lergists, the allergenic pollen in the atmosphere cause allergy symptoms if pollen are found in great abundance in air and pollen are buoyant and transportable, wind-pollinated and the plants producing these pollen are widely distributed. Obviously, the plants known for high-pollen productivity and are wind-pollinated are more significant for pollen allergy problems in human beings. Hence for any studies on the botanical aspect of respiratory allergy, data on the pollen incidence have to be correlated with those of pollen productivity.

3. Assured reproductive success of a plant species may be brought about by several ways: increased probability of the male and/or female gametic success in fertilization, faster and ensured development of seed, etc[14]. A plant during its flowering period produces large amounts of pollen grains, most of which are not involved in fertilization and instead remain suspended in air as pollen grain, before settling on the ground or water surface. Cross-pollinated plants usually produce greater number of pollen grains than self-pollinated ones, thus increasing the probability of success of fertilization.
4. Although aquatic plants produce less quantity of pollen grains compared to terrestrial plants, the pollen released by the aquatic plants affects the water environment. Consequently, a knowledge of quantitative production and methods of dispersal of pollen grains are significant as these factors, directly or indirectly, are involved in causing pollution in the environment.
5. Survey of the deposition of pollen grains of a particular area and production of pollen grains of a plant can sometimes be used as an index of the vegetation pattern of that area.

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ACKNOWLEDGEMENTS. We thank the CSIR, New Delhi for providing financial support for the present investigation.

Received 5 September 1997; revised accepted 11 March 1998

Late Quaternary sea level changes in western India: Evidence from lower Mahi valley

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The Mahi and Kothiyakhad are two recently established marine formations from the Late Quaternary continental succession of the lower Mahi valley, Gujarat. These formations have yielded fairly rich assemblages of foraminiferids, confirming their marine origin. The Mahi Formation indicates that the first major transgression of about 7–8 m high took place around 240 Ka in the Mahi valley during Late Quaternary. However, the second transgressive phase at ~ 4,000 years BP, represented by the Kothiyakhad Formation, is to be viewed in the light of the tectonic uplift in recent times. Results of radiocarbon dating of bottom and top mud layers of Kothiyakhad section indicate that the sea-level was high up to 2,000 years BP.

THE Mainland Gujarat across which the Mahi river flows, comprises a huge thickness (100–500 m) of partially indurated sediments of diverse origin. These have been investigated in the past for their detailed lithologic, stratigraphic, sedimentological characteristics and depositional environments[1–4]. The emphasis so far has been on the processes and agents of deposition and the climatic variations. No concrete evidences for Late Quaternary sea-level changes have been recorded from the Mainland Gujarat. Studies from the off-shore region of the west coast are however better documented which provide evidence in support of the Late Quaternary sea-level changes[5–8], and similar evidences are required from the mainland to address this problem.

Our studies on geomorphic, stratigraphic and micropalaeontologic aspects of the lower Mahi valley (Figure 1) provide records of high sea-levels during Middle Pleistocene (~ 240 Ka BP) and Holocene (~ 4,000 years BP).

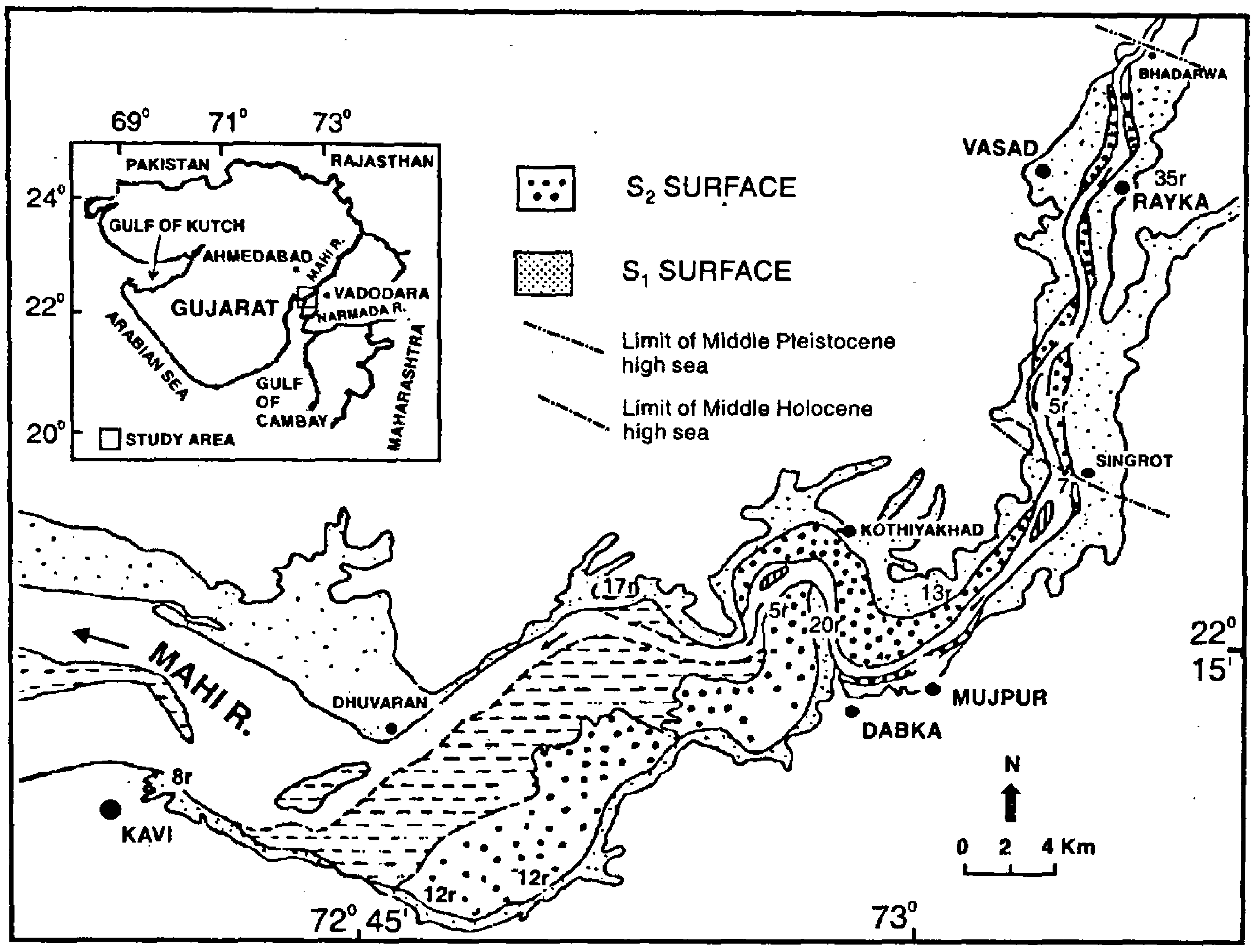

Figure 1. Geomorphic map of the Lower Mahi Valley[10] showing limits of the Middle Pleistocene and Middle Holocene high sea levels (Inset: location map).

Two marine formations from the lower Mahi valley namely the Mahi and the Kothiyakhad formations have been recently reported[3–4]. These two formations occurring at different stratigraphic levels are characterized by abundance of foraminiferids. This communication attempts to record the foraminiferids from the above two formations, and provides database on the two major transgressive phases in the lower Mahi basin during Middle Pleistocene and Holocene, which may be useful to compare the off-shore record of the west coast of India.

The lower Mahi basin, a major part of which encompasses the alluvial plain and the estuarine zone (Figure 1), is dominated by sediments of marine, fluvial and aeolian origin. It falls within the southern part of the Cambay basin. Numerous signatures of the Cambay basin tectonics are engraved on the Quaternary sediments. Reactivation of the various Tertiary faults helped in opening up several sub-basins that formed the sites for the accumulation of Quaternary sediments. The E–W Mahi estuary marks the Mahisagar fault which demarcates the Cambay–Tarapur block to the north and the Broach–Jambusar block to the south. The fault has displaced the trappean basement by more than 1300 m[9]. The subsurface East Cambay Basin Margin Fault (ECBMF) crosses the river near Singrot[1]. A distinct change in the meandering pattern is observed as the river enters the Cambay basin. Several step faults, parallel to the ECBMF, have influenced the meander pattern of the river and controlled the sedimentation pattern in Mahi basin[1,10].

The Mahi channel has incised the Quaternary sediment successions in the form of vertical cliffs as high as 40 m in the alluvial plain. Two distinct surfaces, an older surface (S_1) and a younger surface (S_2), have been identified (Figure 1). The S_1 surface is paired, highly dissected, comprising; clays, gravels, sands, and silts of diverse origins ranging in age from Middle to Late Pleistocene (~ 240 Ka to 10,000 years BP). The downcutting of this sedimentary succession and the extensive ravine erosion, giving rise to a deep incised valley is attributed to an Early Holocene tectonic uplift[10]. Four distinct formations (Rayka, Shihora, Singrot and Kothiyakhad) have been identified within the exposed Quaternary sediments along these two surfaces in the Mahi river basin[2] (Figure 2). The oldest exposed marine clays, termed as basal clay[1], have now been assigned status of a separate formation namely the Mahi Formation[3].

The younger surface (S_2) is represented by a low flat-topped surface that typically corresponds to the morphology of a terrace. It occurs as a series of unpaired elevated surfaces along the river channel that terminates abruptly against the older surface (Figure 1). These valley fill terraces are noticed on the convex banks of the present day meanders of the Mahi river and were deposited as the Middle Holocene high sea transgressed onto the incised fluvial valley[10]. The height of the terraces

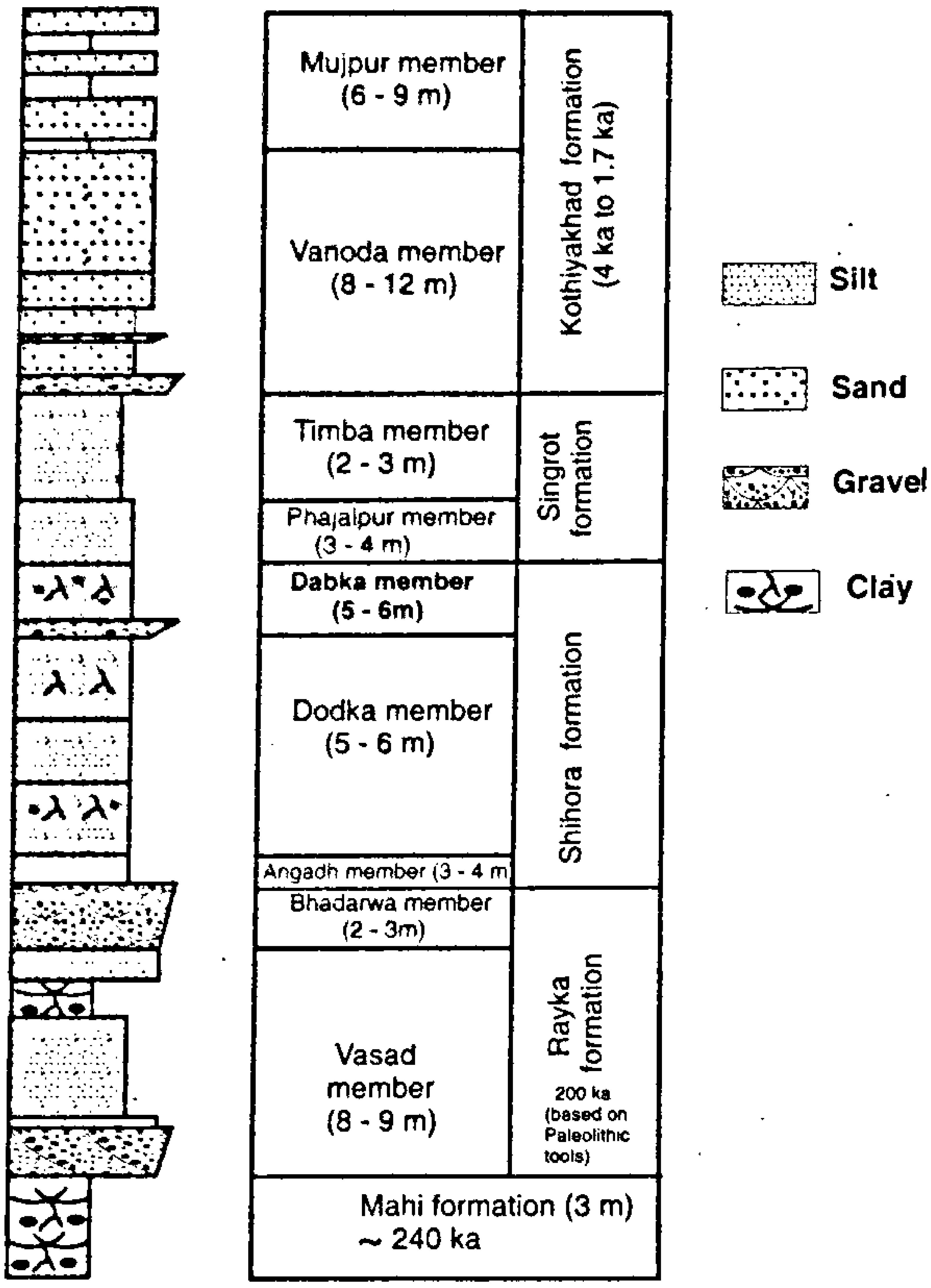

Figure 2. Composite lithostratigraphy of the Mahi basin[2]. Dates of the Kothiyakhad Formation are after Kusumgar *et al.*[23]

varies from 3 to 6 m from the river level. Such surfaces are met all along the lower Mahi right up to the mouth of the river. The incised cliffs, ranging in height from 3 to 6 m, show the sediment nature of Kothiyakhad Formation that builds these terraces (Figure 3).

Microfaunal studies were carried out on the clays of the Mahi and Kothiyakhad formations exposed at Rayka and Kothiyakhad (Figure 1). These two formations have been presumed to be of marine origin on the basis of their field characters[1,10]. The successions exposed at Rayka and Kothiyakhad constitute the best sections in the entire Mahi valley.

The Mahi Formation is made up of a highly pedogenized bluish mottled clay and forms the base of the exposed Quaternary succession (Figure 2). At Rayka, it is made up of greenish-brown clays that ranges in thickness from 0.5 to 3 m and occurs at an altitude of 20 m above mean sea level. The base of these clays is not exposed and continues to a depth of 25 m below the msl at Rayka[11]. The formation is highly fractured and has preserved various field evidences that point to pedogenesis. The entire formation has yielded a fairly good assemblage of benthic foraminiferids comprising (Figure 3) *Pararotalia* sp., *Brizalina* spp., *Nonion* spp., *Cibicides* spp., *Florilus* spp., *Ammonia* spp., and three species of planktonic foraminiferids, viz. *Turborotalia* sp., *Globigerina bulloides* (Parker, Jones and Brady) and *Globigerinoides ruber* (d'Orbigny).

The Kothiyakhad Formation is best exposed at Kothiyakhad and Mujpur. These are located on the north and south banks of Mahi estuary. The bases of both the sections terminate abruptly in the river water which makes them unapproachable during high-tide periods. The exposed section is dominantly made up of silty-sands and intercalated mud layers. The entire thickness of the Kothiyakhad Formation has been grouped into two lithofacies – tidal estuarine muds and medium-to-coarse fluvial sands and silts (Figure 4). The tidal estuarine facies comprise cross-stratified to rippled sand with abundant mud laminae, mud flasers and layers of estuarine mud. The fine-to-medium fluvial sands are well sorted and exhibit parallel horizontal bedding and wave ripples, indicating a subdued tidal influence compared to the underlying tidal estuarine sands and muds. The muddy units have yielded good populations of foraminiferids compared to various silty-sand units and cross-bedded sandy units, which are either barren or have yielded fresh-water ostracods and pelecypod shells. A total of 25 genera of foraminiferids were identified (Figure 4) from the mud units[4]. The benthic foraminiferids are represented by the species of *Brizalina, Bulimina, Bolivina, Biloculina, Lagena, Triloculina, Pseudobulimina, Hopkinsina, Sagrina, Ammonia, Cibicides, Discorbis, Discorbinella, Florilus, Hastegerina, Melonis, Nonion, Nonionella, Pyrgo, Pararotalia, Parafissurina, Pyrgoella* and *Rosalina* along with few other rotaliids. Few planktonic foraminiferids, which include *Globigerinoides sacculifer* (Brady), *Globigerina bulloides* (Parker, Jones and Brady), *Globigerinoides ruber* (d'Orbigny) have been recorded.

The studies along the coasts of Mainland and Saurashtra envisage high sea-levels ranging from 2 to 25 m during the Late Quaternary[12–16]. The two transgressions recorded are during Middle Pleistocene (~ 240 Ka and ~ 130 Ka) and Middle Holocene (6,000 to 4,000, years BP). The Pleistocene high sea-level rose to + 2 to + 6 m (130 Ka BP) (ref. 12), + 25 m (~ 240 Ka BP) (ref. 13), + 25 m (~ 240 Ka BP) (ref. 15), + 7 m (~ 130 Ka BP) (ref. 14), whereas the Middle Holocene sea level has been reported to range from + 6 to + 8 m (6,000 years BP to 4,000 years BP) (refs 13, 15) and 2–6 m (6,000 years BP) (ref. 12). Juyal *et al.*[16] have however invoked that the Holocene transgression rarely exceeded 3 m in Saurashtra.

The recognition of Mahi Formation as marine from the Mahi valley has a great bearing on the Middle Pleistocene high sea along the west coast of India[4]. The formation occurs 20 m above the present day sea level and extends up to Bhadarwa, which is about 45 km

AGE	Mahi formation (3 m)	SAMPLE POSITION	Turborotalia sp.	Ammonia sp.	Brizalina sp.	Cibicides sp.	Pararotalia sp.	Nonion sp.	Florilus sp.	Globigerina bulloides	Globogerinoides ruber
~240 ka		RP-5	P	P	P	P	P	P	P	P	P
		RP-4	P	P	P	P	P	P	P	P	P
		RP-3	P	P	P			P	P		P
		RP-2	P	P	P	P		P	P	P	
		RP-1	P	P	P			P	P		

Figure 3. Distribution chart of foraminiferids in the Mahi Formation (P = Present).

AGE (Yr.B.P.)	LITHOLOGY	SAMPLE POSITION	Ammonia sp.	Biloculina sp.	Bolivina sp.	Brizalina sp..	Bulimina sp.	Cibicides sp.	Discorbis sp.	Discorbinella sp.	Florilus sp.	G. bulloides.	G. sacculifer	G. ruber	Hastegerina sp.	Hopkinsina sp.	Lagena sp.	Melonis sp.	Nonion sp.	Nonionella sp.	Parafissurina sp.	Pararotalia sp.	Pseudobulimina sp.	Pyrgo sp.	Pyrgoella sp.	Rosalina sp.	Rotaliids	Sagrina sp.	Triloculina sp.
	0 m	MP-28							P																				
		MP-27									P				P					P									P
1760 ± 80		MP-26			P	P			P	P								P	P							P	P		
		MP-25							P									P								P			
		MP-24	P						P		P							P	P								P		
		MP-23																											
		MP-22																											
		MP-21																											
		MP-20																											
		MP-19				P													P	P									
		MP-18	P		P						P				P				P			P							
2850 ± 90		MP-17	P	P				P	P		P	P	P	P	P	P	P	P	P	P	P	P			P				
		MP-16																											
	silty-sand	MP-15																											
		MP-14	P			P	P	P	P					P															
		MP-13																											
		MP-12	P	P		P		P	P	P	P	P				P					P		P						
3320 ± 90		MP-11	P		P	P		P	P	P	P		P	P		P	P	P		P	P	P			P				
		MP-10																											
		MP-9																											
	Cross bedded sand	MP-8																										P	
		MP-7	P		P	P	P		P	P				P			P										P	P	P
		MP-6												P													P		
		MP-5																											
	Sand	MP-4																											
		MP-3																											
3660 ± 90	Mud	MP-2	P	P	P	P	P				P										P	P	P	P		P			P
	6 m	MP-1																											

Figure 4. Litholog of the Kothiyakhad Formation with distribution of foraminiferids (P = Present). Age data is after Kusumgar *et al.*[23]

north of the present day shore line of the Gulf of Cambay. Based on archaeologic data, the overlying gravels of Rayka Formation have been assigned an age of ~ 200 Ka (refs 1, 17). The underlying Mahi Formation can thus safely be dated to ~ 240 Ka (refs 1, 17), suggesting that the Middle Pleistocene sea in this part was high, which correlates well with the warm event in the Indian Ocean during this period[18]. According to Merh[13], these 'blue-green clays' represent the + 25 m Middle Pleistocene strandline of Saurashtra in the alluvial plains of central Gujarat. However, this contention is not supported by geomorphic or marine microfaunal evidences. It has now been established that the Lower Mahi river basin, which forms the southern part of the active Cambay basin, has witnessed phases of uplifts around 9 and 2 Ka BP (ref. 10). The Middle Pleistocene high sea-level is thus difficult to visualize until the exact magnitude and rates of uplifts are determined. However, the data on the sea-level and neotectonism of the area suggests that the Middle Pleistocene (~ 240 Ka) high sea was perhaps 7–8 m only above the present level of sea. CLIMAP members[19] suggested a rise of about 7 m during 130 Ka and the sea level seems to have risen to 7–8 m during similar palaeowarmths. Similarly along the Saurashtra coast, a tectonically-active area, the Middle Pleistocene sea level has been recognized as high as + 7 m (ref. 14) after making correction for tectonic uplift. Higher levels of sea envisaged by other workers[13,15] did not take into account the Late Quaternary tectonic activity in Saurashtra and adjoining areas. The global sea-level curves show that the level of sea fluctuated considerably during Upper Pleistocene[20,21].

Rise in sea-level was rapid during early Holocene and reached its present level (or slightly higher than the present) around 6 Ka (ref. 22). The unpaired younger terraces of the Lower Mahi valley are reported to be a product of Middle Holocene high level sea (refs 4, 10, 23). The ^{14}C dates reported by Kusumgar *et al.*[23] of bottom and top mud layers of Kothiyakhad section indicate that deposition of the terrace continued up to the last 2,000 years BP. The sediment record does not indicate any regression of the Holocene sea, however, periods of subdued marine influence during the course of deposition are readily identifiable[10]. Evidences for the Late Holocene regression envisaged by Merh[13,24] on the Gujarat coast have not been found. Alternatively, the occurrence of raised mudflats and sandy beaches on Mainland Gujarat coast could be attributed to the Late Holocene–Recent uplift of the area[10]. As the sea level is presumed to have remained at the same level[22,25,26], the asymmetrical lower terraces all along the Mahi valley attained the present elevations mainly because of the tectonic uplift of the area and this continues even today[10]. Since the Holocene transgression is overlapped by tectonic uplift, it is not possible to ascertain the net magnitude of sea-level rise during the Holocene. Similar conditions are encountered on the Saurashtra coast where the Holocene sea rise is masked by tectonic emergence of land[14,16].

The Mahi basin has evolved as a result of several phases of tectonic uplifts and sea level changes as discussed above. Remarkably, similar observations regarding the sea level changes and neotectonic activity on the west coast have been made by Rao *et al.*[7]. The results obtained so far are more correlatable to the offshore sea level record rather than the variously interpreted continental record of Gujarat. A critical evaluation of the Late Quaternary neotectonic activity in the region is needed before a dependable curve for sea level changes are put forth as illustrated by Pant and Juyal[14].

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ACKNOWLEDGEMENTS. The authors thank Dr Pratap Singh of ONGC Ltd., Baroda for his help in the identification of foraminiferids. We thank the two anonymous reviewers for critical comments. Financial assistance provided by CSIR through a Senior Research Fellowship to RR and by DST through Grant No., ESS/CA/A1-21/94, to DMM and LSC is gratefully acknowledged.

Received 22 September 1997; revised accepted 19 March 1998