CHAPTER 7

PALAEOENVIRONMENTAL STUDIES

The landscape of the lower Narmada basin exhibits a dominant impact of neotectonics due to the obvious influence of the active Narmada-Son Fault (NSF). However, the exposed sediments show several evidence of Late Quaternary environmental changes. Two factors have influenced the environmental conditions in the area. One is the sea level fluctuations and the other is the regional climatic changes. The environmental changes are very well seen in the varying nature of sediments deposited over a period of time. The environmental changes have been preserved in the sediments by virtue of their nearness to the coast and location of the area in a climatically sensitive semiarid- subhumid region of western India. The major environmental changes are imprinted in the sedimentary characteristics of the Late Pleistocene and Holocene sediments of the lower Narmada basin. Reconstruction of palaeoenvironment requires a multidisciplinary approach involving physical, climatic and biotic factors. The palaeoenvironmental changes in the lower Narmada basin have been deduced from the field characteristics and laboratory analyses of the selected horizons/formations. In the present study emphasis was however laid on clay mineralogical studies, estimation of palaeodischarge levels, and palynological studies. These studies helped to substantiate the environmental conditions deduced from the sediment successions deposited under diverse microfluvial environments and also to reconstruct the palaeoenvironments in the lower Narmada basin.

Clay Mineralogy

Clay minerals in sediments are good indicators of palaeoenvironmental conditions. While they don't provide direct evidences of climatic conditions but can give an integrated record of overall climatic impacts (Singer, 1984). They usually record any major change and thus prove to be excellent indicators of climatic patterns (Dilli and Pant, 1994). Keeping this in view clay mineralogical studies were carried out on the basal clays exposed at the base of Nanderiya section (Figs. 4.7, 4.8, 7.1). For a high resolution data 20 samples were collected at an interval of 10 cm, from a 2 m exposure of the basal clays. Oriented clay aggregate slides were prepared and were examined under X-ray diffractometer at National Institute of Oceanography (NIO), Goa.

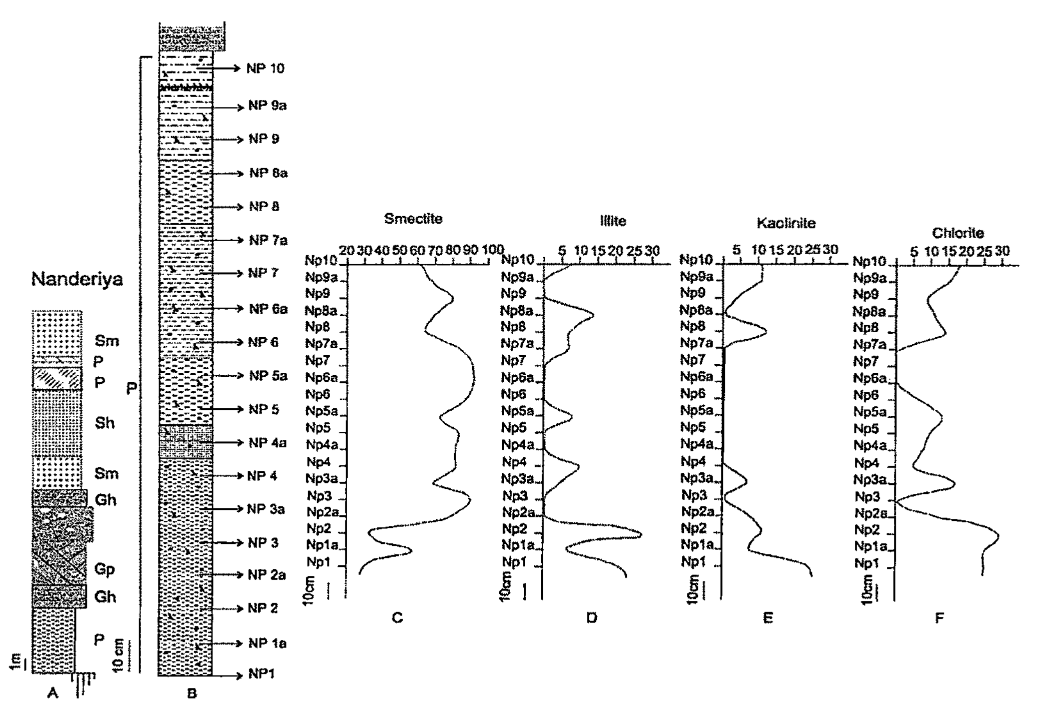

Fig. 7.1. A. Litholog showing the exposed sedimentary sequence at Nanderiya. **B.** Detailed log of the basal clays showing the sample locations for the clay mineralogy and palynological analysis. **C to F.** are the percentage of Smectite, Illite, Kaolinite and Chlorite

Results

The soils exposed at the base of Nanderiya are dark coloured and intensely fractured resulting in the formation of sub-angular cohesive blocks. Horizontal zonation is weakly developed because of self mixing resulting from the shrinking and swelling of the clay with drying and wetting (Wilding and Tessier, 1988; Dudal and Eswaran, 1988). They show concave upward curviplanes and slikenslides. These planes have also given rise to pseudoanticlines. The homogenization of the soil profile and the presence of folds or concave-up curvi-planar joints suggest the soil to be of vertisol type (Dudal and Eswaran, 1988; Coulombe et al. 1996). The clay mineral assemblage is dominated by very high percentage of smectite in all the samples (Fig. 7.1 B). This is followed by subordinate quantities of Illite, Kaolinite and Chlorite. The dominance of smectite in the Nanderiya section is very significant as vertisol all over the world show dominance of this particular clay species (Malik et al. 1999; Coulombe et al. 1996, Gradusov, 1974). The soil is susceptible to large scale shrinking and swelling. It is formed by the weathering of basic igneous rocks in low relief areas where rainfall is moderate or seasonal (Weaver, 1989). Weathering of basalts (Deccan Traps) is the main reason for the soils being rich in montmorillonite (Gradusov, 1974; Singh and Murti, 1975). A high smectite could be indicative of volcanic detritus carried into the depositional basin by water or wind and altered to smectite on the sea bottom or the palaeoclimate in the area including the depositional basin was alternately wet and dry, probably warm, with smectite precipitating from solution during the dry season, using ions that were taken into solution during wet season (Weaver, 1989). It is difficult to infer the climatic conditions in the past particularly when there are high contents of smectite as it is difficult to distinguish between authigenic and detrital smectite clays (Singer, 1984). The relationship between climatic parameters and clay mineral formation is complicated by the intervention of extra-climatic factors such as topography, geomorphology, lithology and time (Singer, 1984).

The vertisols of the neighbouring Mahi River basin which occurs at the same stratigraphic level is comparable to the one exposed at Nanderiya. Vertisols of Mahi also show similar characteristics and high smectite (montmorilonitte) contents (Malik et al. 1999). They are also found rich in marine micro fauna (Raj et al. 1998a) and have been deposited at ~125ka (Juyal et al. 2000), a period of global sea level rise. The vertisols of Mahi have been deposited in estuarine marine conditions Abundance of smectite over diverse latitudes suggests uniformity of climate (Chamley et al. 1979, a,.b; 1980; Singer, 1984) thus emphasizing that the basal clays at Nanderiya were also deposited under estuarine marine conditions.

Palaeohydrology

Estimation of palaeodischarges form an important component of palaeohydrological studies which are useful for characterisation of past fluvial environments and their channels (Dury, 1970; Ethridge and Schumm, 1978; Gardner, 1983; Williams, 1988). Hydrologic estimations can be made directly at gauging stations, however, empirical equations developed and tested during the last few decades are used in the absence of gauging data (Williams, 1978; 1988). Exposed palaeochannel cross-sections offer a more direct way of estimating palaeofluvial characteristics that can closely be compared with the data from gauged sites in terms of accuracy.

This is possible as it allows the use of measures rather than estimated input variables into an empirical equation (Williams, 1988).

Palaeofluvial estimates also allow study of hydrologic events in palaeoclimatic context (Kale et al. 1994). The events and estimates are interpreted in the context of climatic variation in magnitude and frequency. The palaeobankfull discharges are estimated from the palaechannel cross-sections exposed as vertical palaeobanks in lower Narmada valley. The formation of palaeobanks has been primarily attributed to tectonic uplift during the humid phase of Early Holocene (Maurya et al. 2000; Chamyal et al. 2002).

Methodology

The bankfull discharge at a river cross-section is the flow which fills the channel to the top of the banks marking the conditions of incipient flooding (Williams, 1978). A number of definitions have been given on bankfull discharges in various papers by different authors (Williams, 1978, 1984, 1988; Cheetham, 1980). Williams (1978), however discussed four common ways of determining bankfull discharges i.e. 1) rating curves, 2) hydraulic geometry, 3) flow recurrence frequencies and 4) flow equations.

Of the above four methods three of them (rating curve, hydraulic geometry and recurrence interval) can be used only at gauging sites because they depend on the previous discharge measurements for the site where as the flow equation is the only one applicable to ungauged sites.

To determine the bankfull discharge at ungauged sites Williams (1978) developed a regression equation:

$$Q_b = 4.0\ A_b^{1.21} S^{0.28}$$

where Q_b (bankfull discharge) is in cubic meters per second, A_b (area) is in square meters and S (slope) is dimensionless. This equation has been used as it is more precise for large rivers (large bankfull discharges) than for small streams (Williams, 1978). This equation has been used in the present study, as no data are available from the gauged sites to determine the bankfull discharges using the palaeobanks.

In the lower Narmada basin the younger terrace surface abuts directly against the abandoned cliffs (palaeobanks) of S_1 and S_2 surfaces (Fig. 3.19). The palaeobanks run almost all along the Narmada River in the lower reaches (Fig. 3.3). Hence palaeobanks were used to determine the bankfull discharge during the early Holocene period. The cross-sectional area (A_b) was determined by measuring the distance between the channel and the palaeobanks and the depth using the height of the cliff sections all along the river (Fig. 7.2).

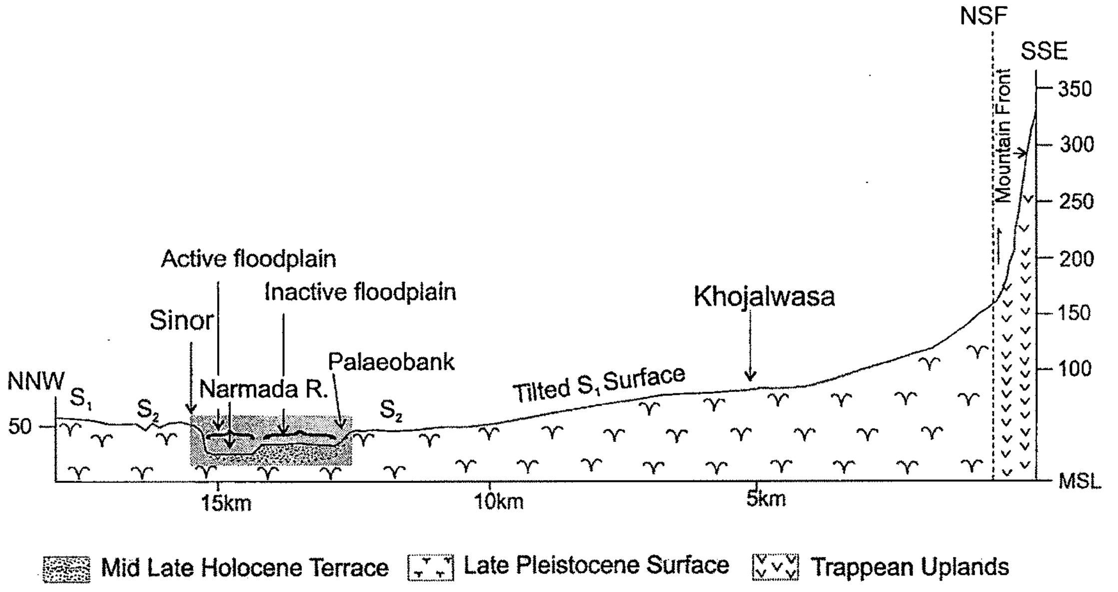

Fig.7.2. Cross section across the Narmada basin with active and inactive floodplains and the palaeobanks

Results

Bankfull discharge for the Narmada River was calculated using the equation given by Williams (1978)

$$Q_b = 4.0\ A_b^{1.21} S^{0.28}$$

where Q_b is bankfull discharge in m^3/sec, A_b is the bankfull area in m^2 and S is the slope which is dimensionless. The results of the analysis are tabulated in Table 7.1. The bankfull discharges were calculated using the palaeobanks. The distance between the palaeobanks has been used to determine the width and the maximum cliff height at the location was used to determine the area (A_b). The results estimate the bankfull discharge using the present day river width as well as the bankfull discharge of the Narmada River in the past using the palaeobank width to calculate the area covered during the period when the river was in spate (Fig.7.2). The bankfull discharge calculated for the present day is 90,808.21 m^3/sec where as the bankfull discharge of the Narmada River in the past using the palaeobanks was calculated to be around 341776.76 m^3/sec, which is about 3.76 times more than the present.

In peninsular India fluvial discharges are mainly related to monsoonal rainfall, which has been the most important factor in the flooding of the rivers during the months of mid-June to early October supported by cyclones. The Narmada River channel is visited by very large floods separated by several decades, which dominate the channel forms. It flows through a tectonically active zone (Chamyal et al. 2002), meandering across alluvial reaches separated from each other by rocky gorges, rapids and scablands eroded

Location	Distance (km)	Present Width(W_b) m	Palaeobank Width(W_b)m	Depth (D_b)m	Present Area (A_b)	Palaeobank Area(A_b)	Present day bankfull discharge	Palaeo Bankfull discharge
Garudeshwar	0	650	2550	15	9750	38250	29522.16	154325.1
Tilakwada	12.5	600	1100	34	20400	37400	72128.21	150185.26
Chandod	28.5	900	1500	40	36000	60000	143409.75	266082.91
Nanderiya	31	650	1600	30	19500	48000	68295.88	203120.8
Moletha	34.1	1350	1600	20	27000	32000	101251.81	124360.9
Sukhdev Mandir	37	1000	2500	28	28000	70000	105806.87	320642.6
Nani Patan	39.5	750	3000	32	24000	96000	87802.78	469895.04
Kanjetha	46.5	800	3500	30	24000	105000	87802.78	523711.03
Sinor	49.75	600	3050	25	15000	76250	49719.06	355600.9
Kotia	66.5	1300	5750	28	36400	161000	145340.06	878439.76
Lilod	74.1	700	2400	28	19600	67200	68719.9	305189.43
Jhenor	93.9	550	6600	13	7150	85800	20284.43	410177.93
Nikora	101.2	2600	5650	12	31200	67800	120609.005	308489.65
Juna Tavra	110.6	3000	5050	16	48000	80800	203120.88	381434.89
Nava Tavra	111.5	1550	4800	18	27900	86400	105349.81	413651.21
Bharuch	128.6	1350	4800	10	13500	48000	43767.98	203120.88

Table 7.1. Bankfull discharge calculated from the present channel and the early Holocene palaeobanks. The calculations have been done based on the methodology described by Williams (1978)

by high magnitude floods. Such high magnitude floods control the size of the Narmada channel bounded by 30-40 m high banks of alluvium which the river has hardly overtopped in this century and probably on very rare occasions in the Late Holocene (Gupta, 1995). The deposition is confined within the channel mainly as point bars that have been interpreted as flood originated with some wet monsoon flow modifications.

The high discharge levels during Early Holocene as compared to the present suggest a stronger SW monsoon during this period. Sirocko et al. (1993) suggested that the monsoon increased episodically in a series of four steps between 14.3 to 8.7 ka. The studies by Sirocko et al. (1993) interpret that the monsoons were strongest between 9.5 to 5.5 ka. Studies have also revealed that solar irradiances may have varied by as much as 25% during the Holocene (Lean et al. 1992; Lean and Rind, 1994) leading to a cool Tibetean Plateau by as much as 1^0 C for decades and centuries (Rind and Overpeak, 1993). Decades to century long changes in the tropospheric aerosol loading (e.g. Zielinski et al. 1994) or trace gas concentration (e.g. White et al. 1994) may have also been the cause of possible decade to century scale abrupt changes in monsoon intensity (Bryson, 1989). Terrestrial records of past change from Asia and Africa indicate that the monsoon was significantly weaker than present during glacial times (ca. 18ka), much stronger than present during the early to mid- Holocene (ca. 9-5 ka) and weaker up to present day. Peak monsoon strength began at 9.5 ka and waned more gradually after 5.5 ka with slow decrease in summer insolation (Overpeak et al. 1996).

This suggests that there was an increase in the precipitation in the Indian sub-continent during the Holocene period leading to an increase in flood discharge. The bankfull discharge in lower Narmada valley is estimated to be around 90,808.21 m^3/sec. The maximum-recorded discharge in the Narmada River is around 9962 m^3/sec at the gauging site near Garudeshwar (from the last 10 years discharge data provided by Sardar Sarovar Nigam Ltd.). The palaeofluvial bankfull discharge of lower Narmada basin is calculated to be around 341,776.76 m^3/sec. This is about 3.76 times more than the present day calculated discharge which confirms to the globally recorded higher precipitation levels during Early Holocene.

Palynology

Palynology has been considered as an important tool in the interpretation of palaeoenvironments. Palynological studies were carried out on the Late Pleistocene sediments of Nanderiya and on the Late Holocene sediments of the Bharuch section at Birbal Sahni Institute of Palaeobotanhy (BSIP), Lucknow.

NANDERIA SECTION

Three samples were collected from the basal clays of the Nanderiya (Fig. 7.1) section for palynological studies. The samples were first treated with 10% aqueous KOH solution and boiled for five minutes to deflocculate the matrix and to dissolve the extraneous material. The material was treated with HF, HCl and CH_3COOH to dissolve silica, cutines/suberines etc. and to dehydrate the material respectively. Treatment of the mixture of acetic anhydride and conc. H_2SO_4 in the ratio of 9:1 was given to remove humic acid and golden brown colouration of the pollen/spore. Thereafter several washings with distilled water were given and material was sieved to study the micro remains. To preserve maceral, in the 50% glycerin solution few drops of phenol were added. The residue is mounted on slides with glycerin jelly and sealed with paraffin wax. The samples (Np 1 , Np 4 and Np 9) have yielded good populations of spores and pollens and are described below.

NP 1 –

<u>Vitis</u> <u>tomentosa</u>, Heyene

Pollen grain 3- zonocolporate, prolate, spheroidal, 25 x 25 μ; colpi long, ends acute-rounded, ora circular, 2,3 μ in diameter; exine upto 2 μ thick, sexine thicker than nexine, tectate, columellae distinct, reticlate, heterobrochate.

<u>Psilatricolpites</u> <u>sp.</u> , Linn

Pollen grains are angiospermous, isopolar, oblong equatorially with flatly rounded poles, subtriangular in polar view, 22-29 μ x 11-16μ, tricolpate, longicolpate, colpae straight, margins thin, exine surface smooth.

Polypodiisporites sp.

Spores are monolate, bean shaped, belonging to family polypodiaceae, possessing verrucate, gemmate, baculate and often finely reticulate ornamentation. This genus is the most predominant taxon among the fern/pteridophytic spores in the Cambay Basin. Spores with heavily and coarsely versucate sculpture appears to be abundant. Spores are brown in colour, bilateral, plano-convex to slightly concavo-convex laterally. Size varies between 42-50 μ x 28-32μ. They grow in moist shady conditions.

NP 4 –

Psilatricolpites sp., Linn

Pollen grains are angiospermous, isopolar, oblong equatorially with flatly rounded poles, subtriangular in polar view, 22-29 μ x 11-16μ, tricolpate, longicolpate, colpae straight, margins thin, exine surface smooth.

Avicennia officinalis, Linn.

Pollen 3- monocolporate, prolate spheroidal, 34 x 31 μ; colpip long, almost extending upto poles (syncolpate condition also observed) ora ± circular 10 x 9 μ; exine upto 2.5 μ thick, sexine thicker than nexine, tectate, columellae distinct, coarsely reiculate, heterobrochate, tectum surface wavy.

NP 9 –

Psilatricolpites sp., Linn

Pollen grains are angiospermous, isopolar, oblong equatorially with flatly rounded poles, subtriangular in polar view, 22-29 μ x 11-16μ, tricolpate, longicolpate, colpae straight, margins thin, exine surface smooth.

BHARUCH SECTION

The Bharuch section which is a Holocene terrace section, was sampled for palynofacies analysis. The samples were taken from the silty clay and clay horizon of 1.5 m thick profile (Figs. 4.29, 7.3). For land – sea correlation relative proportion of autochthonous and allochthonous elements have been taken into consideration.

Autochthonous or terrestrial elements have been sub-divided into the following groups:

Black Oxidized Debris: It is also known as inertinite. This debris comprises of highly oxidized land plant tissue with no visible cellular structure. The oxidation mostly occurs during prolonged transport or due to post depositional oxidation of woody material. It is considered to be diagenetically modified product and its hydrodynamic property is equivalent to sand sized clastics and thus its dominance in a sediment indicate oxidizing and high energy environment of deposition.

Brown degraded debris: It consists of orange-brown or dark-brown structured or tissue infested land plants with poor cellular structure. Its buoyancy is considered to be higher than the black debris. It mostly dominates in proximal setting in a fluctuating water table condition. Its dominance indicates moderate oxidizing condition at sediment water interphase.

Translucent structured debris: It consists of pale, relatively thin, irregular shaped material. It includes cuticles of land plants with prominent cellular structure, mostly derived from leaves. It is considered the most buoyant material and mostly settles in suspension loads under low energy conditions. Its dominance in the assemblage also indicates reducing environment condition leading to good preservation.

Pollen: They reflect the regional vegetation on land and hence are considered to be good indicators of climatic conditions. They are transported by wind and river to the depositional area. Their higher values in the marine setting indicate higher runoff/increase in wind strength.

Pteridophytic spores: These are derived from shade loving lower plants. Their dominance in a depositional setting indicates prevalence of humid conditions. Its dispersal mostly takes place through water hence in a shallow marine depositional setup its dominance indicates high runoff probably during high precipitation.

Fungal elements: It consists of fungal spores and fruiting bodies. Their dominance indicates prevalence of warm and humid climatic conditions and well oxiginated environment of deposition.

The Autochthonous elements are characterized into

Amorphous debris: It consists of lumpy mass of organic matter without any shape and structure, mostly of bacterial and planktonic origin. It is highly prone to oxidation and therefore its dominance indicates low energy reducing environment of deposition.

Gonayaulacoid cyst: They are autotrophs and mostly dominate in the upper layer of water column in offshore facies. Gonayaulacoid cyst are indicative of current pattern, salinity conditions and temperature.

Peridinioid cyst: They are mostly heterotrophs and dominate in lagoonal, estuarine nearshore facies. Their dominance in fossil record provide information about the productivity of marine system and redox conditions of the water column and at sediment water interphase.

Acritarch: These occur in shallow water, marginal marine restricted areas. Their dominance in an estuarine setting indicates brackish water influence as a result of increased freshwater discharge.

The palynological data of Nanderiya samples suggest tidal estuarine conditions during the deposition of the sediments with terrestrial debris and brackish water flora suggesting fresh water supply or continental influx. Presence of Avicennia officinalis in Np 4 (Mangrove growing in tidal swamp) and continental pollens in Np 1 and Np 6 in the maceral points that the environment during deposition was that of coastal tropical along the border of sea reaching upto the edge of the river where the brackish tidal influence ceases. Further XRD analysis on the soil has revealed high percentage of smectite. These are indicative of volcanic detritus being carried into the depositional basin by water or wind and altered to smectite at the sea bottom (Weaver, 1989).

Palynofacies studies indicate shallow estuarine environment of deposition at Bharuch (Fig. 7.3). The deposition must have taken place in a proximal setting (with respect to continent). Allochthonous elements dominate throughout the section. Gonoyaulacoid dinoflagellate cysts are very low in number, occur in sample B6 and B5 and are represented by Spniferites sp. and Polysphaeridium sp.. Peridiniod dinoflagellate cysts are represented by protoperidiniod forms and occur in moderate quantity in sample no- B4. However, acritarch Holdinium sp. dominates in sample no B2. Amongst the palynodebris black, brown degraded and structured debris dominate sample no B3. Sample no B1 consist of mostly black oxidized debris. Pollen also occurs in low number throughout the section. The sedimentation starts with B6 and B5 in warm and humid climatic conditions. During this period the tidal influence were more pronounced as indicated by

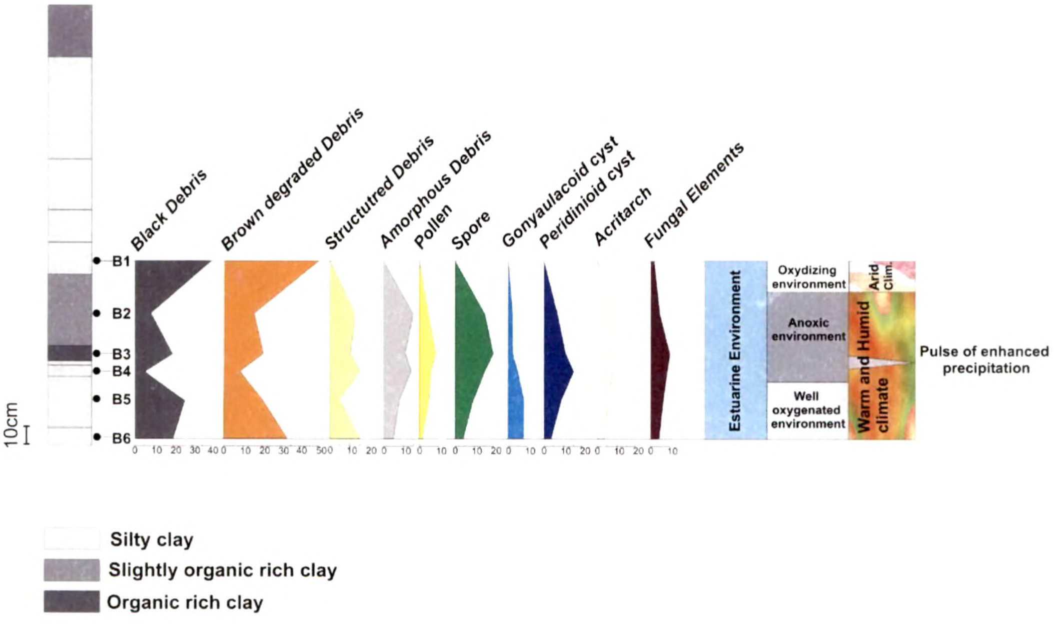

Fig. 7.3. Pollen diagram of Bharuch section. Also showing the environment during its deposition

the presence of Gonaulacoid dinoflagellate cysts. The decreased amount of amorphous organic matter but presence of foraminiferal test linings and dinocyst and fungal elements indicates well-oxygenated depositional environmental conditions. At the time of deposition of sample no B4 and B3 the Narmada estuary was flooded with large amount of fresh water and thus a high water table conditions were interpreted for Narmada estuary during this period. The occurrence of protoperidinioid cysts in sample B4 indicates increased primary productivity as a result of increased nutrient supply into the estuary during this period. The high amount of terrestrial component in B3 indicates slightly higher energy environment and effective transport of land derived organic debris as a result of enhanced runoff. Well-preserved amorphous organic debris in B4 and B2 is indicative of low energy and anoxic bottom water conditions which results in enhanced preservation of organic matter. Stratification of water column due to non-mixing of dense saline bottom water with less dense fresh water upper layer is the reason for the development of anoxia at sediment water interphase. High proportion of acritarchs in sample B2 also indicates strong fresh water influence and development of stable brackish water conditions. Dominance of Black debris in B1 is indicative of high-energy oxidizing environment of deposition.

Overall environment of section from B6-B1 is marginal marine with high influence of fresh water during B4-B3. The lower units (B6-B5) represent tide dominated environment followed by low energy anoxic environment during B4. Another pulse of oxygenated environment is represented by B3 palynofacies. This is followed by anoxic environment of B2. B1 represents high energy oxidizing environment. The palynological studies have corroborated well with the results of the clay mineralogical and fluvial microenvironmental studies and suggest a high sea-level during Late Pleistocene and high precipitation during Early Holocene and warm humid climate related to transgressive high sea level during Mid-Late Holocene.