Late Quaternary environmental changes in South Kerala Sedimentary Basin, Southwestern India

*K. Jayalakshmi, **K.P.N. Kumaran, ***K.M. Nair and ****D. Padmalal

**Department of Geosciences, Osaka City University, Osaka 558-8585, Japan*
***Agharkar Research Institute, G.G. Agarkar Road, Pune – 411 004, India*
****Vakkom Moulavi Foundation, Thekkummodu Jn, Thiruvananthapuram – 695 037, India*
*****Centre for Earth Science Studies, Thiruvananthapuram – 695 031, India*

Jayalakshmi K., Kumaran K.P.N., Nair, K.M. & Padmalal, D. 2005. Late Quaternary environmental changes in South Kerala Sedimentary Basin, Southwestern India. *Geophytology* **35** (1&2): 25-31.

The best development of Quaternary sediments with a maximum thickness of over 80 m is found in South Kerala Sedimentary Basin (SKSB). With the help of lithostratigraphic and radio-carbon dates, the Quaternary sediments have been assigned to Pleistocene and Holocene units pending formal rock stratigraphic names. The oldest (42, 490 ± 860 yr B.P.) is represented by the clay bed at the depth of 6.64 m in Eruva while the youngest (2180 ± 70 yr B.P.) belongs to Kavnar sediments at depth of 6.50 m. The Pleistocene transgression in SKSB is dated > 42 ky B.P. while that of Holocene is ~ 7 ky B.P. Limited palynological observation on samples of six boreholes have indicated that there had been periods of abnormally high, normal and deficient rainfall during Late Pleistocene and Holocene. The relative abundance of *Cullenia exarillata* (Bombacaceae) pollen along with other wet evergreen forest members (Euphorbiaceae, Celastraceae etc.) at certain intervals is of great significance as they indicate prevalence of heavy rainfall and a wet period. The scarcity and even absence of the above palynological taxa at higher levels in the boreholes point towards an arid condition during the Late Holocene. The environmental changes due to climatic variations have been complimented by sedimentology, geochemistry and limited SEM studies on quartz grains.

Key-words – Late Quaternary, Kerala, Stratigraphy, Palynology, Palaeoclimate.

INTRODUCTION

THE study of Quaternary geology has attained great importance in the recent years because the present day landscape and environment are the products of interactions of the biosphere and geosphere. In fact, a thorough knowledge of Quaternary geological processes is of paramount importance for those who have any role in environmental study and issues related to it. Besides, the Quaternary sediments are expected to contain records of sea level changes and other causative factors for the present day landforms in a major part of the state and the environments we depend on. The Quaternary formations of Kerala coast have not received much attention of the geologists though they have been recognized and exploited for mineral deposits and freshwater needs of the rural households. Despite these economic, scientific and social factors, the attention bestowed on the Quaternary sediments is limited to just a few works. All that is known about the Quaternary sediments was a few dates of random samples, a general picture of the 'Recent' sediments and peat accumulation (Nair *et al.* 1998; Rajendran *et al.* 1989). In fact, the entire coastal area has been shown in geological map of Kerala as covered by undifferentiated Cenozoic sediments (Soman 2002). The Quaternary sequences unconfirmably overly the well-known Tertiary formation and it is estimated that about 80 m thickness of sediments occur in the South Kerala Sedimentary basin (SKSB) (Raghavrao 1975;

E-mail: **kpnkumaran@hotmail.com/navneethkumaran@yahoo.co.in

Desikachar 1976; Nair & Rao 1980; Najeeb 1999). The Quaternary sequence is easily distinguishable as the latenite forms the base of the sequence in most places covering SKSB. During 1998-2003, systematic geological and geomorphological analyses of SKSB were taken up with a view to build up the Quaternary stratigraphic sequence and the associated geological events (Nair *et al.* in press). The subsurface data covering the Late Pleistocene and Holocene periods of the SKSB with reference to sea level changes and palaeoclimatic variations have been addressed in the present communication.

The South Kerala Sedimentary Basin extending along the coast between Kollam and Kodungallur, is the landward extension of the off-shore Kerala-Konkan Basin (KKB) (Nair *et al.* 1998). A major part of the basin is situated in the low land (0-7.5 m) above sea level. The SKSB has a curvilinear eastern boundary and is almost located in the coastal plains of Kerala (Fig.1). More than half of the coastal plain is covered by water bodies such as lagoons and perennial/seasonal wetlands with lagoonal deltas and fans (Chattopadhyay 2002). The remaining part is made up of the ridge-runnel system formed by Holocene sedimentary processes. As such, the Quaternary sediments in SKSB can only be studied in detail through samples collected from boreholes. Nearly 120 boreholes drilled in the basin for ground water exploration and extracts, geotechnical purposes and stratigraphic and sedimentological studies have provided the basic data. Accordingly, a general frame work of the sedimentary stratigraphy and the salient structural configuration of the SKSB along with coast has been derived. Table 1 depicts the general stratigraphy of SKSB. The basin can be divided into (1) southern block, (2) a central depression and (3) a northern block (Fig. 2). The deposition of Quaternary sediments has been essentially influenced by the structural pattern inherited from the Tertiary, with modifications (Nair & Padmalal 2003).

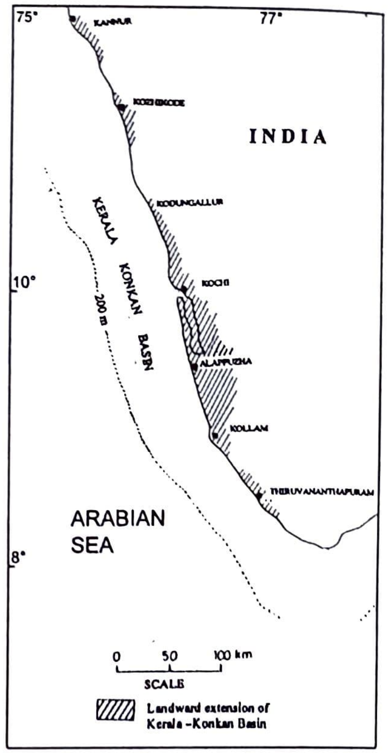


Figure 1. Landward extension of Kerala-Konkan basin showing SKSB

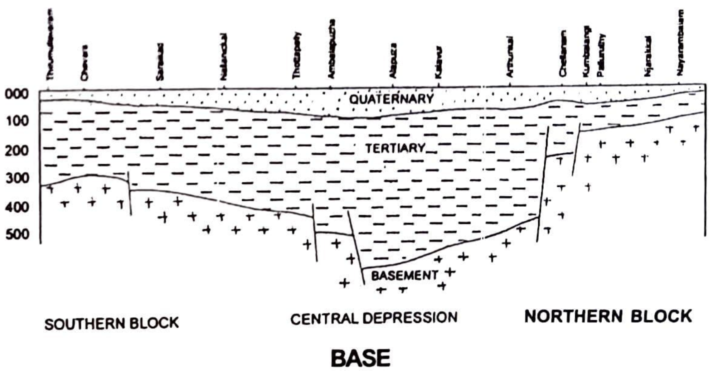


Figure 2. Geological cross section of SKSB

Table 1. Stratigraphic sequence of Kerala (modified after Najeeb, 1999)

Quaternary	Vembanad formation	Sands, clays, molluscan shell beds, Riverine, alluvium and floodplain deposits. Laterite capping the crystallines and Tertiary sediments.
	Warkalli Formation	Sandstone and clay with lignite seams.
Tertiary	Quilon Formation	Limestones, marls, clays/calcareous clays with marine fossils.
	Vaikom Formation	Sandstones with pebbles and gravel beds, clays and lignite and carbonaceous clay.
Mesozoic to Archaean	Intrusive: Veins of quartz, pegmatites, granites, granophyres, dolerite and gabbro.	
	Garnet sillimanite gneiss, hornblende-biotite gneiss, garnet-biotite gneiss, quartzo-feldspathic gneiss, charnockites, charnockite gneiss, etc.	

MATERIAL AND METHOD

All the boreholes studied are located within SKSB (Figure 3 a, b). Sediment cores obtained from eight boreholes, viz. Ramapuram, Pachcha, Haripad, Thakazhi, Kalarkodu, Ernakulam, Eruva and Muthukulam were analyzed for lithology, mineralogy and geochemistry. The details of three boreholes and the available ^{14}C dates are given in figure 4. Palynological analysis of selected samples of six boreholes was carried out at Agharkar Research Institute, Pune while the ^{14}C dates of carbonaceous clays, peats and shells of selected intervals have been provided by the Birbal Sahni Institute of Palaeobotany, Lucknow and Shizuoka University, Japan. Besides, the ^{14}C dates from earlier studies have been used for chronological control while interpreting the Late

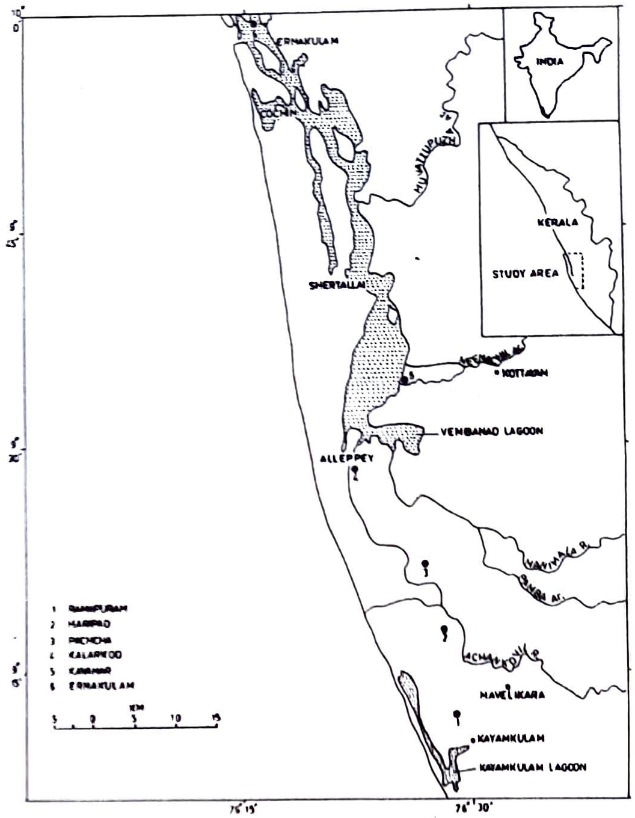
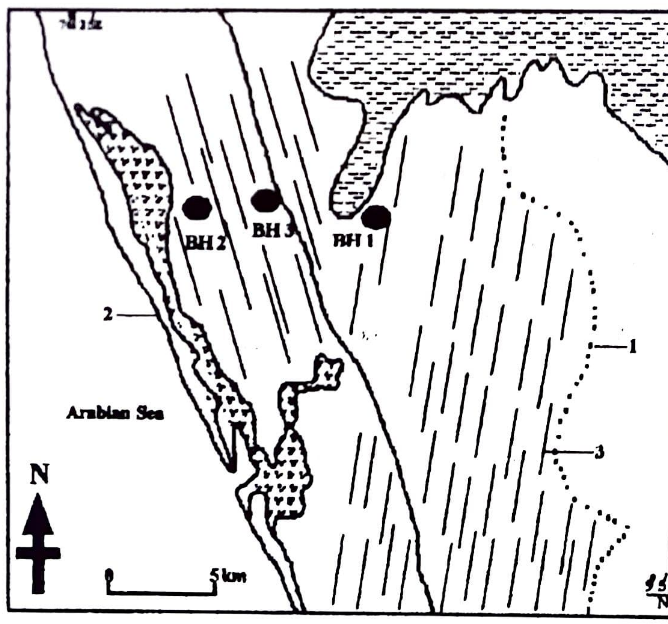


Figure 3a. Location of boreholes of SKSB

Table 2. Results of the radiocarbon analysis of samples from South Kerala Sedimentary Basin. Sample depth is measured from ground surface except 7 and 15, where the depth measurements were made with reference to mean sea level (msl)

Sr. No.	Location	Depth (m)	Sample type	^{14}C yr B.P.
1.	Eruva (BH1)	6.64	Shell	42490 ± 860
2.	Ramapuram (BH3)	12.00	Shell	39370 ± 1000
3.	Eruva (BH1)	4.03-4.05	Shell	39193 ± 923
4.	Eruva (BH1)	2.10-2.20	Shell	36218 ± 813
5.	Ramapuram (BH3)	7.60	Shell	24450 ± 710
6.	Kalarkodu	40.00	Sediment	20380 ± 490
7.	Ernakulam (lagoon)	21.50	Sediment	8330 ± 110
8.	Pathiyoor	1.00	Wood	7510 ± 100
9.	Muthukulam (BH2)	3.00-3.10	Wood	7176 ± 82
10.	Kavnar	9.50	Shell	7090 ± 100
11.	Pachcha	8.50	Shell	6690 ± 160
12.	Kalarkodu	8.45	Sediment	6740 ± 120
13.	Muthukulam (BH2)	2.07	Wood	6276 ± 112
14.	Parayakadavu	6.50	Shell	4610 ± 100
15.	Ernakulam (lagoon)	7.50	Sediment	3800 ± 80
16.	Muthukulam (BH2)	1.27	Shell	3362 ± 114
17.	Ramapuram (BH3)	3.00	Wood	2460 ± 120
18.	Kavnar	6.50	Sediment	2180 ± 70



BH1 - Eruva BH2 - Muthukulam BH3 - Ramapuram

Kayamkulam lagoon

Extension of a wetland in the study area

1 Quaternary palaeo - coastline

2 Present coastline

3 Ridge runnel system

Figure 3b. Location of BH1, BH2, and BH3 of SKSB

Quaternary geological events. Samples from boreholes of Eruva and Muthukulam were obtained using a bloom sampler and the rest of the above boreholes were obtained through a DST sponsored project. Prof. H. Wada of Shizuoka University, Japan has helped by dating two samples besides six dates of Eruva and Muthukulam. In all 18 dates covering the Pleistocene and Holocene periods, the oldest (42490 ± 860 yr B.P.) being the shell bed at a depth of 6.64 m in Eruva and the youngest is of Kavnar sediment (2180 ± 70 yr B.P.) at the depth of 6.50m were obtained. The borehole samples were subjected to textural, mineralogical and geochemical studies following standard procedures at Centre for Earth Science Studies (CESS) in Thiruvananthapuram and Osaka City University, Japan. Results of ^{14}C dating of shell fragment and wood from subsurface sediments of different boreholes of SKSB are given in Table 2.

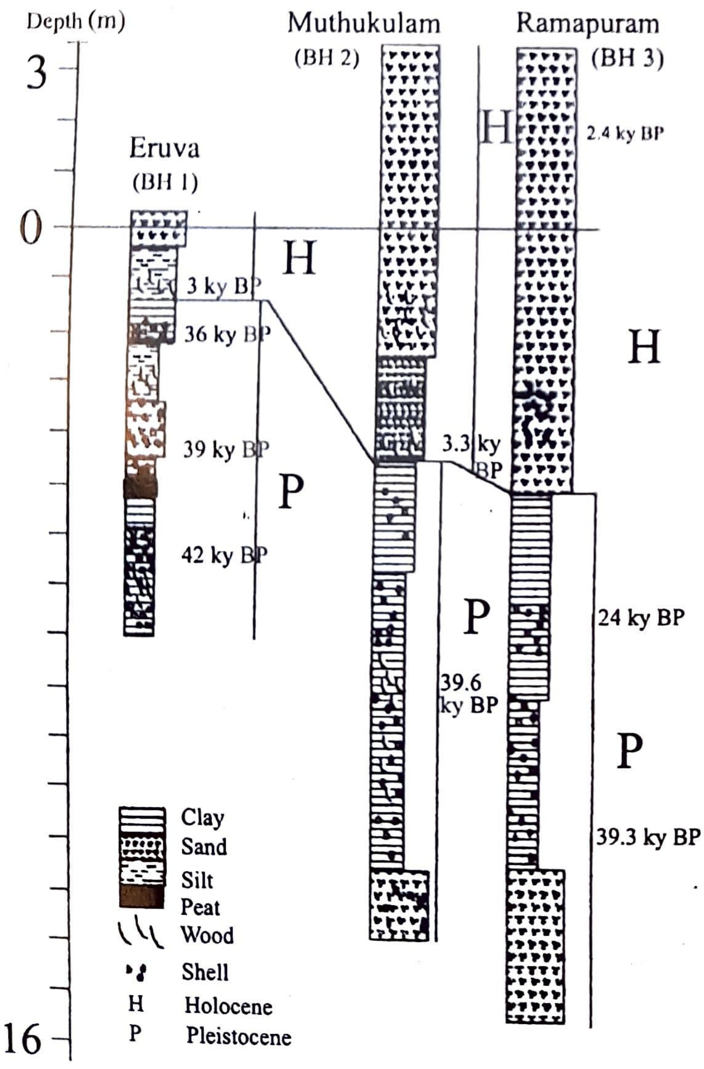


Figure 4. Correlation of BH1, BH2, and BH3 boreholes representing the littoral-marginal marine Quaternary sections of SKSB.

DISCUSSION

An integrated study of subsurface sediments of SKSB using radiocarbon dates and palynological work of Kumaran (2001) coupled with detailed field observations now allows us to address the Late Quaternary geological processes and environmental changes in the SKSB. They are composed of Early Miocene-Middle Miocene Vaikom, Quilon and Warkalli formations overlain by Quaternary sediments. Laterite capping is found on Tertiary sediment and the basement rocks. In fact, laterite is found to separate the Teritary formations from the Quaternary sediments in a large part of the SKSB, thus acting as a useful datum in the subsurface sedimentary column. Quaternary sediments with a maximum thickness of over 80 m are found in SKSB. The sediments of Quaternary age have been named as Vembanad Formation in the area of SKSB by Raha *et al.* (1983) and have their best development in the region of the present day Vembanad lagoon. The Quaternary sediments have been assigned to Pleistocene and Holocene units pending formal rock stratigraphic names for these. Because of a few data gaps no attempt is made here to propose formal or informal rock stratigraphic names of Pleistocene and Holocene units of Kerala.

With the available lithostratigraphic data and the ^{14}C dates it has been possible to divide the Quaternary of SKSB into a Pleistocene unit and a Holocene unit. The Pleistocene unit consists of an undated continental clay and sand overlain by a clay with layers of pebbly and molluscan shells deposited in marine and marginal environments. The marine transgression is dated > 42 Ky B.P. In SB the Pleistocene unit younger than ~ 22 Ky B.P. is not found. The NB also seems to have lost much of the Pleistocene unit. In the CD this unit up to LGM seems to be present. The best development of this unit is in CD which has a net ENE-WSW trend. Besides, it extends almost up to the basin boundary in Kottayam area. Regional analysis suggests that this unit may be preserved as outliers in palaeoestuaries and other palaeotopographic depressions in several places all along the boundary of the basin. This unit is made up of a sequence of sand, clay and conglomerate at bottom, overlain by silt, grey clay with molluscan shells and, capped by sand and pebble bed.

The lithological succession of Holocene unit has been discerned from boreholes, open dug wells and other sources. This unit has very high facies diversity. The thickness of sediments varies from 8 m to 25m. Like Pleistocene, this unit also starts with a continental sand and clay with pebble. The Holocene transgression is dated ~ 7 ky B.P. and has covered the SKSB except the basin margin in the north and south. The marine-marginal/marine water bodies established by the Holocene transgression witnessed deposition of sand and grey organic rich clay with molluscan shell layers. The marine and marginal-marine environments were silted up fast during the regression and sea level recorded to the present position by about ~ 4 ky B.P.

The sedimentation during Quaternary started in continental depositions. In fact, the first marine transgression in SKSB took place *ca.* 42000 yrs B.P. The marine-brackish waters of this transgression did not cover the entire basin uniformly due to palaeotopographic differences. The basal part of Pleistocene unit is composed of ferruginous clay, white clay and clayey sand, and dark grey clay with carbonaceous material deposited in continental environment. The continental clays and sands underlying the marginal marine clay sequence, though not dated, could cover 30-50 ky. The basal continental sediments grade upward through a conglomerate to a clay dominated section with frequent admixture and interbeds of carbonaceous material and molluscan shells deposited in littoral lagoonal environment. The bottom of this lagoonal-littoral section is dated *ca.* 43 ky BP. Both SB and NB have lost part or whole of this unit, by erosion from their crestal parts. The CD seem to have complete record of this unit, but only the upper part could be examined in detail. The unit here is composed of silt sandy clay and stiff caly inter-layered with fine sand. The unit as a whole reflects in continental to lagoonal and marginal marine environment, which changed to lacustrine or fluvial environment and perhaps a spell of non-deposition. There is evidence to show that the SB had accumulated considerable thickness of this unit, buried to grater depths leading to dewatering of clay prior to this uplift. Almost a similar picture is expected to be in the NB.

The Holocene transgression took place in a series of continental depressions where organic rich clay was being deposited. This transgression dated *ca.* 7 ky BP was a fast event covering all parts of SKSB. The regression that followed left behind a vast lagoonal water body (mega-lagoon), which included the areas of the Vembanad lagoon, Kuttanad, Kayamkulam lagoon and the regions adjacent to these. The marine influence in this lagoonal water-body differ from place to place. Silting up of this vast lagoon, resulted in a isolation of Kayamkulam lagoon and conversion of vast areas into shallow seasonal perennial wetlands used for raising paddy crop. The spectacular ridge runnel topography developed during this regression.

The Late Quaternary period witnessed fluctuating climatic conditions in Indian subcontinent. Limited palynological observations on samples from six boreholes have indicated that there have been periods of abnormally high, normal and deficient rainfall during Late Pleistocene and Holocene. The fairly abundant occurrence of *Cullenia exarillata* (Bombacaceae) pollen at certain intervals of various boreholes is significan while inferring heavy rainfall and wet period. Being a member of the wet evergreen forest and enjoying a 3000-5000 mm precipitation range, the presence and relative abundance of *Cullenia* pollen in the mrine and lagoonal facies indicates heavy rainfall. As this taxon is presently seen very far from the sea coast and is restricted to high altitudes, the pollen grains must have been transported through water channels that eventually drained into the lagoons after heavy downpour. The interval at 10.85 m in Ramapuram (BH3) is considerably important in this aspect. Besides, pollengrains of certain other wet evergreen forest members, viz. *Fahreheitia zeylanica, Agrostistachys meeboldii,? Malottus* (Euphorbiaceae) and *Lophopetalum wightianum* (Celastraceae) have been recovered along with *Cullenia exarillata* Accordingly, the presence of these inland/montane plant tax a representing the arborescent plants (AP) of C3 vegetation in the marine sequence is of great significance indicating heavy rainfall and wet period during the Early Holocene. Van Campo (1986) suggested a humid climate around 10,000 B.P. on the basis of pollen analysis of core samples from the Arabian Sea off Kerala. Jayalakshmi *et al.* (2004) too have observed high amounts of TOC derived from terrestrial sources and this is attributed to the presence of a dense forest cover in the provenance fostered by higher rainfall rate than the present. This high rainfall rate is in conformity with the more intense Asian monsoon rain reported from several parts of the world. A reverse trend, that is an aridity situation, has been accounted at 3m depth in Pachcha, Muthukulam, Ramapuram and Kavnar probably towards the later part of Holocene, where recovery of organic matter is very poor. Terrestrial palynodebris (cuticles, tracheids, etc.) is scarce and no representation of AP of C3 vegetaion has been seen at this level. The intervals of most of the boreholes studied show a more stable depositional environment with moderate biotic activity and much less terrestrial supply of organic matter indicating possibly a weakening of the Asian summer monsoon. This eventually led to a period of very low precipitation as revealed by layer of palaeosol, inland aeolian sand dunes and desiccation of the lagoons. The period of this important event in the Late Holocene as fixed by the ^{14}C dates in Muthukulam, Kavnar and Ramapuram is approximately between 3.6 and 2.5 ky B.P. The detailed palynological analysis and palynodebris accumulation of the subsurface sediments of SKSB and its implications are being dealt separately elsewhere (Kumaran *et al.* in press).

The above palaeoclimatic variation is largely supported by sedimentology, geochemistry and limited SEM studies on quartz grains (Nair *et al.* in press). Although there is no unanimity about the time frame of events of high, normal and reduced rainfall/aridity, the available subsurface data of SKSB could be analysed with respect to published information on monsoon rainfall. Out of the several episodes of climatic changes, the heavy rainfall > 3 times the present rate during the 10-4 ky BP seems to be responsible for substantial modifications of the fluvial regime and sediment supply pattern. This seems to have accentuated the effect of an abnormal (40-100% more than the present rate) rainfall experienced during 40-30 ky BP would have resulted in carving wide and deep fluvial channels. It is well known that the rivers in Kerala are 'misfits', i.e. their channels are too wide for draining the present run off. Also, diastemising valleys of tributary steams with vertical cliffed sides and vertical side island within, so common in the midland region have been created due to this high rainfall and lower sea levels.

The highly wet spell of 10-4 ky BP has been followed gradually by a period of reduced precipitations. During the period from 6 to 4 ky BP, the sea receded and reached the present level. The monsoonal activity also declined subsequently. This led to a period of drought or aridity at *ca.* 3 ky BP (to be precisely dated by TL method since horizon representing the aridity is devoid of any carbon material for ^{14}C dating). Besides, there is a clear signature of Aeolian activity modifying the sand ridge of the ridge-runnel system along with formation of sand dunes in a couple of areas in the SKSB. The coast by 4 ky BP had already been established along the present site. The reduced rainfalls after 4 ky BP is reflected in the form of palaeosols, lateritised sediments at < 1 m depths in wetlands peripheral to lagoons and even drying up of lagoon in parts. The yellow ochre layer recorded on the top of the shell bed in the Vembanad lagoon is a product of this period of reduced precipitation/aridity/drying up of the lagoon. The shells from the shell rich layers from Vechur and Mahamma are ^{14}C dated as 3710 ± 90 and 3130 ± 100 year BP respectively. Both these dates fall within the overall period of reduced rainfall.

The sea level rise from LGM to *ca.* 6 ky BP and the following regression has had significant effect on the economic mineral deposits, inhabitation pattern, drinking water availability and even culture and civilization. Thus, the available data obtained from the subsurface sediments of SKSB have far reaching implications in the exploration and exploitation of mineral resources within the Quaternary sediments (Nair & Padmalal, in press). Considering the tremendous potential of mineral and shallow ground water resources of SKSB, the archives that are preserved in the basin are to be appropriately decoded for a better understanding of the geological, geomorphological and palaeoclimatic events of Late Quaternay period.

ACKNOWLEDGEMENT

Jayalakshmi expresses sincere thanks to Prof. Hideki Wada of Shizuoka University and Prof. H. Kumai of Osaka City University, Japan for their help and encouragement. Suggestions and comments of Prof. Muneki Mitamura and Shusaku Yoshikava of Osaka City University and Dr. M. Sathish Kumar of Shizuoka University, Japan are appreciated. KMN and DP thank the DST, Govt. of India for the financial support through a project ESS/23/VES/066/98. KPNK acknowedges the facilities given by the Director, ARI, Pune and the first author greatly acknowledges fellowship support from MONBUSHO (Japan).

REFERENCES

Chattopadhyay, S 2002. Emergence of Central Kerala coastal plain-a geomorphic analysis. pp. 287-298 in: Tandon, S.K. and Thakur, B. (Editors)- *Recent advances in geomorphology, Quaternary geology and environmental geoscience: Indian case studies,* Manisha Publishers, Delhi.

Desikachar, SV 1976. Geology and hydrocarbon prospects of the Kerala west coast basin: *Coastal sedimentaries of India, South of 180 N latitude,* ONGC, Madras.

Jayalakshmi, K, Nair, KM, Kumai, H & Santhosh, M 2004. Late Pleistocene-Holocene palaeoclimatic history of the southern Kerala Basn, southwest India. *Gondwana Research* **7**(2): 585-594.

Kumaran, KPN 2001. *Report on palynological analysis of subsurface samples of SKSB, Kerala,* Agharkar Research Institute, Pune, pp. 1-31.

Kumaran, KPN, Nair, KM, Padmalal, D & Limaye, RB (in press). Palynological analysis of the subsurface sediments of South Kerala sedimentary basin and its importance in Late Quaternary palaeoclimate. *Curr. Sci.*

Nair, KM & Padmalal, D. 2003. In *Project completion report* (ESS/23/VES/006/98), Dept. of Science and Technology, New Delhi, pp. 1-60.

Nair, KM & Padmalal, D. in press. Mineral and ground water resources in the Quaternaries of Kerala. In *Silver Jubilee Compendium of CESS,* Trivandrum.

Nair, KM, Padmalal D, Kumaran, KPN. (In press) Quaternary geology of south Kerala sedimentary basin-An outline. *Geol. Soc. Ind.*

Nair, KM, Padmalal, D & Sajikumar, S 1998. Silting up of a Holocene mega lagoon along Kerala coast: p. 12. In *National seminar on coastal evolution, prcesses and products,* Trivandrum.

Nair, KM & Rao, MR 1980. Stratigraphic analysis of Kerala basin. *Geol. Surv. Ind.* Spl Pub. 5: 1-8.

Najeeb, KM. 1999. Groundwater exploration of Kerala as on 31.3.1999. *Report of Central Groundwater Board, Kerala Region,* Trivandrum.

Raghavrao, KV 1975. Ground water exploration, development and long term aquifer management in Kerala pp. 30-32 in Menon, K.K. (Editor) *Mineral resources of Kerala and their utilization* Geoscience and Technology Association, Kerala.

Raha, PK, Sinha Roy, S & Rajendran, CP, 1983. A new approach to the lithostratigraphy of the Cenozoic sequence of Kerala. *Geol. Soc. India* **24**: 325-342.

Rajendran, CP, Rajgopalan G & Narayanaswamy 1989. Quaternary geology of Kerala: evidence from Radiocarbon dates. *J.Geol. Soc. India* **33**: 218-322.

Soman, K. 2002. Geology of Kerala. *Geol. Soc. India*, Bangalore, 335 p.

Van Campo, E 1986. Monsoonal fluctuations in two 20,000 yr B.P. oxygen isotope/pollen records off southwest India. *Quart. Res.* **26**: 376-388.