EXCELLENT PUBLISHERS

International Journal of Current Research and Academic Review

ISSN: 2347-3215 Volume 3 Number 10 (October-2015) pp. 303-316

www.ijcrar.com

Relative Sea level, Climate and Geomorphological changes since ~8 ka in Krishna river delta, India

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KEYWORDS

Palynology,
sedimentology,
sea level,
Krishna Delta,
Holocene

A B S T R A C T

The low-lying coastal areas worldwide are under the threat of Relative Sea level (RSL) rise either due to changes in climate or geomorphology. The geomorphology of the east coast of India is largely governed by monsoon-driven rivers/streams and show gentle gradient (0.5 to 1m above present mean sea level) extending 5-6 km landwards. A palynological study was carried out in a 500cm deep sediment core deposited since ~8.2 ka in the north-eastern part of Krishna river delta to understand the trends in RSL and climate/ geomorphological changes during Holocene. The entire core shows high salinity and is fine clayey-silt with intermittent bands of sandy layer/ shell particles. The period from 8.2-7.2 ka shows no marine palynomorphs but later between 7.2-4.0 ka records of back mangroves such as *Avicennia* and its associates indicate fluvio-marine ecosystem suggesting that the sea level rise encroached land to about 10 km from the present shoreline. The highest diversity of terrestrial and mangrove pollen was recorded between 7.0-3.0 ka indicating warmer and humid climate and high RSL. However, between 3.0-4.0 ka, a sudden rise in net rate of sedimentation (from ~0.03 to 0.34 cm/yr.) is recorded thereafter, a decline in mangroves indicate a retreat in RSL until present which is attributed to tectonically controlled changes in the region. In the vertical stack of studied core the evidence of 6-7 ka global transgressive event is ~10 km inland and present slightly above the present day mean sea level indicating upliftment of about 1 to 1.5m in the region.

Introduction

In coastal wetlands, the events of flooding and erosion are commonly controlled by land subsidence induced by sediment compaction in vertically stacked sediments through time which directly or indirectly affect the RSL (Mazzotti, et al., 2009).

These changes are vulnerable in areas with low slope gradient which in general have coastal habitation with increased demography. Anthropogenic activity such as ground water and hydrocarbon extraction also triggers the land subsidence (Bianchi and Allison, 2009). Mangrove productivity and diversity is strongly influenced by climate and coastal physiography (Lugo and Snedaker, 1974; Hutchings and Saenger, 1987; Mitsch and Gosselink, 2000; Gilman et al., 2008). The mangrove has ability to change its position towards land during transgression and seaward during regression in coastal areas (Ellison, 2012; Mclover et al., 2013). A number of studies related to Holocene sea level change and the contraction and expansion of mangroves in coastal wetlands have been carried out worldwide (Woodroffe, 1981; Blasco et al., 1996; 2005; Ellison, 2005; Horton et al., 2005; Engelhart et al., 2007; Monacci et al., 2009, 2011; Krauss, et al., 2014). Mangrove palynology has been widely accepted as one of the potential indicators of RSL fluctuation (Banerjee, 2000; Farooqui and Vaz, 2000; Engelhart, et al., 2007; Farooqui and Naidu, 2010; Farooqui, 2014).

The consequences of climate change and land subsidence in coastal areas largely relate to RSL (rise/fall) affecting the economy of the region. It is likely to play a major role in defining biotic or abiotic changes in coastal sediments. Thus, the ecological changes through time affect mangrove zonation its extinction and migration. The present study is aimed to understand the evidence of RSL and climate since Middle Holocene in the vertical stack of coastal sediments and the tectonically controlled geomorphological changes in the region for future prospecting in a highly fertile Krishna river delta.

Climate and Geomorphology of Study Area

The study area is tropical to semi-arid where the mean annual atmospheric temperature is 29^0 C. An annual average 80 – 100 cm seasonal precipitation is during south-west monsoon (June-September) and North-East monsoon (October-December).Tidal amplitude in Krishna river delta is 1.5 m (Jain et al., 2010). The Krishna delta is much above the mean sea level as compared to the Godavari delta in the North-east but nowhere the elevation is above 16m. The slope of the Krishna delta is towards south-east and the core site is located in the northern part of the delta (Figure 1). The Eastern Ghats highland show a NW-SE trend and the sediment deposits in the coastal basin too follow the same dip. The older Gondwana and Trappean group of rocks too show a similar trend. The Krishna Cross trend faults coincide with Krishna River course in NE and SE direction and due to this fault the Krishna delta bulges (cuspate shaped) into the sea and grows towards south into the Nizampatnam Bay. The upper fluvial plain of the delta is characterized by the abandoned river courses and natural levees and the lower coastal strand plain includes beach ridges, mudflats, mangroves swamps, lagoon and spits which reflect the marine influence. An earlier record of geomorphic evolution in the Krishna delta reveals a number of ancient beach ridges that extends 35 km inland from the present coastline dating back to Holocene (Rao, et al., 2005, 2013). Mangroves are prevalent around the distributaries in tidal creeks, channels, lagoons, tidal flats and mudflats. Hamsaladivipaya is the distributary channel of Krishna River that flows close to the study site in the northeast before merging into the Bay of Bengal.

Highlights

1. Palynological record since ~8.2 ka is recorded in 500cm core from Krishna river delta.
2. The shoreline encroached ~10 km inland from the present shoreline ~7 ka.

3. Stabilized estuarine ecosystem recorded between 7- 4 ka and later a fall in RSL is evident.
4. High net rate of sedimentation from 3.0-4.0 ka suggest upliftment/subsidence in the area.

Materials and Methods

A 500 cm deep core sediment sample were collected at Latitude 16° 01'881" N and Longitude 81° 01'617"E from an exposed land in the vicinity of Narsimhapur (Figure 1) situated about 5 km from the present day channel of Hamsaladivipaya (Krishna river tributary), Andhra Pradesh. The core site is located 10 km inland from the present shoreline. The samples were collected with Auger-cum-piston corer (Eijelkamp, Netherland) and sub sampled at 2.5 cm interval and stored in air-tight polythene bags without any preservatives. The textural analysis of the sediment was done by the density method (USDA, 1992) and Salinity (ppt) was measured using 'Orion-5 Star (Thermo-Orion, Scientific Equipment, USA) following Farooqui et al., (2012). For thecamoebian study, air dried 10g of soil samples were treated with warm 10% KOH on sand bath. After passing through 150 mesh size (~105 µm) the filtrate was passed through 650 mesh (10 µm) and the residue was mounted in glycerin for thecamoebian study under light microscope.

For Palynological study about 10 g samples was treated with KOH as mentioned above and the filtered (150 mesh) sediment was treated with 30% HF to remove silica. These samples were acetolysed by using glacial and anhydrous acetic acid following Erdtman (1943) and subsequently passed through 650 mesh. The maceral was maintained to 5ml and stored in 50% glycerin & water. A drop of homogenized sample was mounted on glass slide and observed under high power transmitted light microscope (Olympus BX-52) and ~200-300 palynomorphs and thecamoebians were counted per sample and relative percentages were calculated for the spectrum (Figure 3). The pollen sum includes Mangroves and its Associates, terrestrial Arboreal Pollen (AP) and Non arboreal Pollen (NAP). The aquatic pollen and ubiquitous taxa like Cyperaceae/Poaceae were excluded from the pollen sum and the percentage occurrence was calculated against Pollen Sum. The ratio of AP versus NAP was calculated in order to assess the forest cover. The ratio between Marine (Mangroves, dinoflagellate cysts, foraminifera linings) versus Terrestrial (AP, NAP, Thecamoebians) forms were calculated for analyzing the magnitude of tidal influx in the past. Standard references (Nayar, 1990; Tissot et al., 1994; Thanikaimoni, 1992) and Sporothec in Birbal Sahni Institute of Palaeobotany were consulted for the identification of palynomorphs. Five Radiocarbon dates(C-^{14}) were obtained from Birbal Sahni Institute of Palaeobotany, Lucknow and calibrated Radiocarbon (^{14}C) ages (Stuiver et al., 1998) are given in Table 1.

Results and Discussion

Chronology and Sediment texture

Five Radiocarbon (^{14}C) dates (Table 1) reveal the chronology of the studied sediment core. The age is 6600±100 cal BP at 440-445 cm depth and the extrapolated age at 500 cm depth is calculated to be ~8.2 ka (depth versus radiocarbon age). At 470 cm the age falls ~7.2 ka if the net rate of sedimentation (Figure 2) remained same. This is assumed as the texture of the sediment is almost similar (Sandy clay). The intrapolated age at the depth of 395 cm is ~ 4.9 ka. The radiocarbon date at 354-364 cm is 3900±100 cal BP and at 285-290 cm it is

3400±90 cal BP and the intrapolated age at 215 cm is ~ 3.1 ka. The Radiocarbon date of 140-145 cm is 2900±80 cal BP and at 50-55 cm depth it is 750±70 cal BP. The intrapolated age at 105 cm depth is ~1.5 ka. The five phases (1 to 5) of sediment depositional environment were identified on the basis of pollen/spore, thecamoebian and Physico-chemical characteristics. The bottom most sandy clay sediment of phase 1 at the depth 470-500 cm deposited from 8.2 to 7.2 ka show average salinity of 3.6. Phase 2 shows again clayey sediment with few shell fragments (475-395 cm) which was deposited in 2700 years between 7.6 to 4.9 ka showing high salinity of 3.2. The middle sandy clayey sediment of phase 3 at 395-215 cm depth show 2.1 salinity which was deposited in 2000 years from 4.9 to 3.1 ka. The second topmost clayey sediment of phase 4 between 215-105 cm depth was deposited in 300 years from 3.1 to 1.5 ka and the average salinity is 1.5. The lowest salinity (0.6) was recorded in the topmost clayey sediment (0- 105 cm depth) which was deposited during 1.5 ka.

Palynology and fresh water thecamoebians

Phase 1 (470-500 cm) 8.2 to 7.2 ka.

This phase shows very low preservation of palynomorphs. The palynological spectrum is given in Figure 3. Out of the total palynomorph count only 2-3 pollen grains of *Moraceae* and *Acanthaceae* were recorded. Cyperaceae and Poaceae pollen were absent. Mangrove pollen or any other marine palynomorphs were absent. The diversity of Terrestrial AP (arboreal pollen) recorded here is 2.5% and NAP (non arboreal pollen) is 1.89 % as compared to its percentage in other phases. Pteridophytic trilete spores constitute 10.0% and algae such as *Pediastrum*, *Botryococcus and Chlorotetraedron* constitute about 25% along with 10% of Acritarchs of the total palynomorphs count. Fresh water thecamoebians were absent.

Phase 2 (400-470cm) 4.9- 7.2 ka.

Mangroves and its associate pollen constitute 5.3 %. Out of which the high percentage is of *Excoecaria* (1.2%) and *Rhizophora* (1.7 %) followed by *Avicennia* (0.1), *Aegiceras* (0.4), *Sonneratia* (0.1) and *Nypa* (0.1). The mangrove NAP constitutes *Acanthus ilicifolius* (1.7%).The terrestrial arboreal pollen recorded were Anacardiaceae (7.4 %), Apocynaceae (1.8%), *Bentinckia* (0.1), *Shorea/Hopea* (1.5 %), *Eugenia* (0.1%), Icacinaceae (0.1%), Meliaceae (5.2 %), Moraceae (1.1%), Myrtaceae (0.2%), Sapotaceae (0.3%), Combretaceae (0.9%), *Terminalia* (0.3%) and NAP constitute Rubiaceae (0.2%), Chenopodiaceae (23.0%), Loranthaceae (0.5%), *Tabernaemontanae* (0.1%), *Sauropus* (6.9%), Asteraceae (2.0%), Acanthaceae (6.2%), *Monchema* (1.4%), Amaranthaceae (1.7%), *Artemisia* (1.1%), *Impatience balsamina (0.4%)*, Caryophyllaceae (0.2%), *Hygrophila* (0.5%), *Justicia* (0.5%), Lamiaceae (0.3%), Liliaceae (0.7%), Papaveraceae (0.2%), Urticaceae (0.5%), Euphorbiaceae (1.7 %), Solanaceae (1.0%), *Mallotus* (0.7%). As compared to the diversity in other phases the mangrove AP show 35.3 % and NAP 40 %. The terrestrial diversity of AP shows 30 % and NAP 39.62 % as compared to other phases. Aquatic pollens constitute (1.3 %), Gymnosperms (1.8 %), Pteridophytic spores (8.8 %) that includes Monolete (1.3 %), Trilete (7.5 %) against the pollen sum. Fresh water algae constitute (25.7%) and Thecamoebians (1.6%). Marine palynomorphs such as Foraminifera lining (0.9%) and Dinoflagellate cysts (6.8 %) were also recorded. The cyperaceae and poaceae are 21 % against the total pollen count (Figure 4). The ratio of marine and terrestrial form is 0.3 (Figure 4). The NAP dominates in this phase constituting 49.4 % followed by AP (19 %).

Phase 3 (215-400 cm) 3.1- 4.9 ka.

Total 28.2 % of Mangroves and its associates were recorded. Out of which AP constitutes 13.1 % and NAP is 14.9%. These are *Avicennia* (5.9%), *Bruguiera* (0.4%), *Ceriops* (0.1%), *Excoecaria* (1.4%), *Rhizophora* (3.5%), *Sonneratia* (1.2%), *Xylocarpus* (0.1%) and *Nypa* (0.6%). The mangrove NAP recorded were *Acanthus ilicifolius* (0.7%). The ratio of Mangrove AP and NAP is 0.9. The terrestrial AP constitute Anacardiaceae (14.3 %), Apocynaceae (0.5%), *Bentinckia* (0.1), Bignoniaceae (0.1%), Bombacaceae (0.4%), Careya (0.3%), Clusiaceae (0.3%), *Cullenia* (0.3%), *Shorea/Hopea* (0.9%), *Eugenia* (0.1%) Meliaceae (0.7%), Moraceae (5.6%), Myrtaceae (0.1%), Sapotaceae (0.4%), Caesalpiniaceae (0.1%), Combretaceae (0.8 %) and NAP constitute Rubiaceae (0.1%), Chenopodiaceae (32.0%), Faboideae (0.1%), Asteraceae (1.8%), Acanthaceae (5.5%), *Monechma* (0.4%), Amaranthaceae (1.5%), Apiaceae (0.4%), Caryophyllaceae (0.4%), Campanulaceae (0.7%), *Chrozophora* (0.3%), *Hygrophila* (1.2%), *Lapidagathis* (0.2%), *Polygonum plebeium* (0.1%), Urticaceae (0.4%), Vitaceae (0.4%), Euphorbiaceae (0.3%), Solanaceae (0.8%), *Mallotus* (0.8%). As compared to other phases the diversity of mangroves is highest (47.1%) and NAP is 40 %. The other Terrestrial AP is also high (40 %) and NAP is 40.15%. Aquatic pollens constitute (0.3 %) and Gymnosperms (1.0%), Ferns (23.8%) includes Monolete (3.9 %), Trilete (19.8%), Algae constitute (30.2 %), Thecamoebians (1.8%), Foraminifera linings (29.4%) Dinoflagellate cysts (4.7%). The cyperaceae and poaceae accounts to 70 % against the pollen sum. The NAP dominates (57.4%) in this phase followed by AP (25 %). The ratio of marine versus terrestrial form is 0.9.

Phase 4 (100-215m) 1.5- 3.1 ka.

Good percent of mangroves were recorded in this phase. Mangroves AP constitute (9.3%).Out of these *Avicennia* (4.5%), *Excoecaria* (3.6%), *Sonneratia* (1.2%) and *Acanthus* constitute 1.2%. The arboreal pollen includes Anacardiaceae (2.4 %), *Shorea/Hopea* (1.2%), Meliaceae (0.3%), Moraceae (3.6%), Combretaceae (0.8 %) and NAP constitute Rubiaceae (1.2%), Chenopodiaceae (9.3%), Acanthaceae (0.8%), Caryophyllaceae (0.3%), Euphorbiaceae (0.8%). The Terrestrial AP is 12.5 % and NAP is 9.43%. Aquatic pollens are absent. Pteridophytic spores account to 1.7% which include Monolete (0.8%) and Trilete (0.9%). Algae constitute (0.8 %), Thecamoebians, Foraminifera lining, Dinoflagellate cysts were absent. The Cyperaceae and Poaceae is 22 % of the total pollen count. The ratio of marine and terrestrial form is 0.5.

Phase 5 (0.0-100 cm)

This phase exhibits dominance of AP (18.4%) followed by NAP (14.2%). Mangroves are absent in this phase. The arboreal includes Anacardiaceae (1.3%), Bignoniaceae (0.3%), Bombacaceae (1.9%), Shorea/Hopea (0.5%), Meliaceae (6.7 %), Tiliaceae (7.7%). The NAP constitutes Rubiaceae (4.3%), Chenopodiaceae (2.0%), Celastraceae (0.4%), Sauropus (1.1%), Acanthaceae (2.5%), Apiaceae (1.8%), Malvaceae (2.1%). Thus, the diversity of terrestrial AP is 15 % and NAP is 13.21 % as compared to the records in other phases. Aquatic pollen constitutes (1.9%), Gymnosperm (4.2%) and fern (2.4%), Monolete (0.6%), Trilete (1.8%), algae constitutes (13 %) and Thecamoebian (22%). Foraminifera constitute (2.8%).Dinoflagellate cyst absent in this phase. Ratio of cyperaceae and poaceae is 70 % of the total pollen count and the ratio of marine and terrestrial forms is 0.1.

The salinity in the sediments of coastal wetlands is periodically affected by the rise/ fall in RSL and climate.The dissolved salts in aqueous soil solution find access in the soil solution and is translocated readily downward and upward through capillary force in the inundated areas and exposed land, respectively. In both the processes, increase in salt percolation in ground water and accumulation in clayey-silt sediment or its concentration in the surface soil is almost fatal to vegetation. High salinity recorded in the studied area in the entire core sediment may pose serious hazard through salt accumulation in groundwater and it could also be detrimental for crops and mangrove diversity.

Coastal vegetation particularly mangroves are very specific to their ecological conditions. The influence of tidal effect in coastal wetlands and runoff from land through monsoon-driven rivers/streams typical of east coast plays an important role in defining the species diversity of mangroves. Very low preservation of terrestrial pollen and absence of any marine palynomorphs or fresh water thecamoebians in phase 1 indicate fluvial system which perhaps did not allow the deposition/ preservation. Being lotic ecosystem, thecamoebians too could not find suitable environment as these prefer to establish in lentic ecosystem (Farooqui et al., 2012).

Table.1 Chronology (Radiocarbon- ^{14}C Age) of sediment deposition in Narsimhapur, Krishna river delta

Depth (cm)	Laboratory Number	Radiocarbon (^{14}C) dates (yrs. BP)	1σ Calibrated age (cal BP)	Intra / extra-polated Age (yrs.BP)
50-55	BS 3632	1010±70	750±70	
105				~1500
140-145	BS 3600	3060±.80	2900±80	
202				~3100
285-290	BS 3621	3190± 130	3400± 130	
354-364	BS 3642	3400±90	3900±90	
400				~4900
440-445	BS 3643	5810±110	6600±110	
475				~7200
500				~8200

Fig.1 Location Map of Narsimhapur, Krishna river delta (India) showing the core site

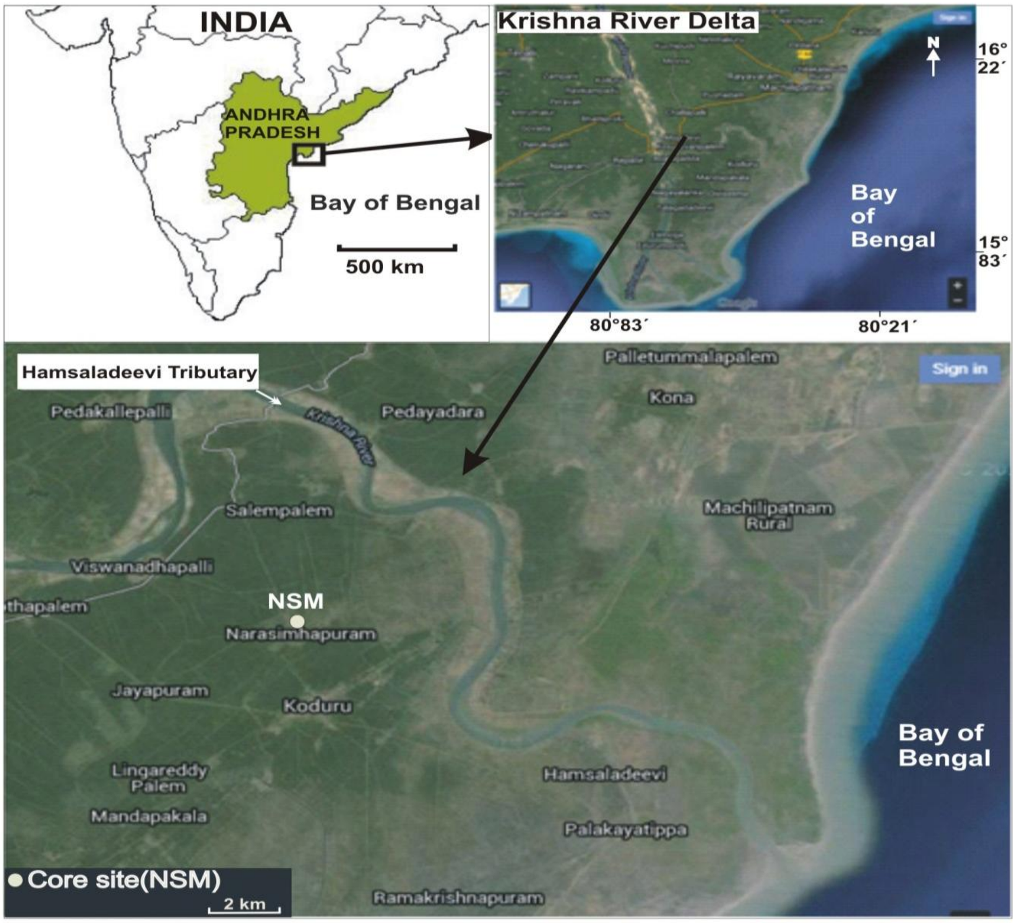

Figure 1

Fig.2 Radiocarbon Age /Depth model showing net rate of sedimentation during middle Holocene in Narsimhapur, Krishna river delta

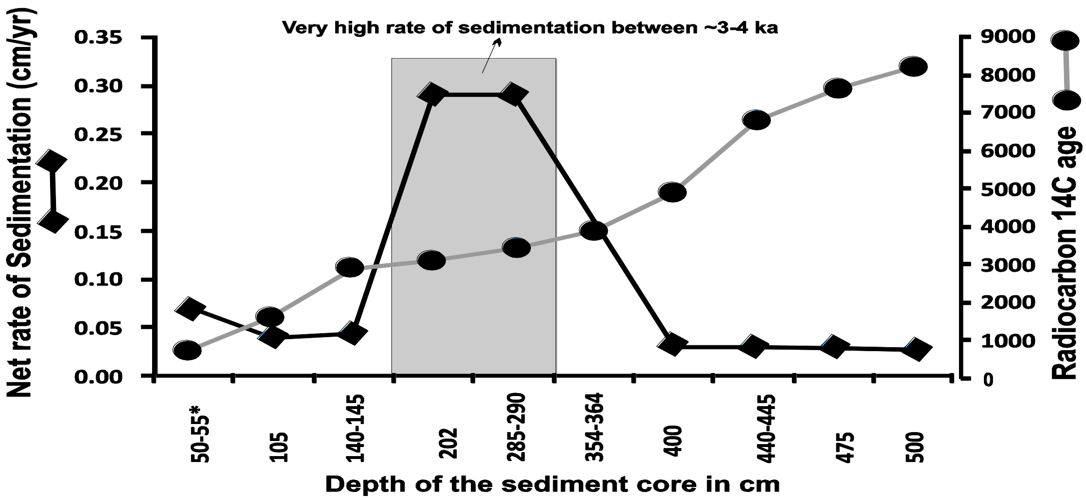

Figure 2

Fig.3 Palynological spectrum of a sediment core in Narsimhapur, Krishna Delta (Andhra Pradesh)

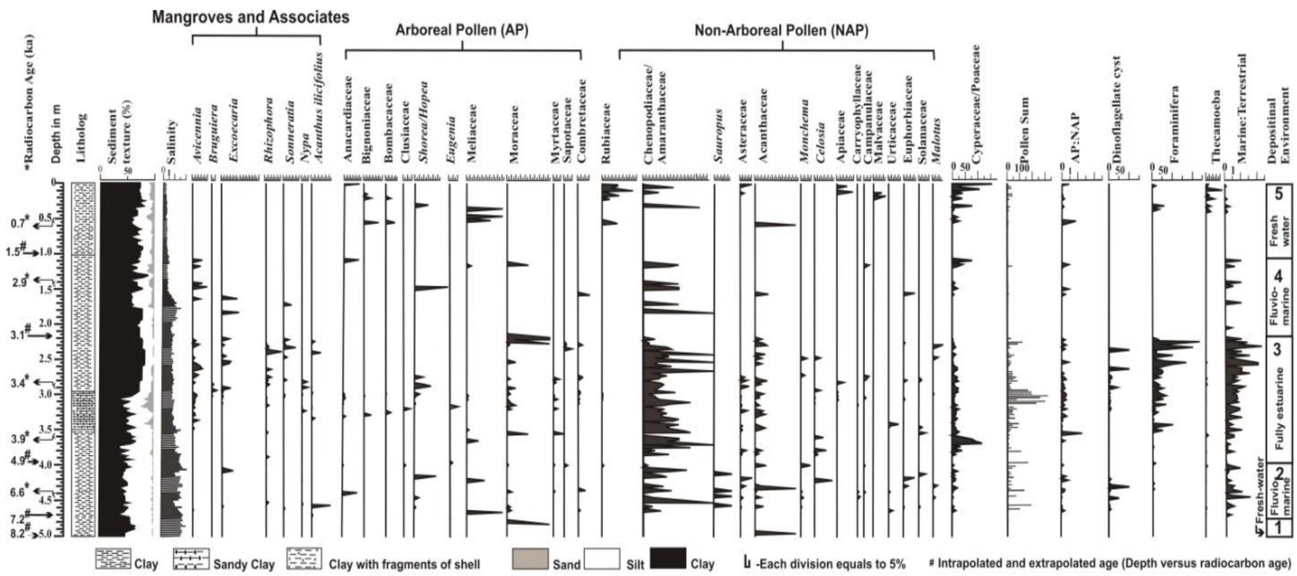

Figure-3

Fig.4 Ratio of marine versus terrestrial and AP versus NAP since ~8.2 ka in Krishna River delta

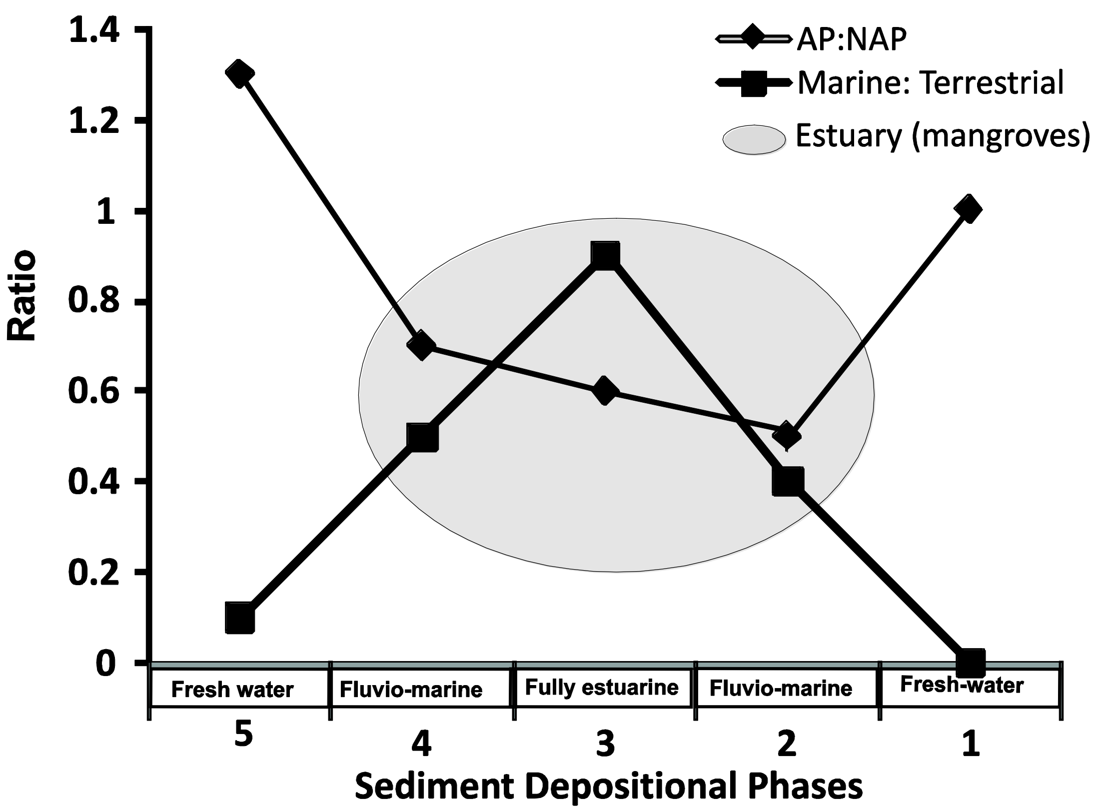

Figure 4

Fig.5 Light Microscopic Photographs (All scales = 10μm)

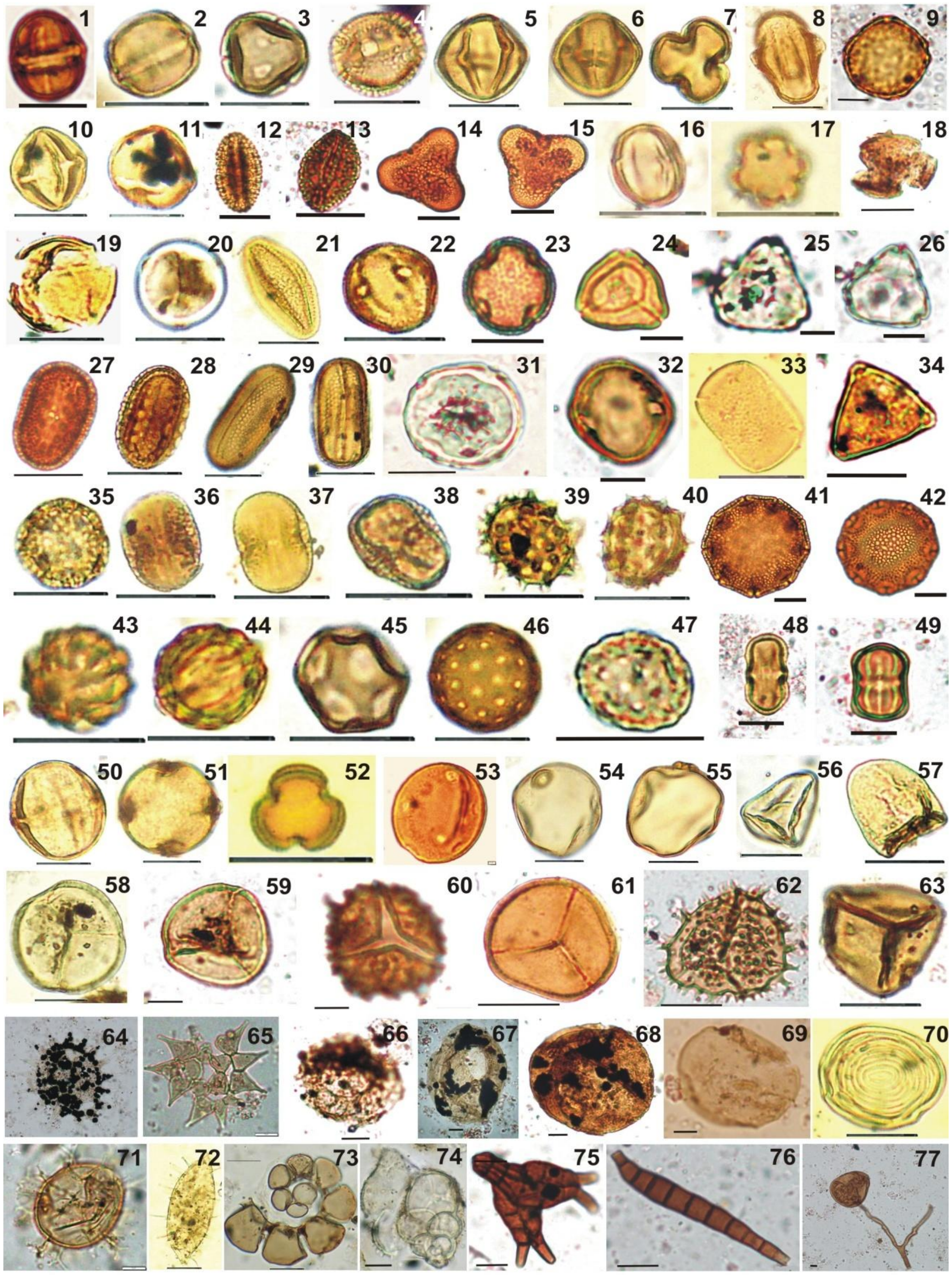

Figure 5

1-3 Rhizophoraceae; 4-*Avicennia*; 5-7 *Excoecaria*, 8-*Sonneratia*; 9-*Xylocarpus*; 10- *Gluta*; 11-*Tabernaemontana* 12-Bignoniaceae; 13-Euphorbiaceae; 14-15 *Bombax ceiba*; 16-17 *Terminalia*; 18-19 *Shorea/Hopea* 20-Moraceae 21- Apiaceae 22-Vitaceae 23-*Garcenia* 24- *Syzygium cumini* 25-26 *Eugenia* 27- 28 *Lepodagathis sp.* 29- 30- *Acanthus ilicifolius* 31-Rubiaceae 32- Sapotaceae; 33- *Impatiens balsamina* ; 34- Icacinaceae; 35 *Celosia* 36- *Peristrophe* 37 *Justicia;* 38 *Monechma*; 39- *Blumea oxyodonta* ; 40- Asteraceae; 41- 42 *Chrozophora prostrata* ; 43-44 *Hygrophila* 45- *Alternanthera;* 46-47 Chenopodiaceae; 48-*Pimpinella;* 49-Polygalaceae; 50-51 Meliaceae; 52- *Artemisia* 53-Caryophyllaceae (*Cerastrium*?); 54-55 *Cerealia* 56 - Cyperaceae; 57- *Cyperus rotundus* ;58 to 60- Trilete spore ; 61 - *Acrostichum*; 62- *Selaginella*; 63- Cytheaceae; 64-*Pediastrum simplex*; (Pyritised) 65- *Pediastrum simplex*; 66- *Centropyxis*; 67-68 *Cyclopyxis* 69- *Arcella vulgaris* ;70- Pseudoschizae ; 71- *Spiniferites* 72- O*perculodinium*; 73-74- Foraminifera linings ; 75- Tetraploa; 76- Fungal spore; 77- Glomus

Presence of fresh water algae in moderate percentage suggests its sporadic growth along the banks of the stream/river under conducive environment. Phase 2 shows records of both terrestrial and marine/estuarine palynomorphs indicating the fluvio-marine/paralic estuarine sediment depositional environment. High percentage of hinterland terrestrial NAP suggests of open area and moist conditions favouring seasonal herbaceous taxa. Diverse assemblage of evergreen to moist deciduous pollen taxa in high percentage indicates a forest cover in the hinterland beyond the mangrove zone that could be possibly riparian community growing along the river/stream entering into the estuarine ecosystem. Overall results reveal that by ~7 ka the shoreline invaded the land and the studied area was a peripheral intertidal zone. Thus, the palaeoshoreline was present about 9-10 km inland from the present day shoreline. The tidal influence remained here for a longer period until 4.6 ka which facilitated the growth of mangroves and its associates in a gradually stabilized estuarine ecosystem.

In phase 3 between 4.0 to 3.1 ka, the high percentage of mangroves and other hinterland terrrestrial arboreal pollen along with dominance of diverse NAP and AP suggest the stabilized climatic and ecological conditions that allowed the establishment of vegetation in this region even beyond the mangrove zone. Thus, the relative sea level ingression that took place ~ 7 ka was later stabilized into a luxuriant mangrove forest in the region along with the riparian forest and the open land in the flood plain. The environmental and geomorphological conditions remained stabilized for about 3 to 4 thousand years between 7 and 3.0 ka although with the slight increase in net rate of sedimentation in phase 3 as compared to in phase 1 and 2 attributed to aggradation in estuarine zone. Comparatively, a high percentage of back mangrove such as *Avicennia* was recorded along with *Excoecaria* pollen which is often found in the landward zone of mangroves suggesting a retreat in sea level.

Interestingly, a sudden rise in net rate of sedimentation in this phase points to some abrupt geomorphological changes that allowed high sediment deposition and possibly these changes triggered a retreat in sea level and the delta prograded. It is inferred that sometime around 3-4 ka the region experienced a change in climate towards aridity leading to reduced precipitation and consequently, drying of monsoon fed rivers/streams which induced vertical compaction of loosely packed estuarine/ wetland sediment. Simultaneously, the shoreline retreated and only stray back mangroves were encountered. Later in Phase 5 the evidences of shoreline or its nearness to it was not recorded due to absence of any marine palynomorphs.

Except that few foraminifera linings were recorded which could be due to contamination through navigation in the channel. The highest diversity of pollen taxa was recorded in Phase 3 and 2 followed by phase 4. The results, therefore, indicate that the climate and environmental conditions were favourable for a longer period that allowed the ecosystem to stabilize. The climate being warmer and humid than present provided adequate runoff from land that facilitated the establishment of an estuarine ecosystem in the delta.

The entire east coast of India is characterized by loads of sediment deposition brought by numerous rivers and its tributaries. The unconsolidated sediments in the modern deltaic plains undergo a common phenomenon of land subsidence due to compaction under the load of subsequently deposited overlying sediments and groundwater pumping (Day et al., 1995; Stanley and Warne, 1994; Dumont and El-Shabrawy, 2007; Meckel et al., 2006). Sea-level zones and typical RSL curve is deduced by Clark (1978) under the assumption that no eustatic change has occurred since 5 ka BP (Woodroffe and Horton, 2005). The sinking of Venice city (Seibold and Berger, 1996) due to subsidence of Po delta sediments and other similar records (Tornqvist et al., 2008; Verosub et al., 2009; Rao et al., 2010) may be a natural phenomenon but the highly populated, urbanized and industrial coastal areas world over, cannot be risked for a huge loss.

Some of the faults have remained active intermittently in the upper crust of the Indian Shield (Banerjee et al., 2001; Ramasamy, 2006; Subrahmanyam et al., 2010), inferred two parallel faults in the continental margin off the Krishna-Godavari delta and relate a continuous existence of Kolleru lake (35 km from the present shoreline) to its location in the tectonically active Gudivada Sub-basin. The concavity observed between the twin deltas (Krishna – Godavari) is therefore, tectonically controlled (Bastia et al., 2006; Subrahmanyam et al., 2010).

The studied core is at an elevation of about 3 m above present mean sea level. If the sea level rise during middle Holocene was about 1.5 to 2m then the evidence of middle Holocene shoreline in the studied core is either at the present day mean sea level (msl) or slightly above the msl. These evidences reveal that the vertical stack of sediment deposited since ~7 ka has undergone upliftment by about 1 to 1.5m in the area. This upliftment could be attributed to tectonic activity in the Krishna Cross Front fault leading to south-eastern flow of Krishna river.

The geomorphology of the K-G delta complex has been described in detail by Rao et al., (2013). The basement framework of K-G basin and an asymmetric South-eastern bulge of Krishna delta is influenced by Krishna Cross trend fault (Bastia et al., 2006; Lal et al., 2009) that indicates the morphotectonic processes and ongoing tectonic activity in the region. The inference drawn through studies of a number of riverine, coastal and hydrological anomalies show that the southern part of India is tectonically very active (Ramaswamy, 2006). The climatic changes too directly or indirectly induce local geomorphological changes in a region. Therefore, the estimation of RSL rise or fall is a local effect largely influenced by geomorphological changes rather than due to global warming and related sea level rise along the Indian coastline.

Conclusions

Pollen/spores, thecamoebians, marine palynomorphs such as dinoflagellate cysts and foraminifera linings were recorded in a 500 cm core sediment deposited since ~8.2 ka in the Krishna river delta. The shoreline encroached ~10 km inland from the present shoreline ~7 ka. During the period from ~7-3.0 ka, an estuarine ecosystem was recorded but the estuary stabilized between 4 to 3.0 ka. During this period abundance of mangrove pollen and marine palynomorphs show high diversity and the net rate of sedimentation too remained static. Between 3.4 to 2.8 ka a sudden rise in net rate of sedimentation increased from ~0.03 to 0.34 cm/yr. accompanied by low percentage of estuarine/marine palynomorphs suggesting a fall in RSL which continued until present.

The accumulation of increased sediment in the studied site is attributed to tectonically controlled geomorphological changes in the region that triggered the retreat in shoreline since ~3.0 ka. The studied core is at an elevation of about 3 m above present mean sea level. If the sea level rise during middle Holocene was about 1.5 to 2m then the evidence of middle Holocene shoreline in the studied core should be either at the present day mean sea level (msl) or slightly above the msl. Mangrove evidences reveal that the vertical stack of sediment deposited since ~7 ka has undergone upliftment by about 1 to 1.5m in the area. This upliftment is attributed to tectonic activity in the Krishna Cross Front fault leading to south-eastern flow of Krishna river.

Acknowledgement

We are grateful to the Director, Birbal Sahni Institute of Palaeobotany (BSIP) Lucknow, India for providing necessary facilities to accomplish this work. One of the authors 'Ranjana' is thankful to BSIP (DST, New Delhi), Lucknow for research scholarship.

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