just above beach sand deposit having lots of marine shells. The layer above VIIb is VIIa and indicates towards local ponding zone. Unit VI (that overlies sub unit VIIa), contains lots of marine shells and pottery and is devoid of freshwater/terrestrial shell pieces, thereby indicating sediments to be of marine origin that indicates transgression of the sea at some point during the Early Historical Period. Formation of dune above this unit VI points towards regression of sea. This unit contains pottery indicating constant interaction of humans with the dynamic landscape of Sopara.

Mid Holocene sediments of SPR-I also indicate fluctuating environment. Unit III has alternating lenses of concretized sand mixed with small freshwater shell fragments and fine silty deposits indicative seasonal ponding and drying of depressions and development of non-pedogenic (groundwater calcrete) at the junction of sand and silt. Unit IV has alternating lenses of compact and loose sand as well as sand

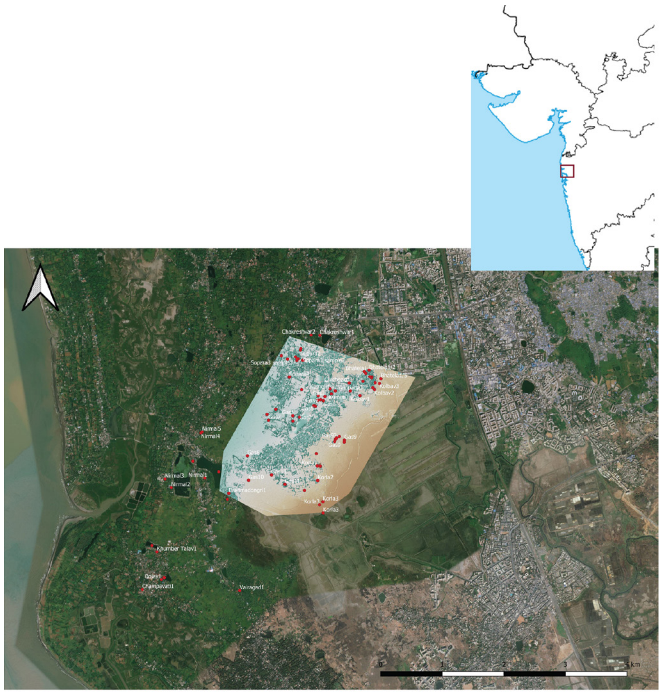


Figure 1: Map of Study Area

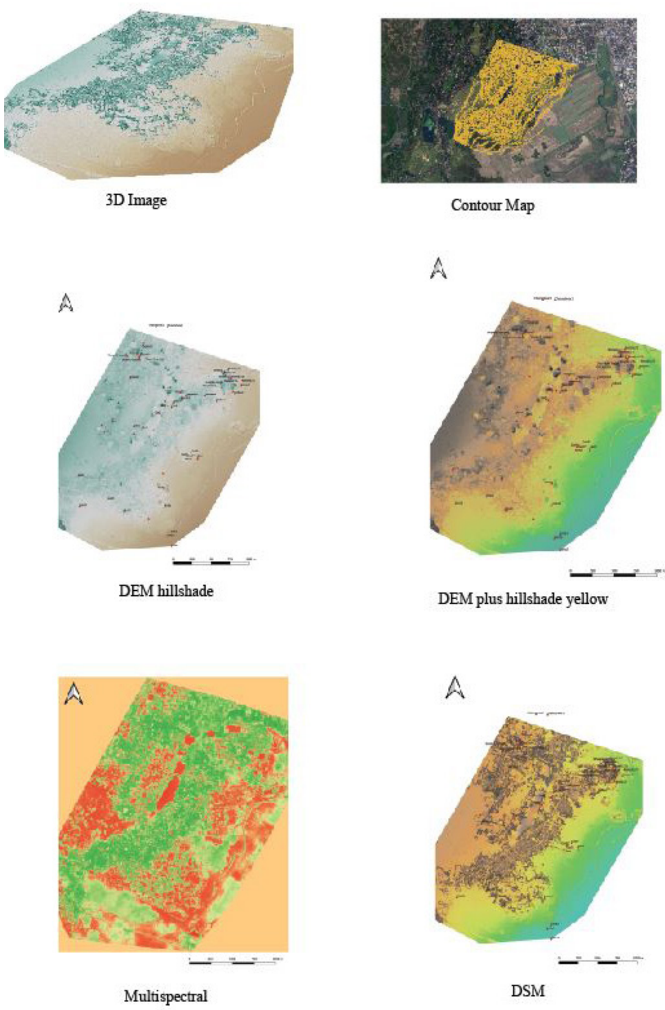


Figure 2: Areal images of Sopara DEM, DSM, Contour, Multispectral and 3D

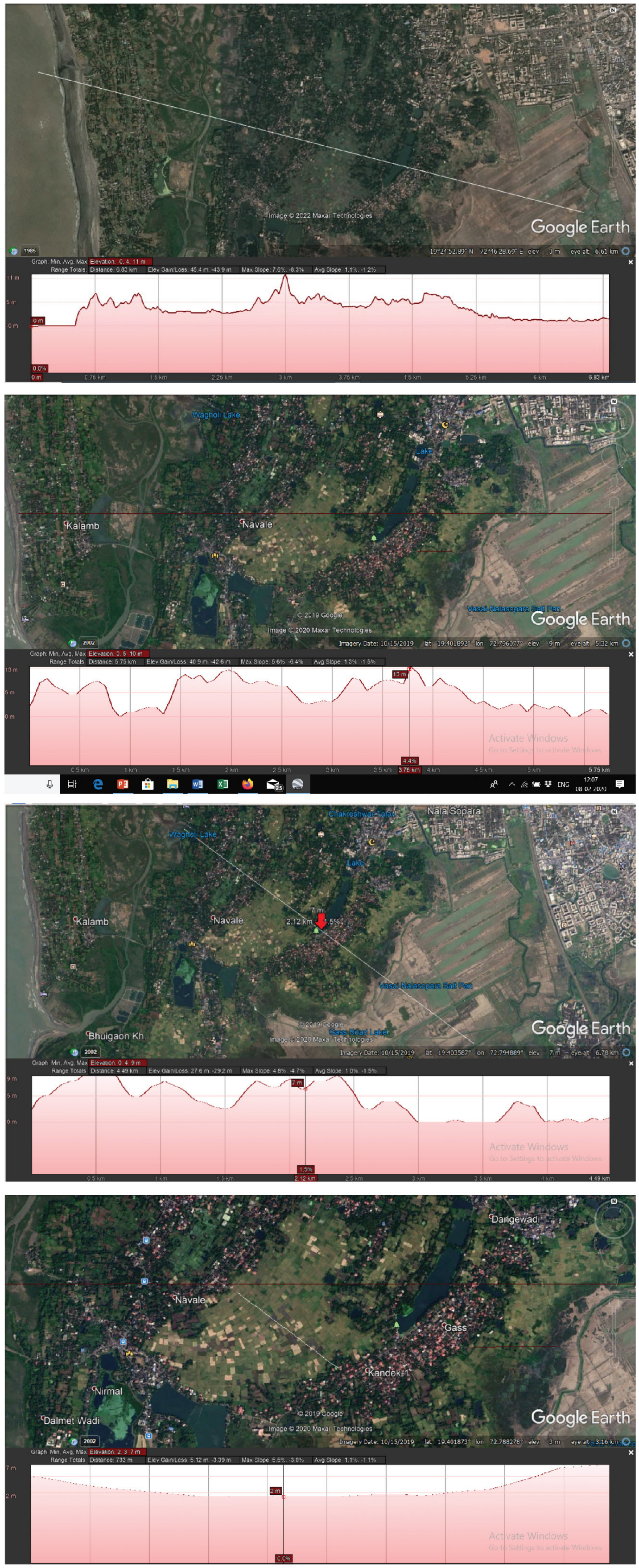


Figure 3: Elevation profile of various zones at Nalasopara

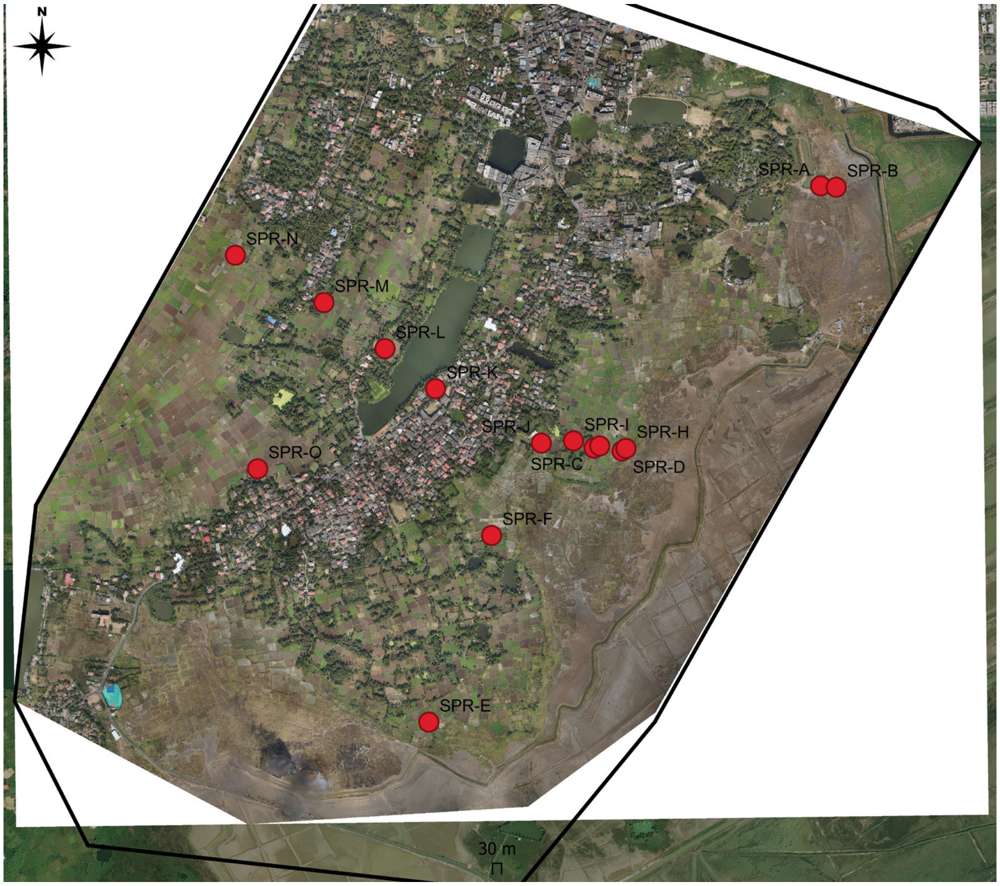


Figure 4: Map of study area showing borehole locations

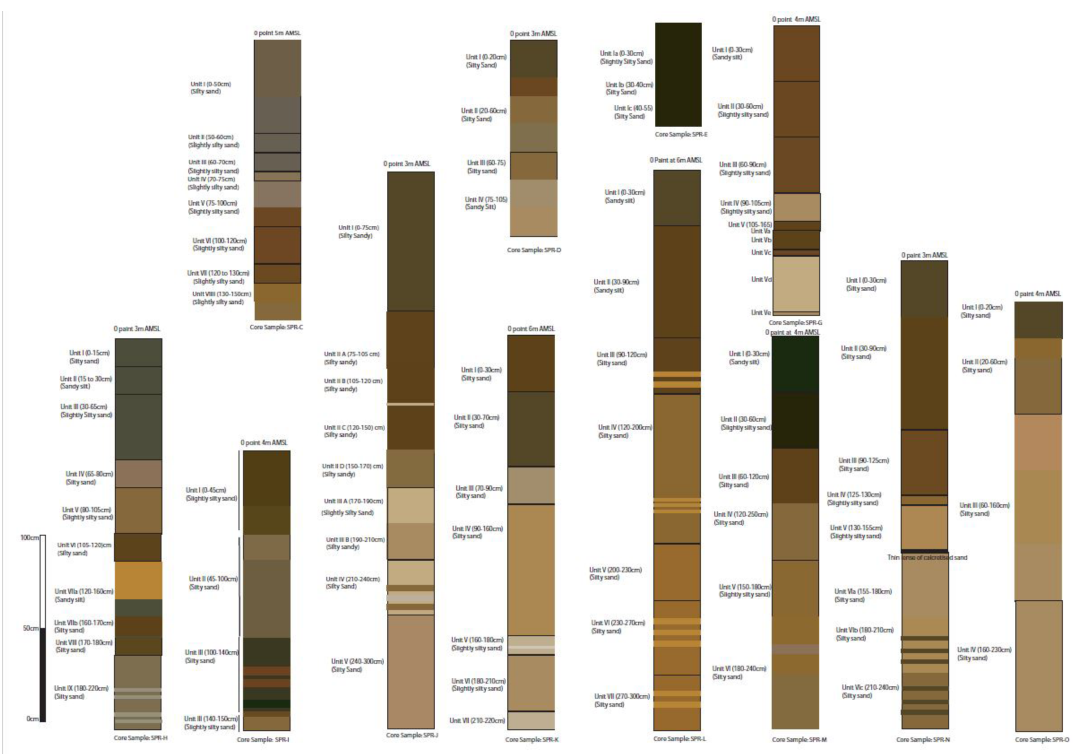


Figure 5: Collated Sections of boreholes

Table 1: Showing geomorphological characters of different Units of Augur Samples taken at Nalasopara

Sample ID	*Location*	*Units*	*Description*	*Tentative Period**
SPR-C	19.402839, 72.801091; This auger sample is taken near the banana plantation 560m east of Gass lake and 140m west of creek. The area is a part of habitation site and elevated than other areas of the wider landscape. It seems the ancient habitation was on the ridge. This point is located almost at the most elevated area of this mound.	Unit I (0-50 cm)	The soil (30cm) recovered is fine powdery habitation soil (sandy-silty nature). It contains high composition (26.49%) of very fine sand. There is the presence of pottery and brickbats as well as some amount of chalcedonic silica, clayey grits, calcrete, basalt and roots. From 40 cm onwards some difference can be seen in colour and compactness and it becomes sandy-silty in nature. The composition of very fine sand is high in the soil, i.e. 35.5% and it contains sub-rounded to angular chalcedonic silica, pottery grits, basalt and clay lumps as well as calcrete. Between 40 and 50 cm, there is some change in the composition and the unit is dominated by fine sand (24%) and very fine sand (24.12%). It is slightly darker than the previous layer. It also contains pottery, chalcedonic silica, basalt, clay grits, and calcrete. The sand-silt percentage is 68.50% and 27.66%. (10y/r 3/3-dark brown to 10y/r 3/2 -very dark grayish brown).	Late Holocene
		Unit II (50-60cm)	Texture wise this unit is finer and loose (less compact) than the previous layer. It is dominated by very fine sand (32.32%). Chalcedony silica, calcrete, few basalt pieces and broken pottery pieces are present in this unit. The sand-silt percentage is 65% and 24.50%. (10y/r 3/2 -very dark grayish brown).	Late Holocene
		Unit III (60-70)	It is more powdery and loose than the previous layer. It is dominated by fine sand (33.52%) and very fine sand (31.04%). It contains chalcedony silica, basalt, clay grits, calcrete and pottery pieces. The sand-silt percentage is 76.46% and 22.12%. (10y/r 3/3 -dark brown).	Late Holocene
		Unit IV (70-75cm)	This unit is very fine sandy in nature as the composition is dominated by very fine sand i.e. 44.68% and fine sand 31.9% and has more water content. The presence of pottery pieces, calcrete, clay grits, basalt nodules, microlith (burin) and chalcedonic silica have been also seen in the sample. The presence of microliths and pottery indicate that the Mesolithic population possibly occupied the stabilized dunes which were later used by the early Historic settlers. Sand-silt the percentage is 82.62% and 17.3%. (10yr 4/4 -dark yellowish-brown). A Microlith (Burin) on chalcedony	Early Historic/Late Holocene
		Unit V (75-100cm)	From 75-90 cm the layer is dominated by very fine sand (48.6%) and contains potsherds. The color of the soil is lighter than the preceding layer. It contains rounded and sub-rounded basalt and chalcedonic silica nodules as well as calcrete and clay grits. The frequency of small chalcedony/ basalt grits is lesser than the previous unit. From 90 to 100cm fine sand (39.48%) slightly coarser than the previous unit dominates the unit. It contains well rounded to surrounded small grits of chalcedony silica and basalt as well as larger angular basalt pebbles having a rough surface. It also contains calcrete nodules and calcrete coating can be seen on the basalt pellets. No bioturbation as well as no cultural material. Both the layers of this unit contains very small particles of calcareous bodies (Freshwater) in the same proportion. The sand-silt percentage is 82% and 18%. (7.5yr 4/3-brown to 7.5yr 3/4 -dark brown).	Mid Holocene
		Unit VI (100 to 120cm)	The sediments are dominated by very fine sand composing an average of 38.67% of the sample. Texturally the sediment in the layer is coarser than the previous unit due to the high percentage of medium-grained sand. It contains well rounded to sub-rounded basalt and chalcedonic silica nodules and angular pottery fragments. It also contains calcrete and calcrete coating can be seen on the basalt pellets. Very minute particles of calcareous masses can be seen in the layer. In the upper part of this unit very small grits of clay are evident, whereas in the lower levels of this unit calcrete and pottery pieces are absent. The sand-silt percentage is 80.50% and 15.4%. (7.5y/r 3/4 -dark brown).	Mid Holocene
		Unit VII (120-130cm)	This unit is as sandy as the previous layer and is dominated by very fine sand, i.e. 41.66%. However, a considerable increase in minute calcareous particles is evident. These particles are cemented together in the sandy matrix and can be identified as bivalve and mollusk shell pieces (presence of freshwater shells/terrestrial shells can be interpreted as an episode of a fluvial activity on the sand dune surface. The absence of marine shell fragments indicates a non-marine origin of sediments of this unit). A few fragments of palm/ date leaves can be also seen. Other than this, rounded to sub-rounded as well as angular fragments of basalt, chalcedony silica is also present. In the lower 5cms presence of concretized sand and cemented sandy gravel is another character of this layer. Sand-silt the percentage is 67% and 10.4%. (10yr3/4-dark yellowish-brown).	Mid Holocene
		Unit VIII (130 to 150cm)	This layer is as sandy as the previous layer and is dominated by very fine sand, i.e.47.74%. A thin lens of cemented sand with large shells pieces is a part of this unit as well as fragments of cemented thin lenses of sand containing lots of very small fragments of shells is also part of this unit. This layer is represented with a considerable increase in calcareous body and has comparatively less chalcedony silica and less nodular/ reworked calcrete pellets. A few clay lumps along with rounded to sub-rounded basalt, chalcedonic silica as well as calcite particles is also visible. The encountering of small mollusk saltwater shells is indicative of beach sand. Other than this few fragmentary pieces of operculum were also encountered in this layer. The lower 10cm of this unit is dominated by very fine sand, i.e. 46.63% almost the same as overlying 10cm and the only difference is an increase in the number of calcareous masses. A solitary rhizoconcretion, a reworked calcrete nodule, chalcedony silica, angular basalt fragment and cemented sand is present in the lower horizon. Calcareous masses (saltwater bivalve and mollusk shell fragment) has also increased. The overall sand-silt percentage is 87% and 9.7%.10yr4/4 (dark yellowish-brown) to 10yr4/3 (brown).	Mid Holocene

Sample ID	*Location*	*Units*	*Description*	*Tentative Period**
SPR-D	19.40274, 72.80209, The auger sample is taken 105m east of SPR-AUG_2020.C and 14m west of the creek. The area is submerged under the water during the rainy season. The auger point lies in the paddy field, which is uncultivated having lot of cracks on the surface. The cracks are as deep as 20 cm. This upper level is devoid of cultural material, rock fragment and calcrete. Possibly, only one crop is taken in the field. However, water is available in plenty.	Unit I (0-20cm) (Silty Sand)	Sand and silt percentage is 56.6% and 40.19%. (10yr3/2 -very dark grayish brown). Anthropogenic activity, habitation soil. Contains pottery, chalcedonic silica and basalt.	Late Holocene
		Unit II (20-60cm) (Silty Sand)	Sand and silt percentage is 39% and 46.5%. (10yr3/4-dark yellowish-brown in the above 10cm and 10yr4/3 -brown in the lower 15 cm). Anthropogenic activity, habitation soil. Contains pottery, chalcedonic silica and basalt. Sudden increase of cultural material in the middle layer.	Late Holocene
		Unit III (60-75) (Silty sand)	Sand and silt percentage is 35% and 62%. (10yr4/3 -brown). Anthropogenic activity, habitation soil., contains pottery, chalcedonic silica and basalt.	Late Holocene
		Unit IV (75-105) (Sandy Silt)	Sand and silt percentage is 48.27% and 52.13%. (10yr5/2-greyish brown to 10YR5/3 -brown). Anthropogenic activity, habitation soil, chalcedonic silica, basalt and calcrete. The presence of minute marine shell pieces in the lower layer reflects that the human habitation was formed on beach sand.	Mid to Late Holocene
SPR-E	19.395038, 72.796389; This auger sample is taken in the paddy field 160m west of creek and 390m north of Gass-Vasai road.	Unit Ia (0-30cm) (Slightly Silty Sand)	Sand and silt percentage is 61.42% and 21.54%. (10yr3/2-very dark grayish brown). No anthropogenic activity, freshwater shells	Late Holocene
		Unit Ib (30-40cm) (Silty Sand)	Sand and silt percentage is 60.12% and 33.32%. (10yr3/2 -very dark grayish brown). No anthropogenic activity, freshwater shells	Late Holocene
		Unit Ic (40-55) (Silty Sand)	Sand and silt percentage is 48.1% and 34.16%. (10yr3/2-very dark grayish brown)., No anthropogenic activity, freshwater shells	Late Holocene
SPR-G	19.40288, 72.80143; This auger sample is taken in the paddy field, 35m east of SPR-C and 70m west of SPR-AUG_2020.D. The gradient of the area is towards east.	Unit I (0-30cm) (Sandy silt)	Sand silt ratio is 32 and 66. 10y/r 3/4 (dark yellowish brown). Sandy Silt, Anthropogenic activity, habitation deposit	Late Holocene
		Unit II (30-60cm) (Slightly silty sand)	The total sandy matrix is 78.5% in this unit. (10yr3/4-dark yellowish-brown). Anthropogenic activity, habitation deposit	Late Holocene
		Unit III (60-90cm) (Slightly silty sand)	The sandy content is about to 86% and the silt content is 10.9 % whereas in the above unit it is 18.5% (7.5YR3/4-dark brown). Anthropogenic activity, habitation deposit	Early Historic/Late Holocene
		Unit IV (90-105cm) (Slightly silty sand)	The overall ratio of sand and silt is 79.56: 16.97. (10YR4/4-dark yellowish-brown). Natural Soil, calcified cemented lenses possibly show the demarcation between two varied strata of soil.	Late Holocene
		Unit Va to Ve (105-165cm)	Natural soil with alternating lenses of very fine to fine sand is sometimes mixed with shell fragments and lenses of clay. These layers have nodular calcrete in them or are present at the junction of two different alternating layers. These geomorphologic features indicate formal sea levels, tidal zones as well as dune landforms as well as climatic fluctuations as indicated by various types of calcrete. No anthropogenic activity.	Mid Holocene

Sample ID	*Location*	*Units*	*Description*	*Tentative Period**
SPR-H	19.402806, 72.802206; This auger sample is taken is the paddy field near the tamarind trees in the low lying area. It is 14m north-east of SPR-D and 5m west of creek.	Unit I (0-15cm) (Silty sand)	Sand silt percentage is 50.76% and 48.07% and the color is 10YR3/1-very dark grey color). Anthropogenic activity. A sizable amount of very fine sand in the sediments possibly indicate that blown sand contributed to the development of this landform. Habitation Soil	Late Holocene
		Unit II (15 to 30cm) (Sandy silt)	Sand and silt percentage in this unit is 72.83% and 23.98%. Color is (10YR3/1-very dark grey color). Sandy Silt, Anthropogenic activity, dune activity. Habitation Soil	Late Holocene
		Unit III (30-65cm) (Slightly Silty sand)	The sand silt percentage is 75.6% and 22%. The color of this unit is 10YR3/1-very dark grey color. Slightly Silty sand, Anthropogenic and dune activity	Late Holocene
		Unit IV (65-80cm) (Silty sand)	The Sand-Silt percentage is 56.07% and 42.42%. The Color of the unit is 10YR3/3 (dark brown). This unit possibly reflects some sort of dune activity. Anthropogenic activity, dune activity. Part of habitation soil.	Late Holocene
		Unit V (80-105cm) (Slightly silty sand)	Sand-silt percentage is 71.74% and 24.9%. 10YR4/3 (brown) to 10YR3/3 (dark brown). The development of this unit is partly associated with the marine origin and partly with sand dune activity. Anthropogenic activity,	Late Holocene
		Unit VI (105-120) cm (Silty sand)	The sand and silt percentage in the unit is 73% and 25.40%. The Color of this unit is (10YR4/3-brown). The absence of freshwater/terrestrial shell pieces and presence of marine shells indicates the marine origin of this unit. Silty Sand, beach sand, thereby indicating transgression of the sea (higher sea level). Anthropogenic activity.	Late Holocene
		Unit VIIa (120-160cm) (Sandy silt)	The sand-silt percentage is 55.62 and 40.09. 10YR4/4-dark yellowish-brown to 10YR3/1 (very dark grey lower 10cm). Anthropogenic activity, freshwater shells, sticky clayey nature of sediments indicate towards ponding zone.	Late Holocene
		Unit VIIb (160-170cm) (Silty sand)	The sand-Silt percentage is 61 and 39. The color is 10YR3/3 -dark brown. Anthropogenic activity, presence of both marine and freshwater shells indicates intertidal zone tidal zone.	Early Historic/Late Holocene
		Unit VIII (170-180cm) (Silty sand)	Sand-silt percentage is 71% and 28.25. (10YR6/1-grey). No anthropogenic activity coarse and fine nature of sand and marine shell fragments indicates beach sand deposit.	Beach Sand/ Late Holocene-Mid Holocene
		Unit IX (180-220cm) (Silty sand)	Sand and silt percentage is 62.04% and 31.58%. 10YR5/1 (Grey) and 1 0YR4/2 (dark grayish brown). No anthropogenic activity coarse silt and sand, and marine shell fragments indicate beach sand deposit.	Mid Holocene
SPR-I	19.403015, 72.800640; This auger sample is taken in the vegetable field, 66 m west of SPR-AUG_2020.C and 394 m east of Gass road.	Unit I (0-45cm) (Slightly silty sand)	Anthropogenic activity; freshwater/terrestrial shells and fine sand, habitation soil	Late Holocene
		Unit II (45-100cm) (Silty sand)	Anthropogenic activity, fresh water shells, dominated by very fine sand. The sand silt percentage of this Unit is 60% and 36% .	Late Holocene
		Unit III (100-140cm) (Silty sand)	No anthropogenic activity, alternating lenses of concretized sand mixed with small freshwater shell fragments and fine silty deposit is indicative seasonal ponding and drying of depressions and development of non-pedogenic (groundwater calcrete) at the junction of sand and silt.	Mid Holocene
		Unit IV (140-150cm) (Slightly silty sand)	The sand and silt percentage is 71% and 21%. Slightly Silty Sand, anthropogenic activity, an alternating lenses of compact and loose sand, sand mixed with marine shells indicate fluctuating environment at the site.	Mid Holocene

Sample ID	*Location*	*Units*	*Description*	*Tentative Period**
SPR-J	19.40296, 72.79970; This auger sample is located in a paddy field, 100.74 m west of SPR-AUG_2020.I and 346.40 m east of Gass road.	Unit I (0-75cm) (Silty Sandy)	The above 30cm is dominated by very fine sand (29.13%) and contains pottery, chalcedony silica, basalt pellets and small grits of calcrete. Very few shell of terrestrial nature are found in this sample. Between 30-45 cm the soil is dominated by very fine sand (32.52%) and medium to fine silt (29.79%) with almost similar amount of inclusions as overlying layer. Between 45 and 60cm the soil is dominated by very fine sand (35.99%) and coarse silt (34.55%) with same amount of calcrete and slight increase in fresh water shells. However, the amount of pottery, chalcedony silica and basalt has decreased in the sample. At 60-75 cm the soil is dominated by very fine sand (32.6%) and coarse silt (29.31%) . A considerable increase in fresh water shell pieces is evident in the sample. Also increase in pottery fragment, angular basalt pebbles and chalcedony silica is witnessed than the previous sample. However, the amount of calcrete grits is same as above sample.	Late Holocene
		Unit II A (75-105 cm) (Silty sandy)	The soil sample is dominated by very fine sand (33.62%) and coarse silt (27.56%) and has lots of developed calcrete grits and nodules. Very minute to large marine shell are present in the sample. Also pottery fragments, large basalt pebbles and chalcedonic silica are present in the sample. Some particles of fresh water shells pieces also evident in the sample.	Late Holocene
		Unit II B (105-120 cm) (Silty sandy)	The soil sample is dominated by very fine sand (32.85%) and coarse silt (28.29%) with increase in compactness. Larger chunks of insitu developed calcrete and pottery pieces are found in this level. Small grits of calcrete are also present in the sample. A few basalt pebbles and chalcedonic silica are also found in this level. Very small fragment of fresh water shells and marine shells are encountered in this layer. A thin lens of compact and cemented fine beach sand lenses having lots of calcareous bodies is recovered in this sample.	Late Holocene
		Unit II C (120-150) cm) (Silty sandy)	The soil is dominated by very fine sand (31.49%) and coarse silt (28.58%) . It is very compact, contains lots of marine shell fragments as well as very minute small fragments of fresh water shells. It also contains small grits of calcrete as well as a few pellets and small nodules of basalt and chalcedony silica. It contains pottery in good amount.	Late Holocene
		Unit II D (150-170 cm) (Silty sandy)	The soil is dominated by very fine sand (30.08%) and coarse silt (26.34%) with lots of shell pieces of both marine and fresh water origin and it also contains basalt pebbles, chalcedonic silica, pottery as well as small calcrete grits. However, the amount of calcrete, pottery, basalt and shell pieces is relatively lesser than the above sample.	Late Holocene
		Unit III A (170-190 cm) (Slightly Silty Sand)	This layer is dominated by fine pebbles (38.54%). The sediment (white 10YR6/3 in color) has nodular calcrete but no pottery. It also contains marine shell fragments.	Mid Holocene
		Unit III B (190-210cm) (Silty sandy)	This layer is dominated by very fine sand (28.3%) having lots of marine shell fragments. It also contains calcrete, basalt and chalcedonic silica.	Mid Holocene
		Unit IV (210-240cm) (Silty Sand)	The sediment is dominated by very fine sand (41.84%) and coarse silt (34.72%). Finer than Unit IIIB. It contains concretized sand (very fine in nature) with very minute pieces of marine shell embedded in it. Negligible amount of mollusk shells is also seen. It is devoid of potsherd. But has very small grits of calcrete and a few small grits of basalt and chalcedony silica. It seems that this layer has intercalating fine lenses of silty-clayey deposit (5-6mm).	Mid Holocene
		Unit V A (240-270cm) (Silty Sand)	The sediments are dominated by coarse silt (20.76%) and very fine sand (18.17%) and contains lots of calcareous masses of marine nature. It contains clayey sandy nodules with minute calcareous masses, calcrete, chalcedony silica, basalt and pottery.	Mid Holocene
		Unit V B (270-300cm) (Silty Sand)	Same as the above layer with coarser beach sand and lots of marine shell pieces. It is dominated by very fine sand (22.91%) and coarse sand (20.75%). It has calcrete, basalt and chalcedony silica.	Mid Holocene
SPR-K	19.404397, 72.796568; This auger sample was taken besides a house in an uncultivated area in the Gass village. It is 369 m North-west of SPR-K, 4.88 m west of Gass road and 37.69 m east of Gass lake.	Unit I (0-30cm) (Silty sand)	The sand and silt percentage of this unit is 57% and 41%.10YR3/3 (dark brown). Anthropogenic activity, recent ponding activity	Late Holocene
		Unit II (30-70cm) (Silty sand)	The sand and silt percentage of this unit is 52.75% and 42.3%. 10yr3/2 (very dark grayish brown). Anthropogenic activity, recent ponding activity	Late Holocene
		Unit III (70-90cm) (Silty sand)	Very fine sand (29.64%) and coarse silt (25.11%) and is composed of calcified sand with shells of marine origin. It also has calcrete nodules, pottery fragments basalt, chalcedonic silica and lots of marine shell fragments. The sand and silt percentage of this unit is 44.50% and 34%. 10yr5/2 (grayish brown). Anthropogenic activity, possibly habitation formed on relic beach.	Late Holocene
		Unit IV (90-160cm) (Silty sand)	Calcareous masses of marine origin and also some freshwater shells. It has a high percentage of coarse sand. The sand and silt percentage is 58% and 26% 10YR5/4 (yellowish-brown). No anthropogenic activity, high percentage of coarse sand.	Mid Holocene

Sample ID	*Location*	*Units*	*Description*	*Tentative Period**
SPR-L	19.40566, 72.79507; This auger sample was taken in the recently harvested vegetable field besides the bank of Gass lake. It is 199.44 m north-west of SPR-K and 60.23 west of Gass lake	Unit I (0-30cm) (Sandy silt)	Sand-silt percentage is 32% and 66%. However, it is devoid of calcrete. 10yr3/2 (very dark grayish brown). Upper Surface, recent anthropogenic activity	Late Holocene
		Unit II (30-90cm) (Sandy silt)	The sand-silt percentage is 41.1% and 57.5%. Color is 10YR3/3 (dark brown). A high percentage of very fine sediments and the presence of freshwater shells are indicative of the development of this unit in a ponding environment. No anthropogenic activity has undergone ponding in the past.	Late Holocene
		Unit III (90-120cm) (Silty sand)	The overall sand and silt percentage is 57.18% and 40.89%. A sudden increase in coarse sand is visible in this unit (5.03%). 10YR3/3 (dark brown), Intercalated layer- 10YR5/6 (yellowish-brown). Silty Sand, no anthropogenic activity.	Late Holocene
		Unit IV (120-200cm) (Silty sand)	This unit is devoid of pottery. The overall sand and silt percentage is 56.33% and 40.33%. 10YR4/4 (dark yellowish-brown) and Intercalated silt layer - 10YR5/6 (yellowish-brown). The sudden increase in silt content shows some sort of episodic event. No anthropogenic activity, development of nodular calcrete, freshwater shells increases with depth, very thin lenses of very fine sand.	Late Holocene
		Unit V (200-230cm) (Silty sand)	Devoid of cultural material, freshwater shells have decreases, lenses of cemented sand with marine shells, sand-silt percentage is 60% and 31% respectively. 10YR4/6 (dark yellowish-brown).	Mid Holocene-Late Holocene
		Unit VI (230-270cm) (Silty sand)	The sample is dominated by very fine sand (51.73%) with marine shells, calcrete and few chalcedonic pellets. The occurrence of a thin fine concretized sandy layer with embedded marine shell pieces is noteworthy. Sand-silt percentage is 60% and 36%. 10YR4/6 (dark yellowish-brown). Silty Sand, no anthropogenic activity, the intercalating lens of concretized sand with marine shells indicating transgression of the sea.	Mid Holocene
		Unit VII (270-300cm) (Silty sand)	Contains very fine sand 60%, concretized sand, basalt and a few shell pieces of freshwater or of terrestrial origin. In-situ development of calcrete can be seen in this layer. Sand and silt percentage is 65% and 32%. 10YR4/6 (dark yellowish-brown). No anthropogenic activity, dune deposit with ponding activity.	Mid Holocene
SPR-M	19.40689, 72.79326; This auger sample is located in a harvested paddy field, 241.26 m north-west of SPR-L. The upper 6 cm is silty clayey sediment.	Unit I (0-30cm) (Sandy silt)	Sand-silt percentage is 50.07% and 48%. 10YR2/1 (black). Fresh water shells, few modern pottery sherds.	Late Holocene
		Unit II (30-60cm) (Slightly silty sand)	Sand-silt percentage is 73% and 24.90%. 10YR2/2 (very dark brown). No anthropogenic activity, presence of freshwater shells.	Late Holocene
		Unit III (60-120cm) (Silty sand)	Lower 30 cm only marine shells, beach sand with shells, pottery and large marine shell pieces. Anthropogenic activity; marine and freshwater shells in the upper horizon may indicate intertidal zone.	Late Holocene
		Unit IV (120-150cm) (Silty sand)	Sand-silt percentage is 64% and 33%. 10yr4/4 (dark yellowish-brown). Anthropogenic activity; sandy units with marine shells and partially cemented sandy (with marine shells) units is indicative of regressive and transgressive phases of the sea.	Mid Holocene-Late Holocene
		Unit V (150-180cm) (Slightly silty sand)	Sand-silt percentage is 65% and 15.25%.10YR5/4 (yellowish-brown). No anthropogenic activity, cemented beach sand very calcareous indicates beach deposit.	Mid Holocene-Late Holocene
		Unit VI (180-240cm) (Silty sand)	The lower 30cms (210-240) is less compact than the overlying layer. It contains calcareous masses of marine origin in good number but the concentration is lesser than the overlying layer. A cemented lens having well-rounded basalt pebbles, chalcedony silica, calcrete pellets and lots of calcareous masses is also encountered in this layer. 10YR4/3 (brown). Sand-silt percentage is 66.5% and 28.68%. Anthropogenic activity in upper layer, intercalating fine sandy units with pottery between beach sand deposits are indicative of regressive and transgressive phases of the sea (repeated formation of sand dune occupied by humans and formation of beaches).	Mid Holocene-Late Holocene

Sample ID	*Location*	*Units*	*Description*	*Tentative Period**
SPR-N	19.40821, 72.79064; The auger sample is taken in the harvested field about 302.90m north-west of SPR-M. Upper 5-10cm silty clayey sediments (no pottery)	Unit I (0-30cm) (Silty sand)	The overall sand and silt percentage is 62.05% and 36.44%. 10yr3/2 (very dark grayish brown). Silty Sand, recent cultural material.	Late Holocene
		Unit II (30-90cm) (Silty sand)	In the Upper 30 cm The abundance of calcrete and almost absence of chalcedony silica, basalt and marine shells in the sediments, show that the deposition of sediments possibly occurred in palaeochannel or in a localized depression due to water logging and stagnant water during the rainy seasons. Sand and silt percentage is 74% and 23.3%. 10YR3/3 (dark brown). No anthropogenic activity, ponding environment. In the lower 30cm, sand and silt percentage is 65% and 33%. 10YR3/3 (dark brown). No anthropogenic activity, ponding environment.	Late Holocene
		Unit III (90-125cm) (Silty sand)	Sand and silt percentage is 52% and 46%.10yr3/4 (dark yellowish-brown). No anthropogenic activity, ponding environment. High concentration of freshwater shells.	Late Holocene
		Unit IV (125-130cm) (Slightly silty sand)	Sand and silt percentage is 87% and 10%.10YR4/4 (dark yellowish-brown). A very high percentage of coarse sand shows that this unit was a dune (incipient) formed by blown sand derived from a nearby beaches whose sediments are found below this unit. It also reflects regression of sea. No anthropogenic activity, less freshwater shells, possibly shows incipient stages of dune formation or else is a part of a sand sheet having coarser sand.	Late Holocene
		Unit V (130-155cm) (Slightly silty sand)	The sediment is dominated by very fine sand (41.69%). It contains a huge amount of freshwater/terrestrial shells and also some amount of marine shells (possibly blown from the beach. Sand and silt percentage is 62% and 22%. 10YR5/4 (yellowish-brown). Anthropogenic activity, pottery, marine and freshwater shells in the sediments indicate estuarine environment; high quantities of very fine sand indicates dune formation. A very thin lenses of calcretic sand is present below this unit.	Late Holocene
		Unit VIa (155-180cm) (Silty sand)	Sand and silt percentage is 51% and 40%. 10YR5/3 (brown). Anthropogenic activity, presence of marine shell indicates beach and a high concentration of very fine sand shows dune activity.	Late Holocene
		Unit VIb (180-210cm) (Silty sand)	Intercalating lenses of alternating layers of calcrete and clayey sediments in these litho-units. Thereby indicating towards fluctuating climate during the deposition of these litho-units. It has the very meager amount of marine shell fragments. There is also the presence of cemented sand, few pieces of basalt and chalcedonic silica. Sand and silt percentage is 50% and 28%, and granules and pebbles are 21%. 10YR5/4 (yellowish-brown). Anthropogenic activity, presence of marine shell indicates beach and a high concentration of very fine sand shows dune activity, clay/silt lenses indicates local ponding.	Late Holocene
		Unit VIc (210-240cm) (Silty sand)	It contains a good amount of marine shell fragments and cemented sand with lots of minute marine shell fragments. Sand and silt percentage is 54% and 40%. 10yr4/3 (brown). No anthropogenic activity, presence of marine shell indicates beach and a high concentration of very fine sand shows dune activity, alternating lenses of clay, cemented sand, loose sand, calcareous sand is indicative of fluctuating climate.	Mid Holocene-Late Holocene
SPR-O	19.40224, 72.79130; The auger sample is taken in a harvested paddy field about 753.68 m west of SPR-F and 351.66 m south-west of Gass lake. The upper soil is clayey in nature. *as informed by a local in the ward near auger point that the other side of the road has saline soil whereas towards Gass lake and beyond it is sweet water below 18ft.	Unit I (0-20cm) (Silty sand)	Sand and silt percentage is 51% and 44.5%. 10YR3/2 (very dark grayish brown). No ancient anthropogenic activity, freshwater shells	Late Holocene
		Unit II (20-60cm) (Silty sand)	Freshwater shells, rhizoconcretion, calcrete clast developed in fissures and cracks. Few marine shell fragments in lower part. Sand and silt percentage is 44.3% and 35%. 10YR4/2 (dark grayish brown) to 10YR4/3 (brown). No ancient anthropogenic activity, upper surface shows ponding and lower surface indicate marine sediments.	Mid Holocene-Late Holocene
		Unit III (60-160cm) (Silty sand)	It is dominated by very fine sand (53%). It contains in-situ developed calcrete nodules and root cast. The sediments also contain a few larger and mostly very minute shell fragments of marine origin. The percentage and size of shells decrease with depth a and the sediments become less compact. It is devoid of chalcedony silica, basalt and pottery. Sand and silt percentage is 62.3% and 31.6%. 7.5YR5/4 (brown) to 10YR5/4 (yellowish-brown). No ancient anthropogenic activity, marine shells, development of calcrete.	Mid Holocene
		Unit IV (160-230cm) (Silty sand)	The unit is dominated by very fine sand (58%) and has calcrete (root cast), cemented sand, marine shell (very less). It has no pottery, basalt and chalcedony silica, etc. Lots of pores in the sample indicates biogenic action. Between 180 and 210 cms decrease in n the sand and an increase in silt and finer particles is evident. From 210 cm a slight increase in fine sand is noticed. It contains cemented sand with minute shell fragments as well as marine shells and few pieces of basalt and chalcedonic silica. Sand and silt percentage is 63% and 34%. 10YR5/3 (brown). No ancient anthropogenic activity, lenses of fine silt, sand with marine shells, cemented sand with freshwater shells and marine shells in lowest layer.	Mid Holocene

*Sub-division of Holocene Years B.P. (Belcher and Belcher 2000)
Early Holocene 10 ka to7 ka
Mid-Holocene 7 ka to 3 ka
Late Holocene 3 ka to present

mixed with marine shells. The early Historical settlement has formed on the surface of Unit II having a high parentage of very fine sand mixed with terrestrial shell pieces.

The borehole data from Point SPR-J indicates that the Late Holocene sediments are dominated by very fine sand as well as coarse silt. These sediments contains pottery, marine shells, fresh water shells, nodular calcrete, compact and cemented fine beach sand lenses having lots of calcareous bodies. The Mid Holocene sediments (Unit III, IV and V) indicates presence of varying percentages of silt, sand, calcrete, concretized sandy layers, calcareous sand, marine shells is not only indicative of marine environment, but also shows a fluctuating climate during this period.

Sediments from bore hole SPR-K indicates that Early Historical settlement developed above the beach sediments of Mid Holocene Period, whereas data from SPR-L shows that this area was not occupied during the Late Holocene Period. Sediments of Mid Holocene period indicate decrease in freshwater shells and increase in marine shells. Some lenses of cemented sand with marine shells are also present in the sample. The Late Holocene sediments of SPR-L reflects no significant human activity in the upper 60 cms (Unit I and II having medium to fine silt below 31mic.) and shows local ponding environments, however the Mid Holocene units includes marine shells, calcrete, a few chalcedonic pellets, thin fine concretized sandy layer with embedded marine shells and very fine reddish lenses of sand. These are devoid of anthropogenic activity, and the intercalating lens of concretized sand with marine shells indicates transgression of the sea. However, presence of fresh water shells in the lowest units is indicative of riverine/fresh water environment. Calcrete formation and development of concretized sand in these sediments may be result of climatic fluctuations in arid and semiarid type of environment at the site.

Data from borehole SPR-M shows that Unit VI C contains a good amount of marine shell fragments and cemented sand mixed with lots of minute marine shell fragments. Presence of marine shell points towards beach deposit and a high concentration of very fine sand layers devoid of marine shells are indicative of a different environment of deposition. Alternating lenses of clay, cemented sand, loose sand, calcareous sand is all indicative of fluctuating climate during the Mid Holocene Period. The Late Holocene sediments of the same location show absence of any sort of habitation belonging to Early Historical period. However, presence of pottery in the beach sand deposit, clayey sediments containing both marine shells and fresh water shells shows that man was interacting with different types of landscapes during this period.

At SPR-O no anthropogenic activity is evident in the Mid Holocene period. The sediments of this period containing calcrete, root cast, cemented sand, and marine shell fragments are again indicative of fluctuating climatic conditions. Similar inference has been drawn from the microfossil analysis of sediments from SPR-C and SPR-I. It is noteworthy that most of the marine sediments belonging to Mid-Holocene period are found up to the height of 4.25 m AMSL (Figure 6) and the tidal sediments/ inter tidal zones are generally found capping the marine sediments.

Scientific Analysis of two core samples for Phytolithic and Microfossil Observations with remarks on climate and other index

Background to the Phytolith Classification Adapted

Grasses are known to be the major accumulators of opal silica/Phytolith. The basic classification adapted here is derived from grass families as suggested by Twiss (2001) with further modifications by including Phytoliths of anatomical origin and other non-diagnostic silicified cells such as woody elements and perforated cells ensued from shrubs and trees (Eksambekar 2002). Different Phytolith morphotypes were noted that included subtypes within each group.

Taking into consideration the adapted classification the Phytolith morphotypes (Figure 9 and 10) were grouped as follows;

1. Panicoid (e.g. dumbbells)
2. Chloridoid (e.g. saddles)
3. Festucoid (e.g. spherical, square)
4. Elongate (e.g. Rods and tracheids)
5. Trichome (e.g. epidermal hairs)
6. Bulliform (e.g. bulky phytoliths like fan shape)
7. Silicified cells (e.g. woody elements)

Diagnostic Phytolith Summary

In the profile graphs (fig. 7 and 8) please note that the classification is a combination of shapes and possible taxa. As shapes are a basic key to understand the phytolith types they are grouped accordingly. Thus for example bulky pointed trichome- although found in Gramineae and other families are grouped separately as "Trichome" due to their shape classification. Phytoliths observed from each sample were compared with Phytolith Database of Phytolitharium collection housed at the "Phytolith Research Institute" and other published reference. The phytolith morphotypes based on their anatomical origin and structural character suggest the presence of following vegetation in the observed samples:

Table 2: Phytolith morphotypes based on their anatomical origin and structural character

Phytolith Type	*Family/genus*	*Diagnostic level*	*Classification/Remarks*
Rods straight	Acanthaceae	Family	Elongate
Spherical/circular plain	Amaranthaceae	Family	-
Pointed bulky	Panicoid/ Andropogonoid	Family	Trichome
Long pointed hair	Burseraceae/ Fabaceae	Non diagnostic	Trichome
Solid bulky spherical	Cannaceae	Family	Festucoid
Square facetted	Chloranthaceae/ Gramineae	Family	Bulliform
Circular plain	Chrysobalanaceae	Family	Festucoid
Rectangular facetted	Euphorbiaceae	Family	Bulliform
Blunt points	Gramineae/ Triticum	Family	Trichome
short shaft dumbbell	Gramineae/Panicum	Family	Panicoid
Saddle	Gramineae	Family	Chloridoid

Diagnostic summary of Diatom Classification

Diatoms are differentiated between by forms that are centric, i.e. circular, and pennate, i.e. having bilateral form. Diatoms are divided into solitary and colonial forms. Diatoms can be further sub-divided according to whether they possess a raphe (a median line), a pseudoraphe, or completely lack a raphe. Diatoms commonly found in the marine plankton may be divided into the centric diatoms including three sub-orders based primarily on the shape of the cells; the polarity and the arrangement of the processes (Please refer Table 3 and 4; and Figure 7 and 8).

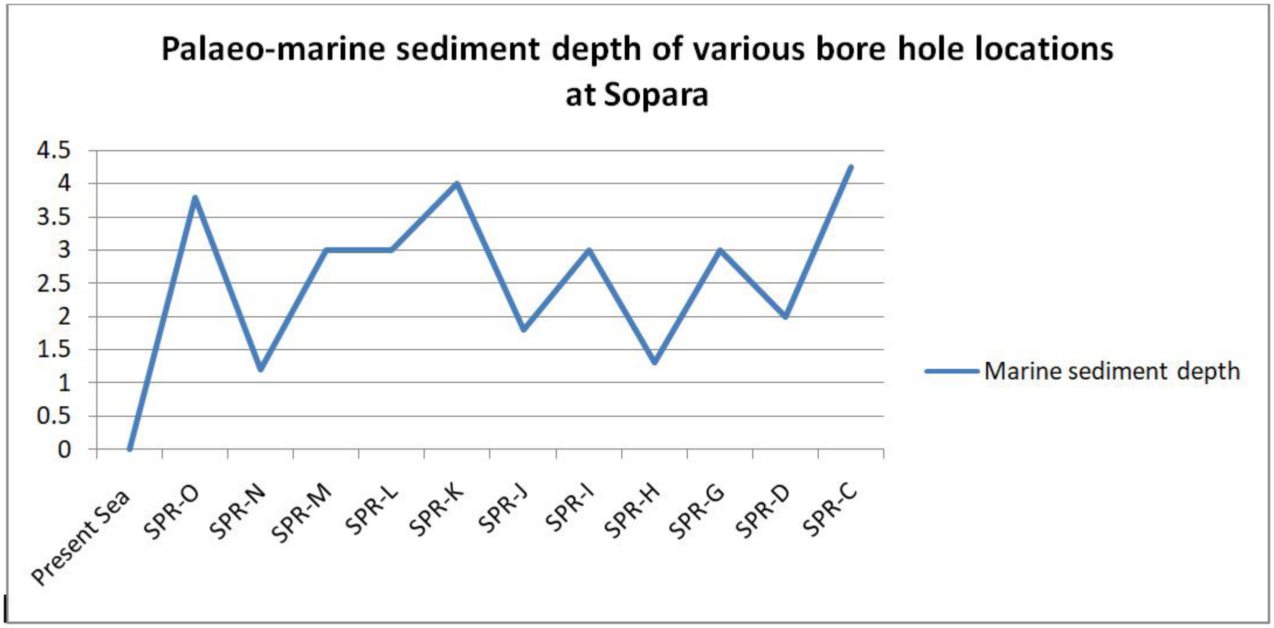
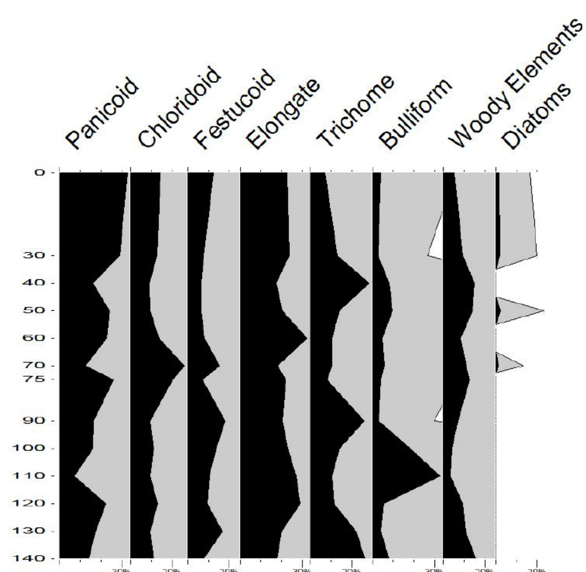
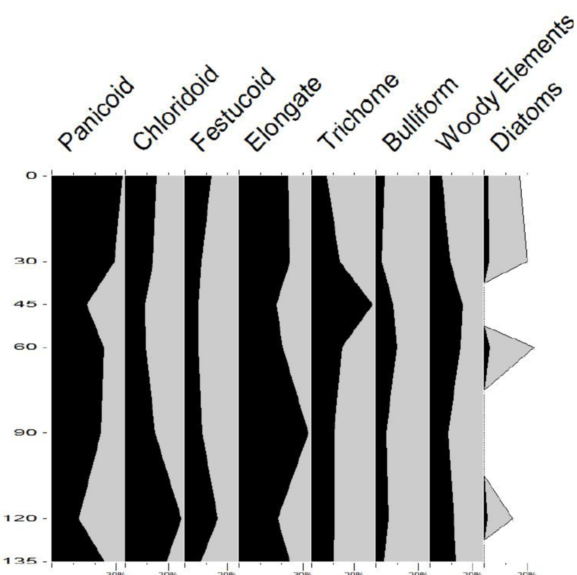


Figure 6: Palaeo-marine sediment depth of various bore hole locations at Sopara



Frequency of Phytoliths from trench SPR 'C' = Nalasopara

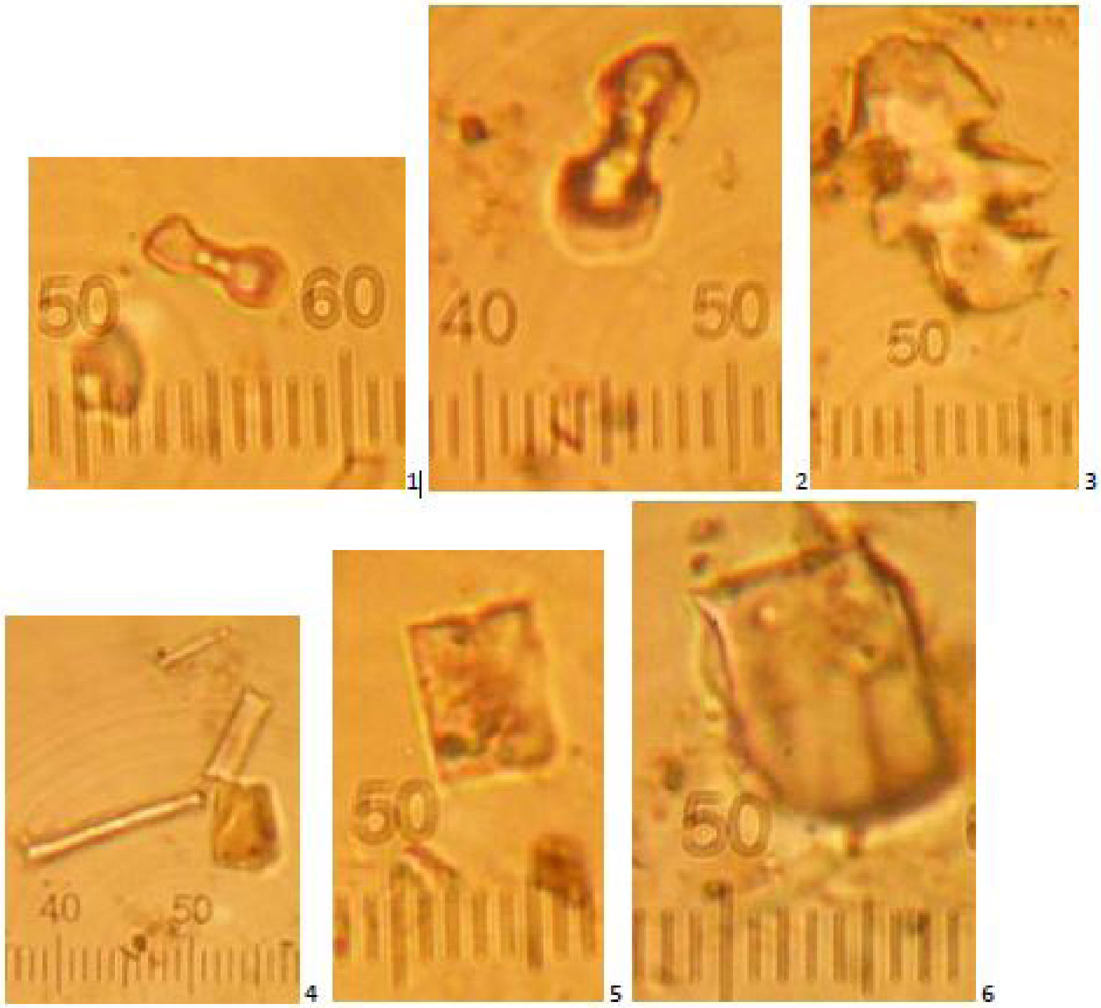
Figure 7: Frequency of Phytoliths SPR 'C'



Frequency of Phytoliths from trench SPR 'I' = Nalasopara

Figure 8: Frequency of Phytoliths SPR I

Phytoliths/ Microfossils from Nalasopara (SPR)



1. Short shaft panicoid dumbell
2. Short shaft panicoid dumbell (occluded)
3. Irregular trilobate
4. Elongate rod types
5. Festucoid Square
6. Bulliform Rectangular

Figure 9: Phytoliths_Microfossil from Nalasopara

Table 3: Phytolith, microfossil observations and climate Index of SPR-C

Core Sample: Gass 09 (Sample ID: SPR-C)
This auger sample is taken near the banana plantation 560m east of Gass Lake and 140m west of the creek (Lat. 19.402839, Lon. 72.801091). The area is a part of the habitation site and elevated than other areas of the wider land-scape. It seems the ancient habitation was on the ridge. This point is located at the most elevated area of this mound. 5m AMSL

Sample no.	*Unit*	*Character*	*Important Features*	*Phytolith and Micro-fossil Observations*	*Remarks on Climate and other Index*
SPR-C-1,2 and 3	I (0-50 cm)	The soil (30cm) recovered is fine powdery habitation soil (sandy-silty nature). It contains high composition (26.49%) of very fine sand. There is the presence of pottery and brickbats as well as some amount of chalcedonic silica, clayey grits, calcrete, basalt and roots. From 40 cm onwards some difference can be seen in colour and compactness and it becomes sandy-silty in nature. The composition of very fine sand is high in the soil, i.e. 35.5% and it contains sub-rounded to angular chalcedonic silica, pottery grits, basalt and clay lumps as well as calcrete. Between 40 and 50 cm, there is some change in the composition and the unit is dominated by fine sand (24%) and very fine sand (24.12%). It is slightly darker than the previous layer. It also contains pottery, chalcedonic silica, basalt, clay grits, and calcrete. The sand-silt percentage is 68.50% and 27.66%. (10y/r 3/3-dark brown to 10y/r 3/2 -very dark greyish brown).	Silty sand. Anthropogenic activity, Habitation soil	The upper 30cm shows degenerated phytoliths along the edges. The frequency of Chloridoid is more as compared to other morphotypes.	Moderate warm humid (low c/w) Arid (High Ip)
				The middle section of this unit (30-40cm) shows well preserved phytoliths with high frequency of elongate types and Trichomes. Fan shaped bulliforms were also observed.	Cool (high Ic and c/w)
				The lowest layer of this unit indicates a high frequency of Trichome, Bulliform and Silicified woody elements. Most Phytoliths were occluded in nature. Presence of Insect chitin was noted.	Cool (high Ic and) to Warm humid (low c/w)
SPR-C-4	II (50-60cm)	Texture wise this unit is finer and loose (less compact) than the previous layer. It is dominated by very fine sand (32.32%). Chalcedony silica, calcrete, few basalt pieces and broken pottery pieces are present in this unit. The sand-silt percentage is 65% and 24.50%. (10y/r 3/2 -very dark greyish brown).	Slightly silty sand. Anthropogenic activity, Habitation soil	Most phytoliths were occluded in nature. With high concentration of Bulli-formPhytoliths. The frequency of Panioic, Chloridoid and Festucooidphytoliths was comparatively low.	Cool (high Ic and c/w)

SPR-C-5	III (60-70cm)	It is more powdery and loose than the previous layer. It is dominated by fine sand (33.52%) and very fine sand (31.04%). It contains chalcedony silica, basalt, clay grits, calcrete and pottery pieces. The sand-silt percentage is 76.46% and 22.12%. (10y/r 3/3 -dark brown).	Slightly silty sand, anthropogenic activity.	This is the only unit indicating a high frequency of panioid dumbbell phytoliths followed by moderate distribution of other Phytolith subtypes.	Cool (high Ic and c/w)
SPR-C-6	IV (70-75cm)	This unit is very fine sandy in nature as the composition is dominated by very fine sand i.e. 44.68% and fine sand 31.9% and has more water content. The presence of pottery pieces, calcrete, clay grits, basalt nodules, microlith (burin) and chalcedonic silica have been also seen in the sample. The presence of microliths and pottery indicate that the Mesolithic population possibly occupied the stabilised dunes which were later used by the early Historic settlers. Sand-silt the percentage is 82.62% and 17.3%. (10yr 4/4 -dark yellowish-brown). *A Microlith (Burin) on chalcedony silica is prepared on a broken flake fragment and measures 13.66mm (L), 12.24 (W) and 3.82 (T) is recovered from this unit. Two burin spalls have been removed from the distal end towards the lateral side. No secondary retouches are visible. However, the flake bears two unidirectional parallel dorsal flake scars and a few small flake scars along the edges. It has a triangular shape and a rectangular cross-section. The platform is missing and no cortical part is visible on the flake. The surface is abraded due to friction with sand.)*	Slightly Silty-Sand, anthropogenic activity.	This unit represents multiform phytoliths especially of Trichome and Festucoid types.	Cool (high Ic and c/w)

SPR-C-7 and 8	V (75-100cm)	From 75-90 cm the layer is dominated by very fine sand (48.6%) and contains potsherds. The colour of the soil is lighter than the preceding layer. It contains rounded and sub-rounded basalt and chalcedonic silica nodules as well as calcrete and clay grits. The frequency of small chalcedony/ basalt grits is lesser than the previous unit. From 90 to 100cm fine sand (39.48%) slightly coarser than the previous unit dominates the unit. It contains well rounded to subrounded small grits of chalcedony silica and basalt as well as larger angular basalt pebbles having a rough surface. It also contains calcrete nodules and calcrete coting can be seen on the basalt pellets. No bioturbation as well as no cultural material. Both the layers of this unit contains very small particles of calcareous bodies (Freshwater) in the same proportion. The sand-silt percentage is 82% and 18%. (7.5yr 4/3-brown to 7.5yr 3/4 -dark brown).	Slightly silty sand. No anthropogenic activity, freshwater shells and clay grits indicating tidal or fluvial activity, sharp increase by 15% in very coarse and coarse sand.	The upper 15cm of this unit showed multiform phytoliths of Bulliform and Trichome types. A large size fraction of Phytoliths (> 100 microns) was recovered. Phytoliths were occluded with slight patination on its surface. Presence of Insect chitin was noted.	Cool (high Ic and c/w)
				Whereas, in the lower 10cm most phytoliths Festucoid and Elongate Phytoliths were predominant. Presence of Insect chitin was noted.	Warm humid (low c/w, Ic)
SPR-C-9 and 10	VI (100 to 120cm)	The sediments are dominated by very fine sand composing an average of 38.67% of the sample. Texturally the sediment in the layer is coarser than the previous unit due to the high percentage of medium-grained sand. It contains well rounded to sub-rounded basalt and chalcedonic silica nodules and angular pottery fragments. It also contains calcrete and calcrete coting can be seen on the basalt pellets. Very minute particles of calcareous masses can be seen in the layer. In the upper part of this unit very small grits of clay are evident, whereas in the lower levels of this unit calcrete and pottery pieces are absent. The sand-silt percentage is 80.50% and 15.4%. (7.5y/r 3/4 -dark brown).	Slightly silty sand. No anthropogenic activity, carbonate shell pieces (Freshwater).	The upper 10cm of this unit is the only sample indicating multiform panicoid dumbbells that of long and short shaft type.	Warm humid (low c/w, Ic) Arid (high Ip)
				Lower 10cm has the highest frequency of Bulliform types of bulky and occluded nature along with other silica matrix.	Cool (high Ic and c/w)

SPR-C-11	VII (120-130cm)	This unit is as sandy as the previous layer and is dominated by very fine sand, i.e. 41.66%. However, a considerable increase in minute calcareous particles is evident. These particles are cemented together in the sandy matrix and can be identified as bivalve and mollusc shell pieces (presence of freshwater shells/terrestrial shells-can be interpreted as an episode of a fluvial activity on the sand dune surface. The absence of marine shell fragments indicates a non-marine origin of sediments of this unit). A few fragments of palm/ date leaves can be also seen. Other than this, rounded to sub-rounded as well as angular fragments of basalt, chalcedony silica is also present. In the lower 5cms presence of concretised sand and cemented sandy gravel is another character of this layer. Sand-silt the percentage is 67% and 10.4%. (10yr3/4-dark yellowish-brown).	Slightly silty sand. No anthropogenic activity, fluvial activity	This unit has a low frequency of Panicoid, Festucoid and Bulli-formPhytoliths.	Warm humid (low c/w, Ic)
SPR-C-12 and 13	VIII (130 to 150cm)	This layer is as sandy as the previous layer and is dominated by very fine sand, i.e.47.74%. A thin lens of cemented sand with large shells pieces is a part of this unit as well as fragments of cemented thin lenses of sand containing lots of very small fragments of shells is also part of this unit. This layer is represented with a considerable increase in calcareous body and has comparatively less chalcedony silica and less nodular/ reworked calcrete pellets. A few clay lumps along with rounded to sub-rounded basalt, chalcedonic silica as well as calcite particles is also visible. The encountering of small mollusc saltwater shells is indicative of beach sand. Other than this few fragmentary pieces of operculum were also encountered in this layer. The lower 10cm of this unit is dominated by very fine sand, i.e. 46.63% almost the same as overlying 10cm and the only difference is an increase in the number of calcareous masses. A solitaryrhizoconcretion, a reworked calcrete nodule, chalcedony silica, angular basalt fragment and cemented sand is present in the lower horizon. Calcareous masses (saltwater bivalve and mollusc shell fragment) has also increased. The overall sand-silt percentage is 87% and 9.7%.10yr4/4 (dark yellowish-brown) to 10yr4/3 (brown).	Slightly silty sand. No anthropogenic activity, fluvial activity (presence of very high percentage of very fine sand, freshwater shells)	The upper horizon (10cm) indicates multiform phytoliths of Panicoid and Bulliform types.	Warm humid (low c/w, Ic)
				The lower layer indicates multiform phytoliths. Trichome and silicified woody elements are found in high frequency.	Warm humid (low c/w, Ic)

Table4: Phytolith, microfossil observations and climate Index of SPR-I

Core Sample:**SPR-AUG_2020.I** This auger sample is taken in the vegetable field, 66 m west of SPR-AUG_2020.C and 394 m east of Gass road (19.403015, 72.800640). 4m AMSL.					
	Unit	*Character*	*Important Features*	*Phytolith and Microfossil Observations*	*Remarks on Climate and other Index*
	I (0-45cm)	The uppermost level of this point is silty in nature with cultural material such as pottery as well as a very small amount of calcrete. The lowermost horizon of this layer has fine sandy silty sediment which is powdery in texture. It contains basalt, chalcedonic silica and freshwater shell fragments, powder calcrete. The sand silt percent in this unit is 71% and 25%. The colour of this Unit varies from 7.5YR3/3 (dark brown) to 7.5YR3/4 (dark brown).	Slightly silty sand, Anthropogenic activity; freshwater/ terrestrial shells and fine sand, habitation soil	High concentration of silicified woody elements followed by Festucoid and BulliformPhytolithmorphotypes. Bulliformphytoliths indicate fluctuations of dry and cool climate dominated by Panicoid/Triticum species. In the lower 15cm very low concentration of Diatoms is observed. Well preserved short shaft panicoids were observed.	Moderate Cool (high Ic and) to Moderate warm humid (low c/w)Arid (High Ip)
	II (45-100)	This the sample is dominated by very fine sand (41.09%). It contains pottery but in a lesser amount as well as basalt, chalcedony silica and very few fragments of freshwater shells. Some amount of powdery calcrete is also present in the sample. In the lower 40 cm the soil is loose. The sand silt percentage of this Unit is 60% and 36% and the colour is 7.5YR4/3 (brown) to 10YR3/6 (dark yellowish-brown).	Silty sand, anthropogenic activity, freshwater shells.	This zone represents a high concentration of silicified woody elements followed by Festucoid and Bulliform Phytolith morphotypes. Bulliform phytoliths indicate fluctuations of dry and cool climate dominated by Panicoid/Triticum species. In this unit very low concentration of Diatoms is observed. Well preserved short shaft panicoids were observed.	Moderate Cool (high Ic and) to Moderate warm humid (low c/w)Arid (High Ip). In lowest layer (40cm) Cool (high Ic and c/w)

	III (100-140)	The general character of this layer is it is fine sandy in nature (37.3%). It contains calcrete, basalt and chalcedonic silica and cemented sand and shell pieces. The presence of thin fine sandy lenses of partially cemented sand (7.5YR6/1; grey) is evident in this layer. This lens contains very fine particles of shell fragments. Below this, a layer containing a thin lens of partially compact sandy-silty deposit (7.5YR4/3; brown) containing very small fragments of shells. The lower 20cm of this unit has alternating lenses of very fine silty deposit (2-5cm), which is devoid of shell fragments. In the lower level, a fine sandy lens has been also encountered. This sandy lens is moderate to highly cemented and essentially contains very minute particles of the shells. However, the presence of basalt, chalcedony silica, calcrete, concretised sand is evident in the lower section of this unit. The colour of the lower 20 cm of this unit is the colour of the upper section is (7.5YR4/3; brown); alternating clayey lense- 10YR3/6(dark yellowish-brown); Lower layer-10YR5/2(greyish brown). The sand and silt percentage of this unit is 58.63% and 25.75%. The development of fine intercalating lenses of calcretiesed sand took place at the junction of silt and sand thereby indicating the development of groundwater calcrete (it has so happened that the fine silty layer that possibly may be regarded as Aeolian dust due to its contrasting colour of dark yellow colour was creating hindrance in percolation of water below thereby trapping the water. As the water evaporated the minerals precipitated and cemented the overlying sandy lenses).	Silty sand, no anthropogenic activity, alternating lenses of concretised sand mixed with small freshwater shell fragments and fine silty deposit is indicative seasonal ponding and drying of depressions and development of non-pedogenic (groundwater calcrete) at the junction of sand and silt.	Sharp peak of panicoid dumbbell, shloridoid and Festucoid short phytoliths is observed followed by bulky bulliformphytoliths. Here the short grasses indicate cool and dry climate. A decline in silicified woody elements is observed in this zone. The phytoliths appear blotchy and eroded at times.	Cool (high Ic and c/w)
				In the lower 20 cm the character is same as overlying layer with sharp peak of panicoid dumbbell, shloridoid and Festucoid short phytoliths is observed followed by bulky bulliformphytoliths. Here the short grasses indicate cool and dry climate. A decline in silicified woody elements is observed in this zone. The phytoliths appear blotchy and eroded at times.	Warm humid (low c/w, Ic) to Cool (high Ic and c/w)

	IV (140-150)	This unit is dominated by very fine sand (42.12%) having lots and lots of shell fragments in it. This unit is less compact and is sandier than the above unit. It has large chunks of developed calcrete nodules. Some large fragments of the marine shell have been also encountered in this layer. A thin layer of partially compact sandy-silty deposit with less concentration of shell pieces has been also encountered. It contains pottery, basalt and chalcedony silica. The sand and silt percentage is 71% and 21%. Large shell fragments may also indicate some sort of anthropogenic activity associated with marine shells. The partial compactness of the sandy-silty layer within the deposit may be indicative of seizure of dune development. The colour of the unit is 10YR4/3 (brown).	Slightly Silty Sand, anthropogenic activity, alternating lenses of compact and loose sand, sand mixed with marine shells indicate fluctuating environment at the site.	This unit has a high concentration of Trichome, Festucoid phytoliths and silicified woody elements as compared to theother zones. Phytoliths were diagnostic but with degenerated edges.	Cool (high Ic and c/w)

Over all inference of Phytolith and Microfossil

In summary it can be understood that the vegetation at Nalasopara was dominated mainly of Pleioblastus/ Andropogonea/reed type of phytoliths. This vegetation pattern at latter levels was of mixed nature represented mostly of Chloridoid and Festucoid grassland. This probably indicates that there was a wet –dry –wet phase within the region. The interpretation and understanding of phytoliths can be clearer by knowing the exact time span/ dates of the depths of the samples under consideration. Silica, SiO2, in dissolved and particulate form, is both a major product of continental weathering. The study estimates of the spatial distribution of silica fluxes under natural conditions, to segments of the coastal zone. It may be noted that some part of the phytoliths is not recycled and may be eroded, as the soil organic matter, and carried by rivers. Freshwater diatoms, living and as detritus, are also considered as biogenic particulate silica. All silica-containing components, including phytoliths are part of the particulate silica of river particulates. The retention of silica in river systems is linked to their trophic state. Besides atmospheric deposition of phytoliths contribute to the surface oceanic system. Phytolith analysis of the grasses from different coastal vegetation communities shows significant variation in shapes and assemblages. Although the study is based on the Phytolith contents of grass plants, the conclusions are supported by the evidence of other microfossils under investigation. The study demonstrates the high potential of phytolith analysis as a tool for identifying vegetation in coastal environments. Each locality under study of coastal environments yielded abundant and distinctive Phytolith assemblages.

It should be noted that Cyperaceae, produce primarily dumbbell, small cross, and Cyperaceae phytoliths. The Pooideae subfamilies of grasses, which are generally common along the maritime forests, produce Elongate phytoliths and long saddle phytoliths.

Climate Index (Ic), Phytolith index (Iph) and Cold / warm ratio (C/W)

The analysis was subjected to calculation of phytolithmorphotypes for Climate Index (Ic)(Bremond et al., 2005), Phytolith index (Iph) as proposed by Diester-Hass et al., (1973) and Cold / warm ratio (C/W) suggested by Lu et al., 2002. The analysis of phytolith assemblages and the variations in the phytolith counts, Ic, IpH and C/W ratios calculated down the sediment profile suggests that the phytoliths spread across the region indicates a Cool (high Ic and c/w) climate at large. However, few interlinings indicate a Cool (high Ic and) to Warm humid (low c/w) climate. In summary it can be understood that the vegetation grown over the SPR-C was dominated mainly Multiform Trichome (Gramineae/ Andropogonoid/ Boraginaceae/Burseraceae/ Fabaceae) type phytoliths. This vegetation pattern was of mixed nature represented mostly of Chloridoid and Festucoid grassland. This probably indicates that there were cycles of wet –dry–wet phase within the region. Irrespective of the context of the sample it is noted that there are multiform phytoliths. Panicoidphytoliths are found throughout the profile right from the lower levels. Multiform Trichome and elongates phytoliths were noted. Few phytoliths were observed to be degenerated indicating either leaching/etching or some other activity that is responsible for such preservation condition. This probably indicates that vegetation conditions were suitable for the grown of flora.

The vegetation at SPR-I was dominated mainly of Pleioblastus/Andropogonea/reed type at earlier levels. This vegetation pattern at latter levels was of mixed nature represented mostly of Chloridoid and Festucoid grassland. This probably indicates that there was a wet –dry phase within the region. This study provides a basis for the interpretation of fossil grass phytolith assemblages recovered from coastal sediments for the reconstruction of coastal environmental changes. Investigation demonstrates that these coastal environments produce distinctive phytolith assemblages that can be used as a supplementary tool in coastal paleo environmental reconstructions. Thus the results have been established for silica fluxes, concentrations and yields for drainage basins of oceans basins and coastal segments of Nalasopara.

Please refer Table 5 and 6 for the summary of Climate Index (Ic), Phytolith Index (Iph) and Cold / Warm (C/W) of samples from SPR-C and SPR-I.

Table 5: Remarks on Climate Index of SPR-C

Sample Number/Region	*Climate Index (Ic)*	*Phytolith Index (Iph)*	*Cold / Warm (C/W)*	*Remarks*
SPR C1	0.410	0.410	0.650	Moderate warm humid (low c/w) Arid (High Ip)
SPR C2	0.710	0.420	3.350	Cool (high Ic and c/w)
SPR C3	0.720	0.260	1.930	Cool (high Ic and) to Warm humid (low c/w)
SPR C4	0.710	0.460	2.530	Cool (high Ic and c/w)
SPR C5	0.580	0.300	3.050	Cool (high Ic and c/w)
SPR C6	0.750	0.230	3.230	Cool (high Ic and c/w)
SPR C7	0.760	0.380	2.840	Cool (high Ic and c/w)
SPR C8	0.710	0.220	3.000	Warm humid (low c/w, Ic)
SPR C9	0.320	0.430	0.750	Warm humid (low c/w, Ic) Arid (high Ip)
SPR C10	0.630	0.210	2.360	Cool (high Ic and c/w)
SPR C11	0.390	0.310	0.820	Warm humid (low c/w, Ic)
SPR C12	0.365	0.320	0.740	Warm humid (low c/w, Ic)
SPR C13	0.310	0.340	0.720	Warm humid (low c/w, Ic)

Table 6: Remarks on Climate Index of SPR-I

Sample Number/ Region	*Climate Index (Ic)*	*Phytolith Index (Iph)*	*Cold / Warm (C/W)*	*Remarks*
SPR -I -1	0.684	0.315	1.630	Moderate Cool (high Ic and) to Moderate warm humid (low c/w)Arid (High Ip)
SPR I - 3	0.652	0.347	1.210	Moderate Cool (high Ic and) to Moderate warm humid (low c/w)Arid (High Ip)
SPR I - 4	0.588	0.411	2.410	Cool (high Ic and c/w)
SPR I - 5	0.520	0.470	3.230	Cool (high Ic and c/w)
SPR I - 6	0.174	0.285	2.570	Warm humid (low c/w, Ic) to Cool (high Ic and c/w)
SPR I - 7	0.666	0.333	1.850	Cool (high Ic and c/w)

Calculation of phytolith morphotypes for Climate Index (Ic), Phytolith index (Iph) and Cold / warm ratio (C/W) shows a fluctuation with High values of Ic point to a cool climate conditions with A high Iph value indicating aridity or a reduced precipitation within the region. The analysis of phytolith assemblages and the variations in the phytolith counts, Ic, IpH and C/W ratios calculated down the sediment profile suggests that the phytoliths spread across the region indicates a Cool (high Ic and c/w) climate at large. However, few interlinings indicate a Cool (high Ic and) to Warm humid (low c/w) climate.

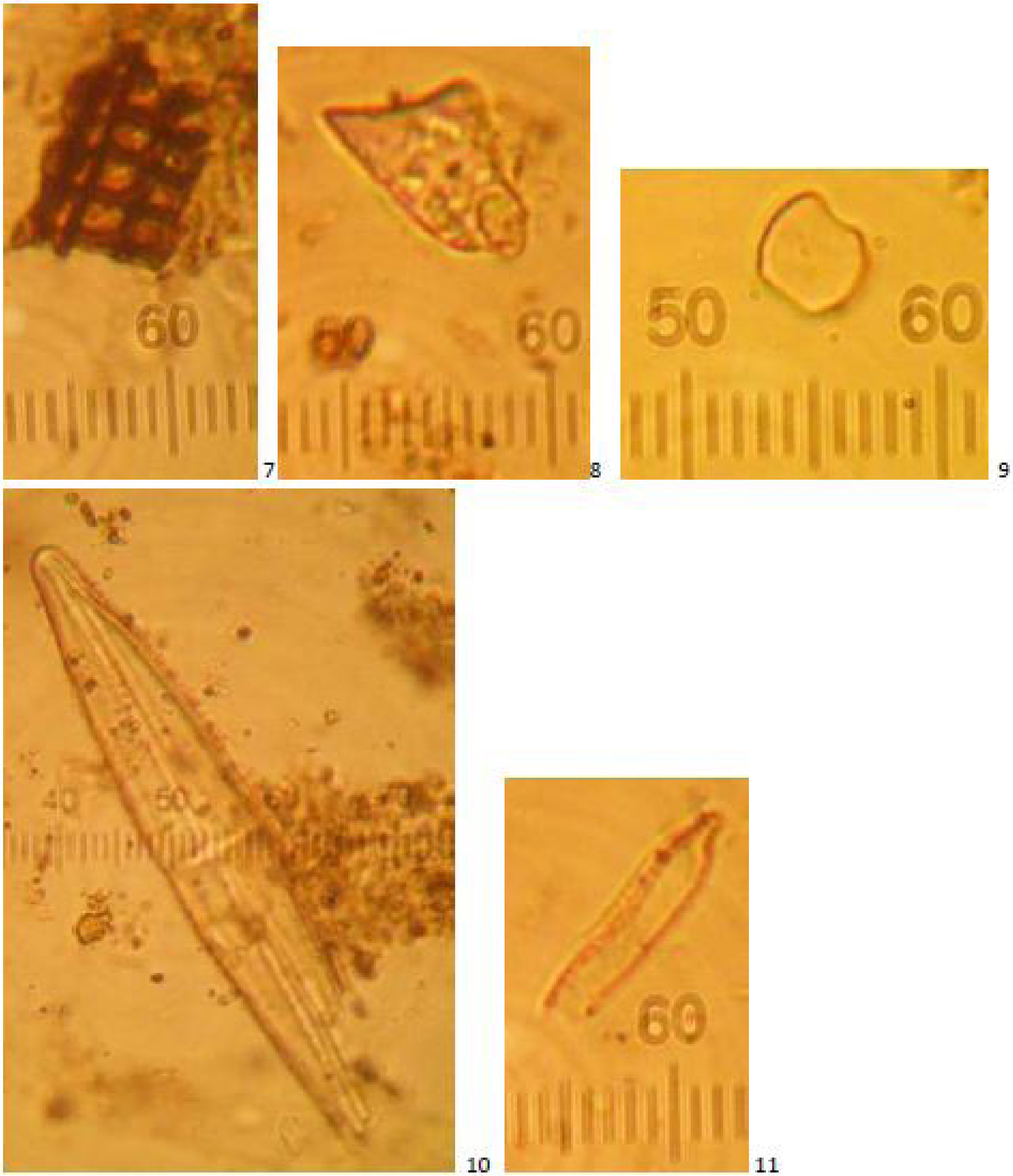
The vegetation at SPR-I was dominated mainly of Pleioblastus/Andropogonea/reed type at earlier levels. This vegetation pattern at latter levels was of mixed nature represented mostly of Chloridoid and Festucoid grassland. This probably indicates that there was a wet –dry phase within the region.

Discussion

The earliest occupation at the site took place during the Mesolithic Period in the Mid Holocene Phase. The Mesolithic hunter-gathers were occupying the sand dunes. The Early Historical archaeological mounds are spread in wider area of Sopara and adjoining villages and some of the sites are located as high as 7 m AMSL. These ancient habitation zones are situated in estuarine environments involving lateral transgressive-regressive phases more or less within the present intertidal zone of the Arabian Sea in a humid environment. It has been suggested that the ancient port of Sopara was once located on an estuary (which has converted to a mudflat now) towards the SE fringe of the Island. This trading estuarine Port of Sopara got defunct due to the accumulation of silt. The findings from a recently dug pond near SPR-A which is located in the vicinity of SPR-1 of (Howells Trench), near the Sopara Bunder excavated by Howell and Sinha (1994) shows that the Early Historical habitation site is buried below 1.5m AMSL and extends about 100 meters away from the site in the present mudflat area thereby indicating active siltation of the creek area during and after the Historical period. This is well corroborated with the findings which shows that the Holocene transgression reached its maximum around, 2800-2000 BP, was almost 1 m higher, and deposited beach ridges in the Konkan Coast between Bombay and Goa (Brückner 1989) and hence it is quite possible that in the past the nature of shoreline was quite different as that of today.

The British period maps eg., India III. Bombay Presidency (Walker sculpt. 1832) clearly shows Sopara creek originating near Jhow Island in Vaitarna River joins Ulhas river near the Island of Panju. Letts, Son & Co. (1883) Statistical & general map of India. No. 3, clearly shows the creek along with the railway track as an active creek. However, 1934 map of the Survey of India (Bombay and surrounding country) clearly shows that the creek has disconnected from the Vaitarna River near Bolinj and has been divided into northerly flowing Bolinj creek and southerly flowing Sopara creek.

Phytoliths/ Microfossils from Nalasopara (SPR)



7. Dicotilidinous woody element
8. Blotchy Trichome
9. Chloridoid Saddle
10. Pennate Diatom (Large)
11. Pennate Diatom (small)

Figure 10: Phytoliths_Microfossil from Nalasopara-1

This shows that within a span of 102 years the active Sopara creek that was connected by Ulhas and Vaitarna River gets disconnected due to heavy siltation.

Survey results and the analysis of core samples indicate that geomorphic units at the site are formed by varying processes such as coastal, estuarine, lacustral, fluvial, as well as aeolian processes during the Holocene Period. The upper units are either finer sands of beach dune origin that are many a time altered by anthropogenic activity of Historical or recent periods or are the fine silty sediments that are deposited by tidal activity or due to localized ponding that has taken place in the interdunal pond or dune slack or ridge depressions.

These preliminary findings contribute to develop some understanding of the early coastal environments and ancient coastal histories of the site of Sopara. Considering the Early Historical sea level 1m higher than today, the analysis of the borehole data indicates that some of the sites in ancient Sopara were located near the estuaries about 0.5m AMSL and some of the inland sites were located below the sea level (Figure 12).

The analysis of auger samples of certain key locations of the site helps us to understand long-term site formation processes. Bore hole data clearly indicates the main geomorphological features of the specific areas of the site as well as it is also helpful in understanding the spatial distribution of ancient settlements. The analysis of the sediments indicates that the ancient habitation formed along the littoral terraces, beach, mud flat surfaces, and coastal plains, along the paleo lakes and creeks, large depressions as well as on the coastal dunes. The study shows that various processes have contributed in the evolution and transformation of the landscape during the Holocene period, specially the Mid Holocene transgressive and regressive changes in the coastline that were not only

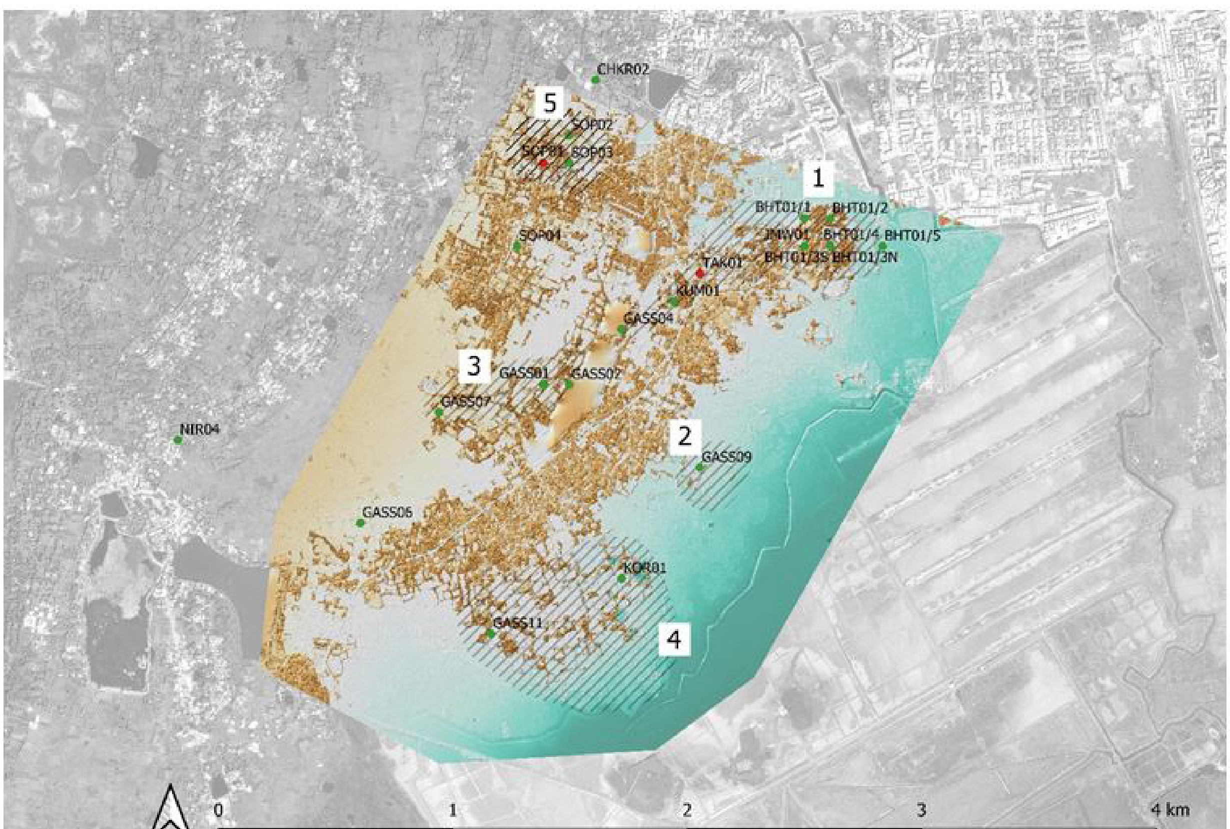


Figure 11: Archaeological Sites Sopara

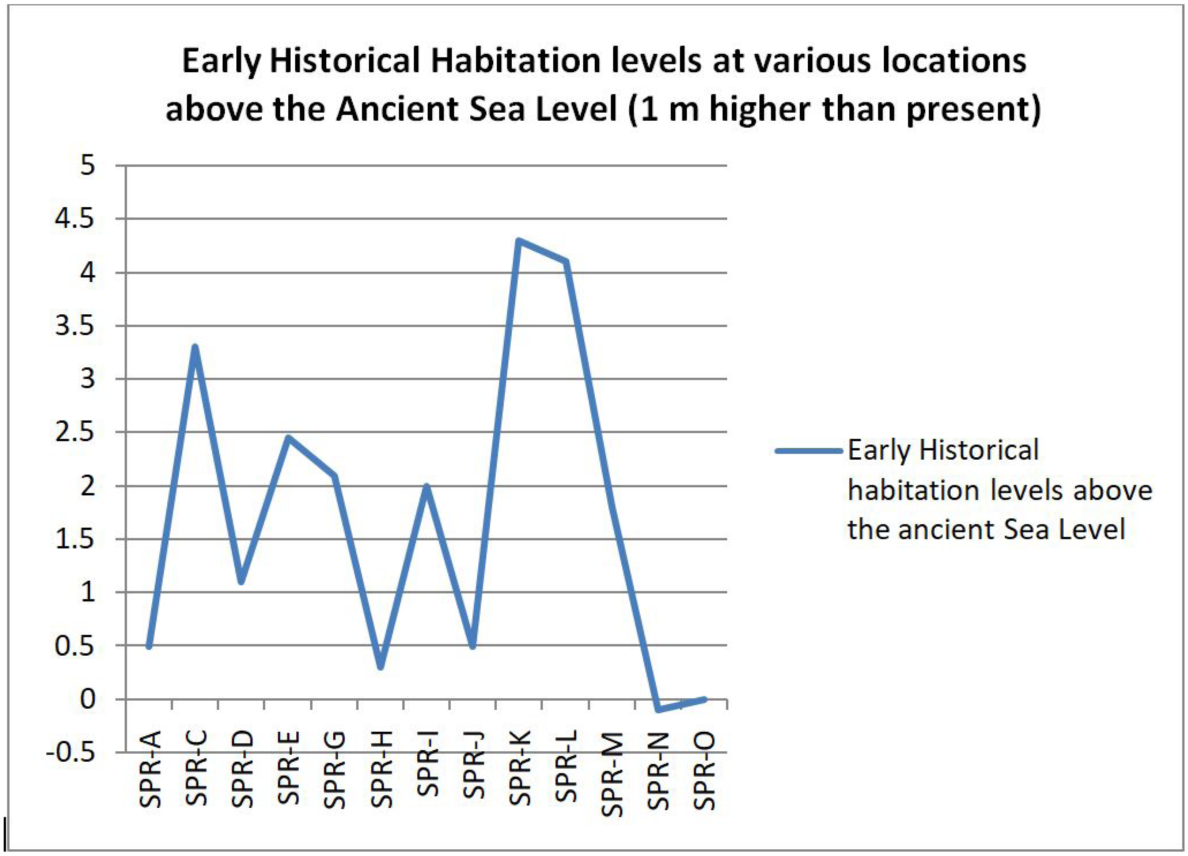


Figure 12: Early Historical habitation levels above the ancient sea level

responsible for destroying the past records of human habitation (Mesolithic occupational areas) but were also responsible in the formation of new occupation zones as well as played an important role in settlement abandonment and reoccupation of sites. These changes were driving force behind shifting of ports and navigable areas. There is a general view that the numerous fresh water lakes in and around Sopara were navigable during the early Historical Period which seems quite unlikely since all these lakes are located about 5 to 7m AMSL and it is quite unlikely that during Early Historical period (2600 BP to 2000 BP) when sea level was c.1m higher than the present, even during the high tides the navigable water have reached all these lakes. It appears that all these lakes were a place of great interest during the ancient period and even after that since these were the only source of portable water and center for performing religious and cultural activities. The remains of innumerable structural activities surrounding these lakes testify this fact.

With this limited data it is not possible to pin point distribution pattern of the entire early historical site and the influence of geomorphological processes on the settlement pattern, structural activities as well as coastline changes that took place in the past. For a detailed geomorphological understanding and past environment, a high resolution borehole data and a geophysical survey of the important locations are warranted.

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