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PALEOCLIMATIC ANALYSIS OF QUATERNARY SEDIMENTS ASSOCIATED WITH THE FLOODPLAIN DEPOSITS OF A TROPICAL ESTUARY ALONG THE SOUTHWESTERN COAST OF INDIA

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Abstract:

The coastal regions of southwest India which falls in the tropical regime, have witnessed many transgression-regression events and climatic extremes in the Quaternary Period. A core, 15 m long, was recovered from the floodplains associated with a typical backwater body (lake) in the southwestern coast of India. The granulometric analysis proved dominance of sand and silt fractions and extremely high energy conditions over the entire core. The TOC/TN ratio indicated a domination of the C4-type over the C3-type plants in the lower half of the core, suggesting a warm climate. The C3-type plants prevail in the upper part of the core, thus reflecting cool and wet environments. Extremely low values of TOC/TN ratio (0.33% to 10%) of the core indicate short periods of very high rainfall events and the rapid influx of nutrients to the basin and the eutrophication of the basin. The presence of slightly brackish, brackish/marine and marine benthic foraminifers at 12.5–9 m depth indicates episodes of transgression and regression. The derived AMS radiocarbon dates suggest the Marine Isotope Stage 3 for the lower part of the core.

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Key words: Foraminifera, Quaternary environment, TOC/TN ratio, Radiocarbon dates.

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INTRODUCTION

The Quaternary period is epitomized by reiterated cycles of cold and warm climatic fluctuations. As a result, the Quaternary environment witnessed episodes of changes in sedimentation pattern and the distribution of fauna and flora. The Quaternary sediments contain annals of environmental and climatic changes. The reconstruction of Quaternary paleoenvironmental and paleoclimatic changes and their influence on ecosystems is very pivotal to understanding the suspected climatic changes being felt at present. It can provide appropriate information on the natural variability of the climate system, essential insights for the understanding of modern environmental dynamics, and the prediction of future climate trends (Nicholson and Flohn, 1980; Behling, 2003; Bradley, 2008). During the Quaternary Period, coastal regions of the Kerala coast witnessed the pompous sea level variations. Many researchers have analysed the Quaternary environmental conditions of the western coast of Kerala by studying lithology, paleontology, stratigraphy and geochronology of sediments in the lagoon systems (Nair *et al.*, 2010; Padmalal *et al.*, 2014;

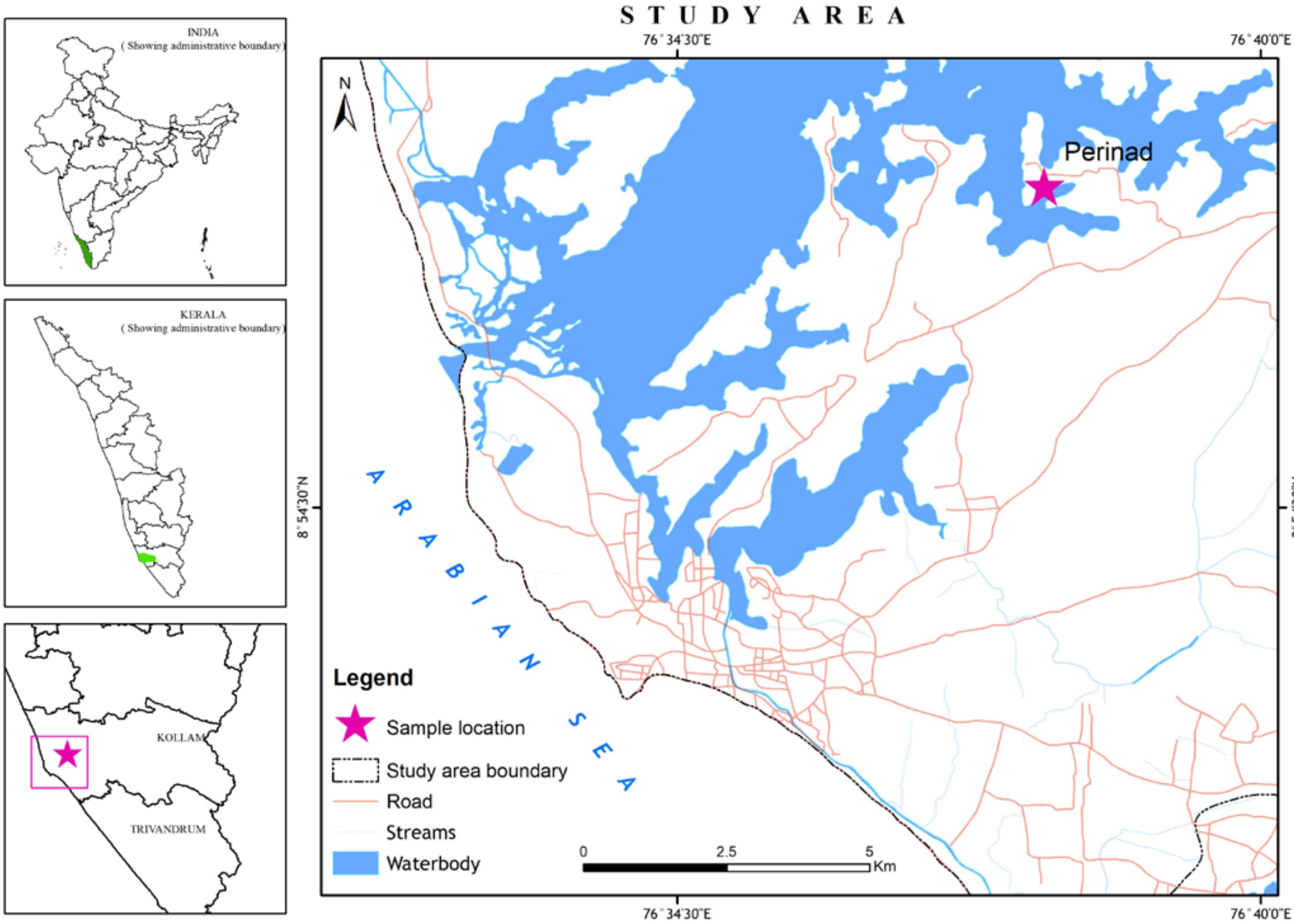

Fig. 1. Location map of the study area.

Veena *et al.*, 2014; Tiju, 2021; Banerji *et al.*, 2021) and identified record of the Quaternary monsoon strengthening and marine transgression, accompanied by consequent weakening of monsoon and sea level regression in the coastal lowlands of Kerala.

The present study aims to understand the Quaternary environmental conditions of tropical estuary of south west coast of India by using granulometric, geochemical, geochronological and micropalaeontological analysis of Quaternary sediments. The study was attempted in the floodplain deposits of Ashtamudi Lake of Kerala state, India. The Ashtamudi Lake falls in the southwestern coast of India which possesses all characteristics of tropical regions. A good amount of sediment cover belonging to the Quaternary Period is found along the floodplain regions of Ashtamudi Lake of Kerala state, India making such sites the ideal location for the Quaternary paleoclimatic studies.

STUDY AREA

The study area forms a part of the South Kerala Sedimentary Basin (SKSB) (Nair *et al.*, 1998, 2006) at the latitude 8º57'27.61"N and the longitude 76º38'1.53" E (Fig. 1). Morphotectonic and sea level oscillation studies of the coastal tracts of the southwestern coast of India reveal that a major part of SKSB is in a submerged block, and areas in the southern and northern parts are characterised by cliffs and bays indicating emergence and subsequent coastal erosion under the rising sea level in the late Quaternary (Brückner, 1989; Nair, 2007). Geomorphologically, the area comprises hillocks, valleys and gently sloping plains. Hillocks that bound the lake basins have moderate to steep slopes. Stratigraphically, the area is made up of three major rock formations including the Archaean crystalline basement as well as the Neogene and Quaternary sedimentary sequences. The Archaean crystalline basement is represented by garnet–biotite gneisses, khondalites and charnockites. The Neogene sediments are composed of the Quilon and Warkalli Formations of the Lower Miocene age. The Quilon Formation, occurring below the Warkalli Formation is represented by fossiliferous limestones and sandy carbonaceous clays. The Archaean crystalline basement and the Neogene sedimentary sequences are lateralized at the top. The Quaternary deposits are represented by alluvial clays, sandy clays and peat at the southeastern side of the lake. In the present study, the core has been recovered at the floodplain associated with the Ashtamudi Lake.

MATERIALS AND METHODS

The core has been collected up to a depth of 15m from the ground surface using the rotary calyx drilling method. The samples were recovered from each 50 cm depth and were packed in neatly labelled polythene bags for further analysis. The subsamples were subjected to granulometric analysis following the standard method of sieving (Ingram, 1971) and pipetting (Galehouse, 1971). The samples were wet sieved using a +230 mesh (63 microns) ASTM sieve to separate the sand sized fraction from the mud (silt and clay) fraction. The coarse fraction of the sample (+230 ASTM mesh) was dried to find out the sand percentage and the -230 fraction was used for pipetting to find out the mud fraction. The conventional pipette analysis (Galehouse, 1971) was used for grain size analysis of finer (-230 ASTM size) particles.

Total Nitrogen (TN) and Total Organic Carbon (TOC) in the core samples were measured using CHNS analyser (Elementar Vario EL CUBE) at Central Laboratory for Instrumentation and Facilitation (CLIF), University of Kerala. The high-temperature combustion and subsequent examination of the combustion gases form the basis of the CHNS elemental analysis. In order to estimate the organic carbon, the inorganic carbon was removed by decarbonization of the sediment samples with 0.5N HCl. The samples were dried, and approximately 20 mg of each sample was packed in tin boats, then released into a combustion chamber at 1120ºC of the pyrocube Elementar Analyzer.

The procedures proposed by Cushman (1948), Brasier (1980) and Murray (1973) were used in the laboratory to separate and study of microfossils. The weighed-out fractions were transferred into the micropaleontological ASTM sieve of 230 meshes for wet sieving. A controlled jet of water was projected to the screen in a swirling motion so that the sediments will sort out easily without damaging the tests. The washing continued till clear water passed through the other side of the sieve. The residue was then concentrated at the edge of the mesh, then transferred to separate dishes and dried at the temperature below 50ºC in a hot air oven. The fractions were then scattered on a tray. The material was examined under the stereo binocular reflection microscope (SZ 61 Stereo Microscope) and subjected to counting of the microfossils on species wise. Two or three representative specimens of each species (hypo types) were mounted on single pouch slides and used for the identification of microfossils up to the genus/species level.

For radiocarbon dating, three samples were taken from different depth intervals and the radiocarbon measurement of samples was done using 1MV AMS (Auris) at Geoscience Division, Physical Research Laboratory, Ahmedabad, India. The targets used for radiocarbon performance test was the NIST Standard NBS 4990C Oxalic Acid (Ox II) and blank

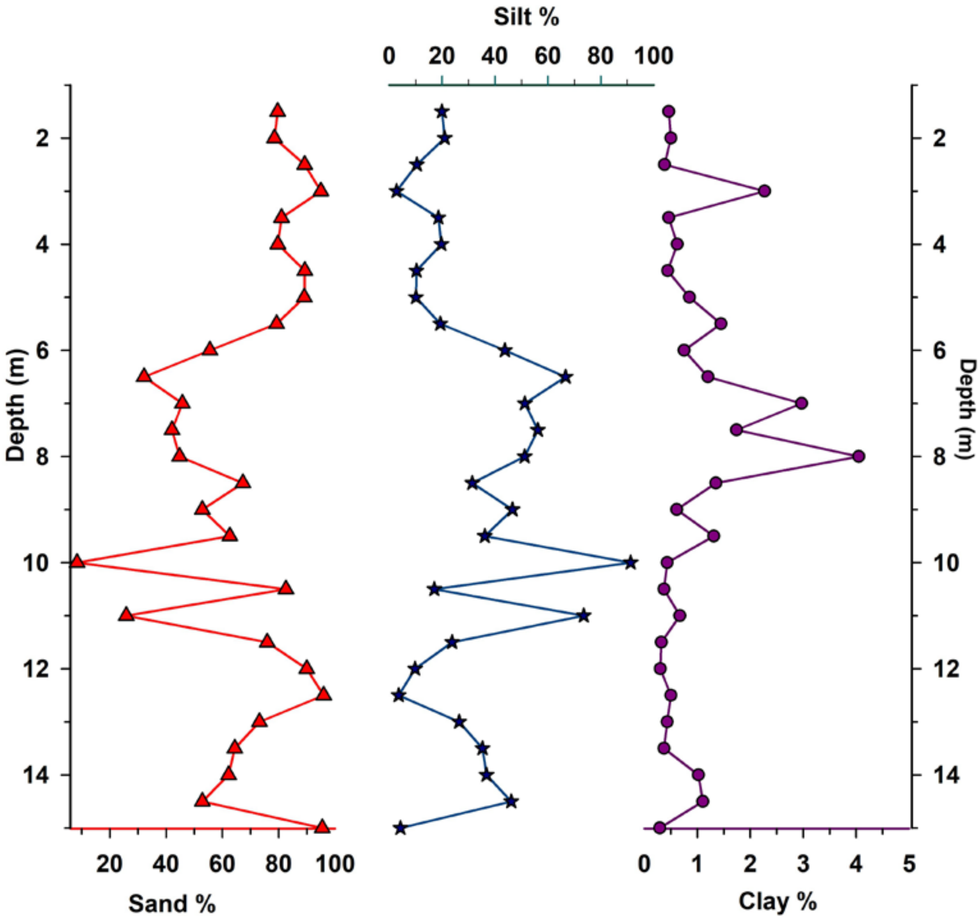

Fig. 2. Down core variation of sand, clay and silt particles of the core samples.

was a solid graphite. For radiocarbon measurements, the charge state 14C2+ was used as it had higher stripping efficiency at 1MV with transmission of 44%. Ions like $^{7}Li^{+}$ having similar mass /charge ratio to that of $^{14}C2+$ pass through kinematic filters and interferes with $^{14}C2+$ signals. Such interferences could be reduced by fine tuning the instrument as their trajectories differed slightly from that of ^{14}C, and using the energy resolution of the detector. The ratio of specific activity of new oxalic acid (Ox II) to old oxalic acid (Ox I; NBS 4990B) was used to check linearity of the instrument (Bhushan *et al*., 2019a, b).

RESULTS

Granulometric analysis

The sand content in the core varies from 8.32 to 95.93%, and that of silt from 2.79 to 91.241%. All samples are characterized by a very low amount of clay, ranging from 0.29 to 4.05% (Table 1). Both sand and silt content fluctuate drastically along the core (Fig. 2). The sand-silt-clay percentage was plotted in the ternary diagram of Flemming (2000). Slightly silty sand dominates the upper part of the core to 6 m depth. Thereafter, the slightly clayey sand dominates towards the core bottom, with often occurrences of extremely silty sandy mud and slightly silty sand. The extremely silty slightly sandy mud is present at 10 m depth and sand occurs at 3, 12.5 and 15 m depth (Figs 3, 4). The sand-silt-clay percentage of all samples was plotted in the ternary diagram of Pejrup (1988), where all samples fall in the category IV, indicating a dominance of

Table 1. Textural aspects of core sediments.

Sample no	Depth (m)	Sand (%)	Clay (%)	Silt (%)	Sediment type (after Flemming, 2000)
PND1	1.5	79.615	0.46	19.925	slightly silty sand
PND2	2	78.503	0.5	20.995	slightly silty sand
PND3	2.5	89.176	0.38	10.442	slightly silty sand
PND4	3	94.933	2.27	2.797	sand
PND5	3.5	80.953	0.46	18.591	slightly silty sand
PND6	4	79.652	0.62	19.727	slightly silty sand
PND7	4.5	89.26	0.44	10.302	slightly silty sand
PND8	5	89.059	0.85	10.094	slightly silty sand
PND9	5.5	79.227	1.45	19.319	slightly silty sand
PND10	6	55.523	0.75	43.726	slightly clayey sand
PND11	6.5	32.166	1.2	66.63	extremely silty sandy mud
PND12	7	45.785	2.97	51.245	extremely silty sandy mud
PND13	7.5	42.065	1.74	56.195	extremely silty sandy mud
PND14	8	44.772	4.05	51.178	extremely silty sandy mud
PND15	8.5	67.263	1.35	31.385	slightly clayey sand
PND16	9	52.84	0.61	46.555	slightly clayey sand
PND17	9.5	62.649	1.31	36.09	slightly clayey sand
PND18	10	8.32	0.43	91.247	extremely silty slightly sandy mud
PND19	10.5	82.578	0.37	17.052	slightly silty sand
PND20	11	25.834	0.67	73.492	extremely silty sandy mud
PND21	11.5	75.917	0.32	23.762	slightly silty sand
PND22	12	89.95	0.3	9.755	slightly silty sand
PND23	12.5	95.938	0.5	3.562	sand
PND24	13	73.146	0.43	26.427	slightly clayey sand
PND25	13.5	64.393	0.37	35.235	slightly clayey sand
PND26	14	62.209	1.02	36.769	slightly clayey sand
PND27	14.5	52.828	1.1	46.07	slightly clayey sand
PND28	15	95.476	0.29	4.234	sand

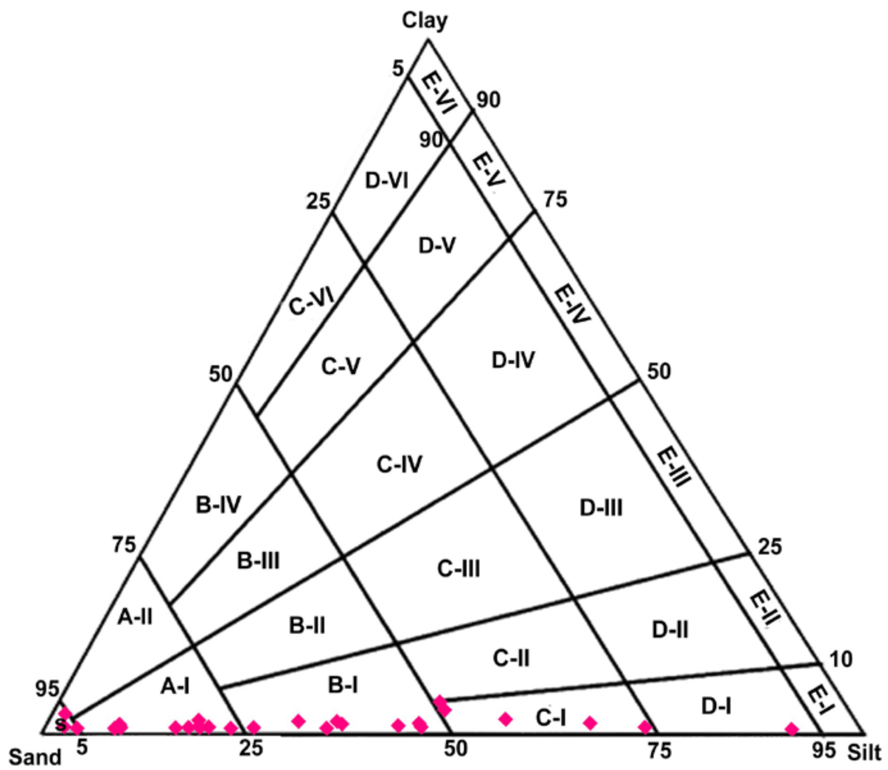

Fig. 3. Sediment type of the core (after Flemming, 2000).

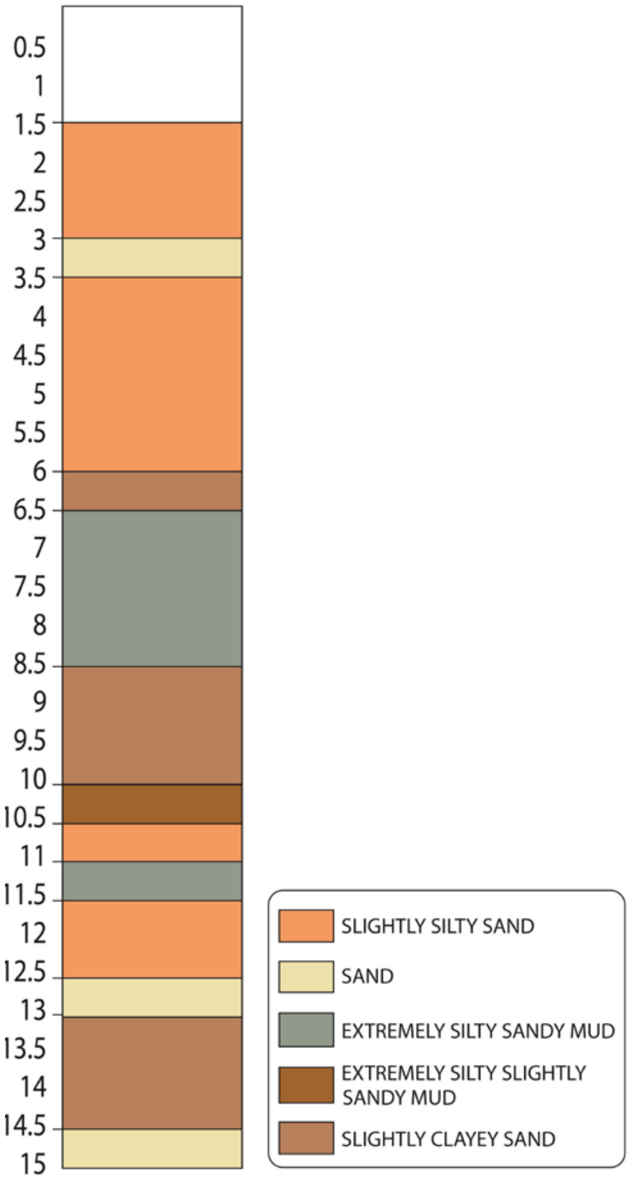

Fig. 4. Litholog of the core based on Fleming's classification (2000).

extremely violent environmental conditions during deposition (Fig. 5).

Geochemical analysis (TOC/TN ratio)

In the present study, the TN values range from 0.01 to 0.31% and that of the TOC ranges from 0.01 to 9.104%. The TOC/TN ratio is from 0.33 to 93.65% (Table 2). A dominance of the higher values of the TOC/TN ratio in many parts of the core indicates a predominantly allochthonous source for the organic carbon. Among the allochthonous sources, the C4 type plants dominate over the C3 type from 7.5 m depth to downwards (Fig. 6).The C3 type plants dominate in the upper part of the core. Low values of the TOC/TN ratio shown at core depths 3.5m, 6m, 11m and 13 m indicate the autochthonous source for organic carbon (Fig. 6).

Table 2. Geochemical aspects of core sediments.

Sample no	Depth (m)	TN (%)	TOC (%)	TOC/TN (%)
PND1	1.5	0.25	9.104	36.45
PND2	2	0.03	0.598	19.93
PND3	2.5	0.02	0.37	18.5
PND4	3	0.02	0.301	15.05
PND5	3.5	0.03	0.3	10
PND6	4	0.02	0.299	14.95
PND7	4.5	0.01	0.21	21
PND8	5	0.02	0.25	12.5
PND9	5.5	0.03	0.391	13.03
PND10	6	0.04	0.35	8.75
PND11	6.5	0.03	0.51	17
PND12	7	0.02	0.289	14.45
PND13	7.5	0.01	0.60	60
PND14	8	0.03	2.71	90.33
PND15	8.5	0.08	2.517	31.46
PND16	9	0.31	5.231	16.87
PND17	9.5	0.12	7.697	64.14
PND18	10	0.13	4.17	32.07
PND19	10.5	0.02	0.654	32.70
PND20	11	0.06	0.462	7.700
PND21	11.5	0.1	4.49	44.90
PND22	12	0.02	1.873	93.65
PND23	12.5	0.025	1.14	45.6
PND24	13	0.03	0.01	0.33
PND25	13.5	0.035	0.75	21.42
PND26	14	0.04	1.716	42.90
PND27	14.5	0.11	4.227	38.42
PND28	15	0.06	2.821	47.0

Table 3. List of benthic foraminiferal species.

Sl no	Depth (m)	Species name	Number of tests
1	9	*Ammonia beccarii*	61
		Elphidium crispum	10
		Elphidium clavatum	4
2	9.5	*Ammonia beccarii*	122
		Elphidium crispum	24
		Elphidium clavatum	1
		Operculina ammonoide	109
3	10	*Elphidium crispum*	31
		Operculina ammonoide	106
4	10.5	*Ammonia beccarii*	1
		Elphidium crispum	9
5	11	*Ammonia beccarii*	9
		Elphidium crispum	28
		Operculina ammonoide	45
6	11.5	*Ammonia beccarii*	593
		Elphidium crispum	26
		Elphidium clavatum	13
		Operculina ammonoide	14
7	12	*Ammonia beccarii*	8
		Elphidium crispum	1
		Elphidium clavatum	4
		Operculina ammonoide	2
8	12.5	*Ammonia beccari*	379
		Elphidium crispum	28
		Elphidium clavatum	191
		Operculina ammonoide	107

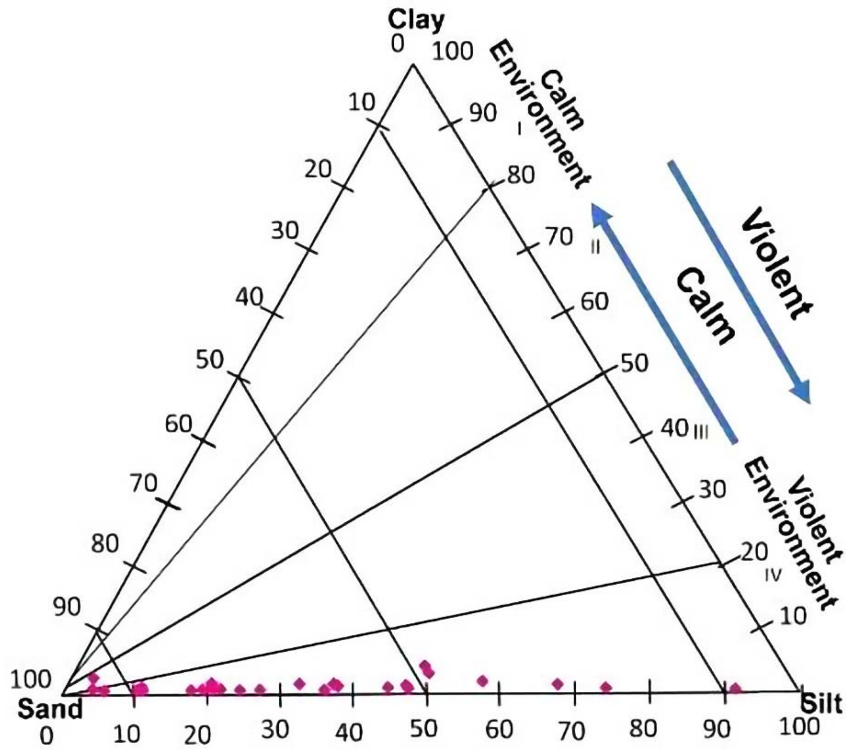

Fig. 5. Ternary plot of Pejrup (1988) showing the depositional environment of the study area.

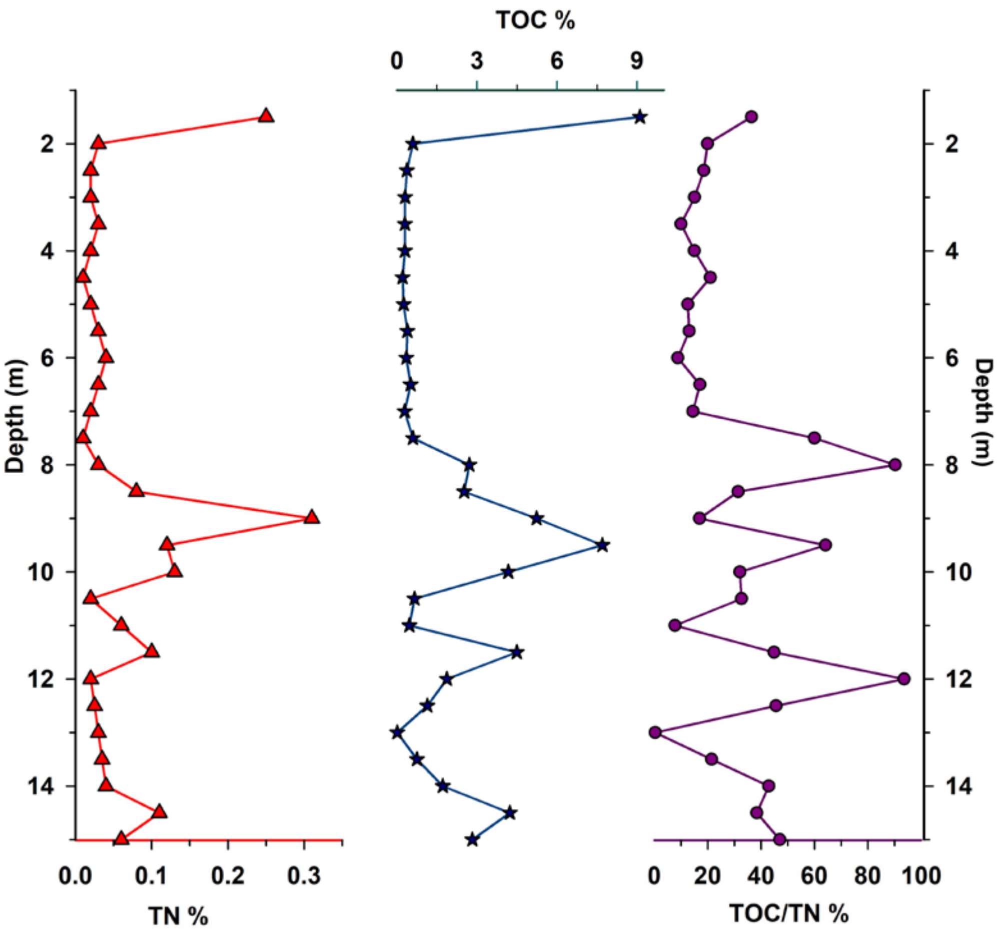

Fig. 6. Down core variation of TN,TOC and TOC/TN values.

Foraminiferal analysis

Four species of benthic foraminifera namely *Ammonia beccarii, Elphidium crispum*, *Elphidium clavattum* and *Operculina ammonoide* were found at 9–12.5 m depth (Fig. 7).The species name, number of tests and the corresponding core depth are summarized in the Table 3. Out of the four species, *Ammonia beccarii* is the prepotent taxon (Fig. 8A).The euryhaline benthic foraminifer *Ammonia beccarii* is a common cosmopolitan species dwelling in littoral and neritic environments. It is a brackish to marine species and deep infaunal in anoxic and surface sediments. In the core, *Ammonia beccarii* is found in slightly clayey sand, slightly silty sand, extremely silty sandy mud and sand . Higher number of tests were collected from 11.5 and 12.5 m depth. *Elphidium crispum* is a shallow water species with normal marine salinity and is commonly present in moderately sheltered low tidal and subtidal beaches (Fig. 8B). In the present study *Elphidium crispum* was found at 9–12.5 m depth and associated with slightly clayey sand, extremely silty slightly sandy mud, slightly silty sand, extremely silty sandy mud and sand. The species is represented by an extremely low number of tests. The species *Elphidium clavatum* is infaunal and lives in slightly brackish conditions (Fig. 8C). In the core,

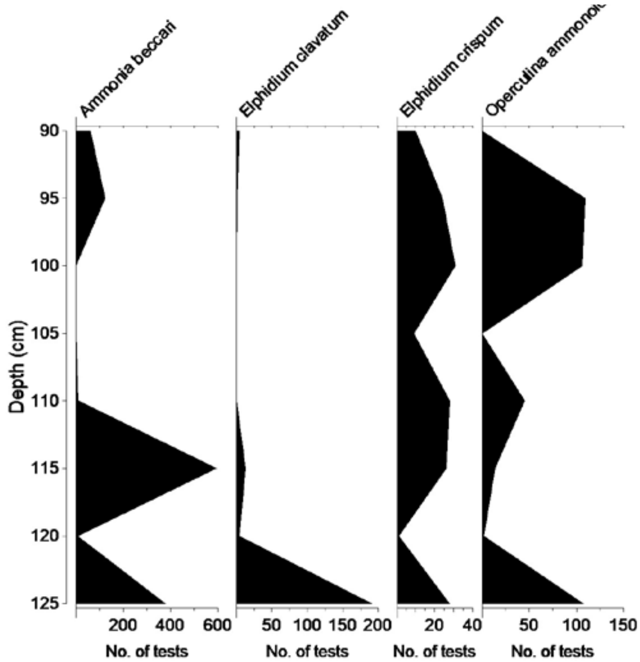

Fig. 7. Downcore distribution of foraminifers.

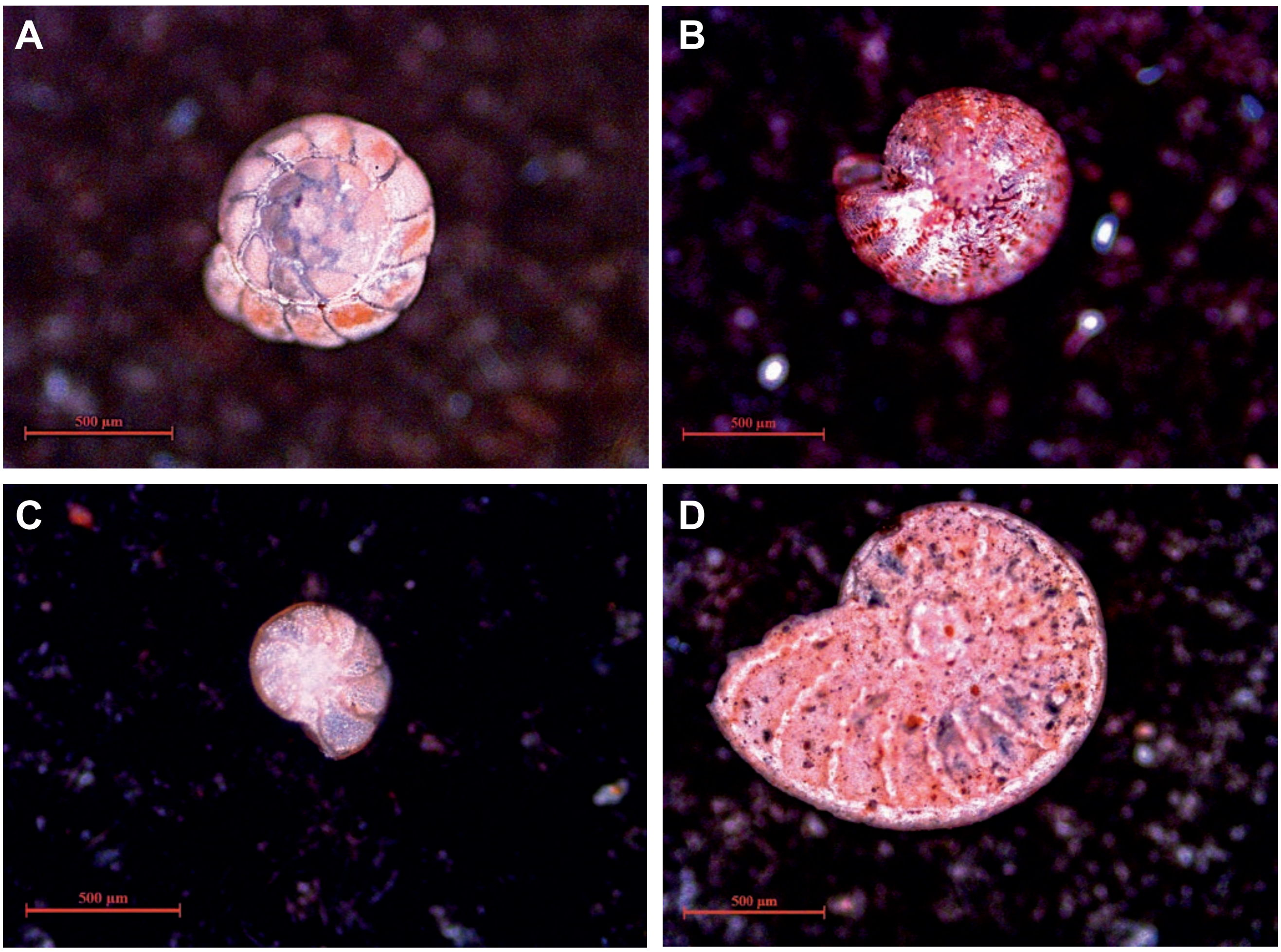

Fig. 8. Microscopic images of benthic foraminifers; A: *Ammonia beccarii*, B: *Elphidium crispum*, C: *Elphidium clavatum*, D: *Operculina ammonoide*.

it is associated with slightly silty sand, slightly clayey sand and sand. In the present study, *Elphidium clavatum* was not found at 9, 9.5, 11.5, 12 and 12.5 m depth. The *Operculina ammonoide,* found at 9.5–10 and 11–12.5 m depth, seems to be a reworked fossil (Fig. 8D). It is associated with slightly clayey sand, extremely silty slightly sandy mud, slightly silty sand, extremely silty sandy mud and sand. *Operculina ammonoide* is a planispiral symbiont bearing large benthic foraminifera. It is an epifaunal, tropical species that lives on inner shelves and in lagoons at warm temperature. The maximum number of tests is found at 9.5, 10 and 12.5 m depth and the minimum number of tests at 12 m depth.

Radiocarbon Dating

AMS radiocarbon dating is used to determine chronology of the late Quaternary (Waelbroeck *et al.*, 2002). In the present work, AMS radiocarbon dating was done for three sediment samples at 9, 9.5 and 10 m depth (Table 4). They were dated as 34,426, 38,995 and 42,404 cal, respectively and all the dates indicates the Late Pleistocene age i.e. Marine Isotope Stage 3 (MIS 3).

Table 4. Details of the radiocarbon dates of core samples from the study area. Calibration done by Calib 8.2; IntCal20.

Sample ID	LAB ID	Radiocarbon Age (years)	Calibrated Age Range (1 Sigma) years BP	Median Age
PND-9m	AURIS-04765	29960±122	34318–34536	34426
PND-9.5m	AURIS-04766	33846±168	38718–39308	38995
PND-10m	AURIS-04768	38736±447	42228–42572	42404

DISCUSSION

The downcore variation of sediment types indicates more extensive sedimentary depositional environments with few minor rapid variations (Fig. 4). The dominance of the higher values of the TOC/TN ratio, as seen at many parts of the core, indicates a predominantly allochthonous source of organic carbon (Meyers, 1994). Among the allochthonous sources, the C4 type plants dominate over the C3 type from 7.5 m core depth onwards towards the bottom and the C3-type plants dominate the upper part of the core. The predominance of high TOC/TN ratio (13.03% to 93.65%) throughout the period indicates moderate terrigenous supply (Meyers, 1994). Extremely low values of TOC/TN ratio at certain depths of the core denote the autochthonous source for organic carbon, possibly due to aquatic phytoplankton activity and eutrophication of the basin/lake. This may further indicate short periods of very high spells of rainfall and the rapid influx of nutrients to the basin and the eutrophication of the basin (Meyers, 1994; Tyson, 1995).

Presence of slightly brackish, brackish/marine and normal marine benthic forams at 9–12.5 m depth indicates normal marine conditions and followed by a regression after that. The AMS radiocarbon dates at 9, 9.5 and 10 m depth comes to be as 34,426, 38,995 and 42,404 respectively, which suggest MIS 3 for the lower part of the core. MIS 3 considered a relatively warm transitional interglacial stage that lasted from 60 ka to the beginning of the Last Glacial Maximum (LGM; 26 ka) and is characterized by highly variable climate (Weiss *et al.*, 2022). The dominance of C4 plants (21–93.65%) in the lower portion of the core indicates the predominance of warm climatic conditions in the lower part of the core (Meyers, 1994), that is during the MIS 3. The dominance of C3 plants (12.5–19.93%) in the upper part of the core, indicate cool and wet climatic conditions in the upper part of the core. The low TOC/TN ratio at 6 m depth indicates high phytoplankton activity, which may further indicate short periods of very high spells of rainfall, a rapid influx of nutrients to the basin and its eutrophication.

CONCLUSION

The Ashtamudi Lake in the southwestern coast of India forms a part of the South Kerala Sedimentary Basin (SKSB). The paleoclimatic changes were reconstructed using the granulometric, geochemical, geochronological and micropaleontological analysis of Quaternary sediments associated with the floodplain deposits of the Ashtamudi Lake. The results suggest that the study region is subjected to several spells of sea level fluctuations. The downcore variation of sediment types indicates more extensive sedimentary depositional environments with few minor rapid variations. Presence of slightly brackish, brackish/marine and normal marine benthic foraminifers at 9–12.5 m depth indicates marine-terrestrial contributions. The dominance of C4 plants in the lower part of the core suggests warm climatic conditions during the MIS 3. The C3 plants found in the upper part of the core indicate cool and wet climatic conditions. The extremely low TOC/TN values at 6 m depth represents a high phytoplankton activity, which may further indicate short periods of very high spells of rainfall, rapid influx of nutrients to the basin and its eutrophication.

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Conflict of interest

The authors declare no conflict of interest.

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