Holocene valley-fill terraces in the Lower Mahi valley, Gujarat

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The geomorphic features of the Mahi valley indicate a complex interplay of tectonism and base level changes in its evolution. Two distinctive surfaces, an older (S1) and a younger surface (S2) have been identified. The pre-Holocene surface (S1) is paired, highly eroded and extensively dissected surface, comprising sand, silt and gravel mainly of fluvial and aeolian origin. The younger Holocene surface (S2) occurs as unpaired elevated terraces, comprising two lithofacies – tidal estuarine mud and sand and fine to medium sand of mixed environment. Two phases of tectonic uplift and fluctuating sea-levels have helped in shaping the landscape of lower Mahi valley.

THE Mahi river is one of the major rivers of Gujarat plain. It originates near Sardarpur in Madhya Pradesh and after crossing the Aravallis and a vast stretch of Gujarat alluvial plains, meets the Gulf of Cambay. The Gujarat alluvial plains comprise Quaternary sediments which are well exposed in the incised cliff sections along the various river valleys[1,2]. Studies carried out on these sediments in the semi-arid basins of Gujarat, viz. the Sabarmati, the Mahi and the Narmada have revealed an identical depositional and climatic history from Middle Pleistocene to Terminal Pleistocene[1–3]. However, the geologic evolution of the Gujarat plains during the Holocene has remained uninvestigated. The Lower Mahi valley, the study area of the present investigations (Figure 1) has preserved numerous interesting geomorphic features that provide evidences of the evolution of this part of Mahi during Holocene, through a complex interplay of tectonism, climate and base level changes. The sediments that make up the various landforms are deposited by marine, fluvio-marine, fluvial and aeolian processes[4,5]. A detailed field mapping, visual interpretation of the satellite images (IRS, FCC images on 1:50,000 scale) and Survey of India topographical maps helped in delineating the various landforms and associated features (Figure 1). Considering the landform association, lithology and climatic conditions that prevailed during the deposition of these sediments, an attempt has been made to decipher the morphostratigraphy of the lower Mahi basin (Table 1).

The pre-Holocene morphology of the lower Mahi is rather difficult to visualize because the Holocene eustatic sea level changes have considerably modified the Lower Mahi Valley. The general topography of the area is that of a flat alluvial plain broken only by frequent development of ravines. The most conspicuous geomorphic features include a long line of imposing river cliffs, ravines, unpaired valley-fill terraces, present day point bars, and mudflats within the channel. All these geomorphic features form two distinctive surfaces; an older surface (S1) and a younger surface (S2) (Figure 2).

The older surface (S1) rising up to 40 m from the river level, is paired, highly eroded and extensively dissected surface. The surface is characterized by deeply-cut ravines (10–15 m) suggestive of a badland topography. The sediments that make this surface date back to Middle Pleistocene[1–4] and are well exposed in vertical cliffs ranging in height from 8 to 35 m in the study area. These sediments comprise semi-consolidated cross-stratified gravels, sands and silts, and multiple palaeosol horizons[2,6]. A very prominent horizon of this older sequence is a reddish buried soil in the upper part of the sequence, which has been used for inter-basinal as well

Table 1. Morphostratigraphy of the Lower Mahi valley

Morphological unit	Lithology	Event	Tectonic/Sea level	Age
Younger surface (S2)	Tidal-estuarine mud and sand showing mud flasers and herringbone structure with horizontally bedded silty sand and mud at the top.	Erosion of younger sequence giving rise to the formation of a terrace, low incised cliffs and present day meanders.	Tectonic uplift of the area	Late Holocene to Recent
		Deposition of tidal estuarine sediments.	Middle Holocene High sea	Middle – Late Holocene
Older surface (S1)	Fluvial and aeolian sand and silt with cross-stratified gravels and multiple layers of palaeosols.	Erosion of the older sequence giving rise to ravines and incised cliffs.	Tectonic uplift of the area, rising sea level	Early Holocene
		Deposition of fluvial sand and silt (punctuated by episodes of pedogenesis) ending with the accumulation of aeolian silt and sand.		Middle Pleistocene to terminal Plestocene

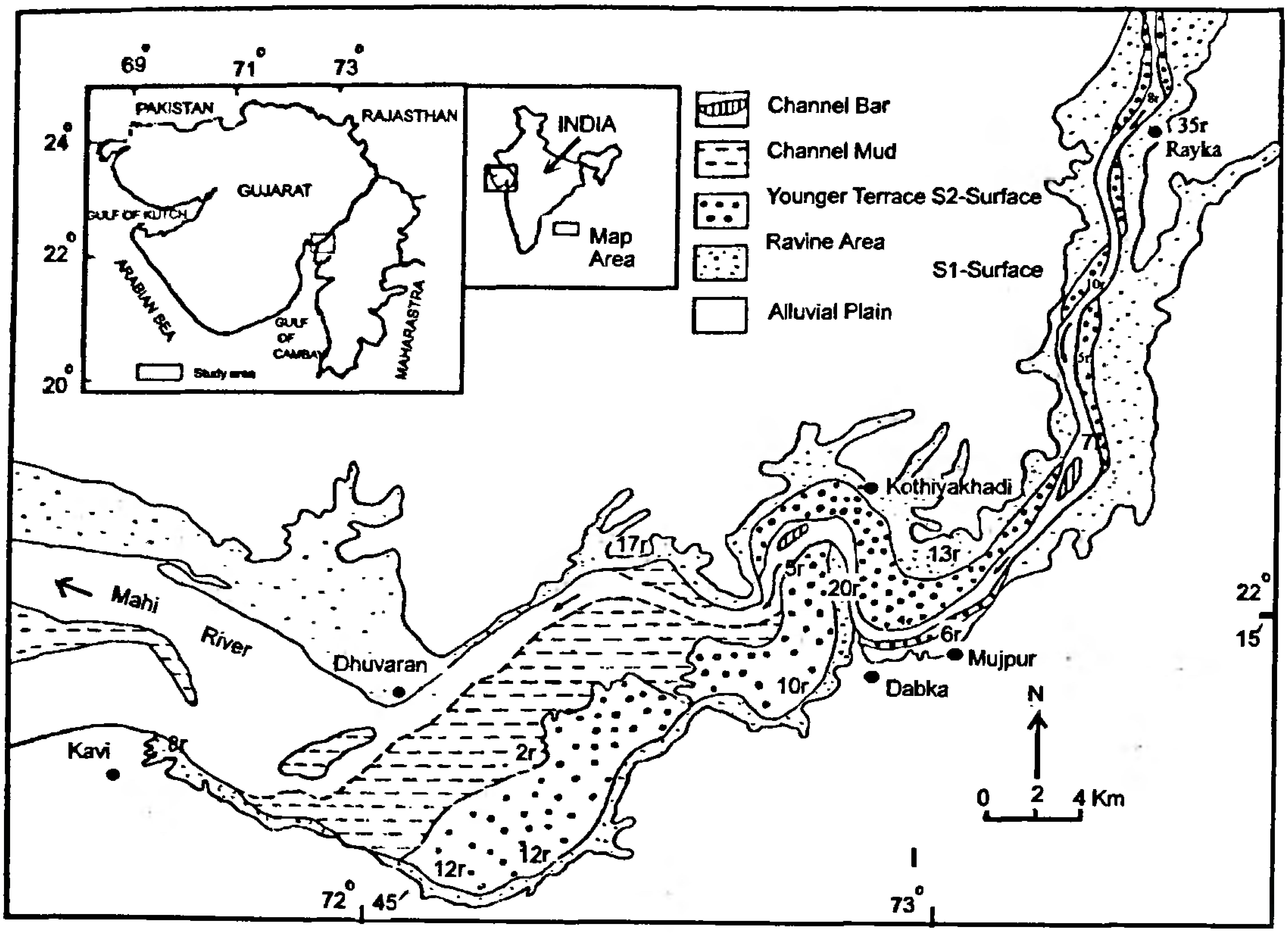

Figure 1. Geomorphic map of the Lower Mahi valley. Inset: Location map.

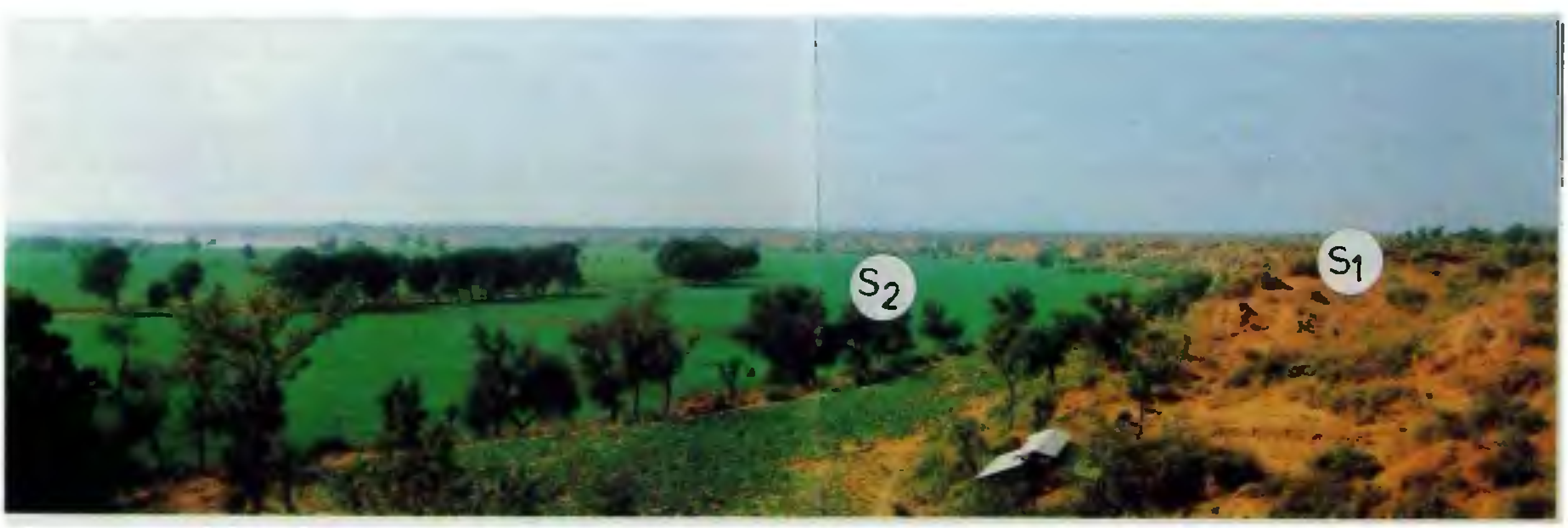

Figure 2. Field photograph showing the two surfaces (S1 and S2) at Kothiakhadi.

as intra-basinal correlations[1,2,4]. Radiocarbon dates of pedogenic calcretes from this horizon indicate an age of 22600 yr BP (ref. 7). This is overlain by aeolian sediments of last glacial age[2,4]. Roles of climate and tectonism in the deposition of these sediments have been previously highlighted[6,8].

The younger surface (S2) is represented by a low flat topped surface that typically corresponds to the morphology of a terrace (Figures 1, 2). It occurs as a series of unpaired elevated surfaces along the river channel that terminate abruptly against the older surface. These terraces are preserved on convex banks of the present-day meanders of the Mahi river indicating their deposition as channel bars. The height of the terrace varies from 3 to 6 m from the river level. The surface shows no sign of ravine erosion and is used for agriculture. These surfaces are encountered all along the lower Mahi right up to the mouth of the river (Figure 1). The low incised cliffs ranging in height from 3 to 6 m show the sediment nature that makes these terraces. At Kothiyakhadi, a 3.6-m thick section (Figure 3 *a*) shows a 0.3 m thick horizontally laminated very fine silty-sand at the base, overlain by 0.5 m thick mud horizon. The contact between the two is erosive and is marked by mud flasers (Figure 4). Overlying is a 0.95 m thick horizontally laminated silty-sand horizon that shows well-developed herringbone structures (Figure 4) with an average mean current direction 320° NW and 135° SE. This is overlain by 0.85 m-thick mud and in turn by 0.7 m thick laminated silty-sand. The top of the succession is capped by 0.7 m thick mud. The section at Mujpur is exposed as a 6 m high cliff (Figure 3 *b*). The exposed sediment succession shows intercalations of silty-sand and mud and is quite comparable to the one exposed at Kothiyakhadi. However, the obvious dominance of mud-bearing horizons in the Kothiyakhadi sequence as compared to the Mujpur succession (Figure 3 *a*, *b*) could be attributed to the proximity to the estuary mouth.

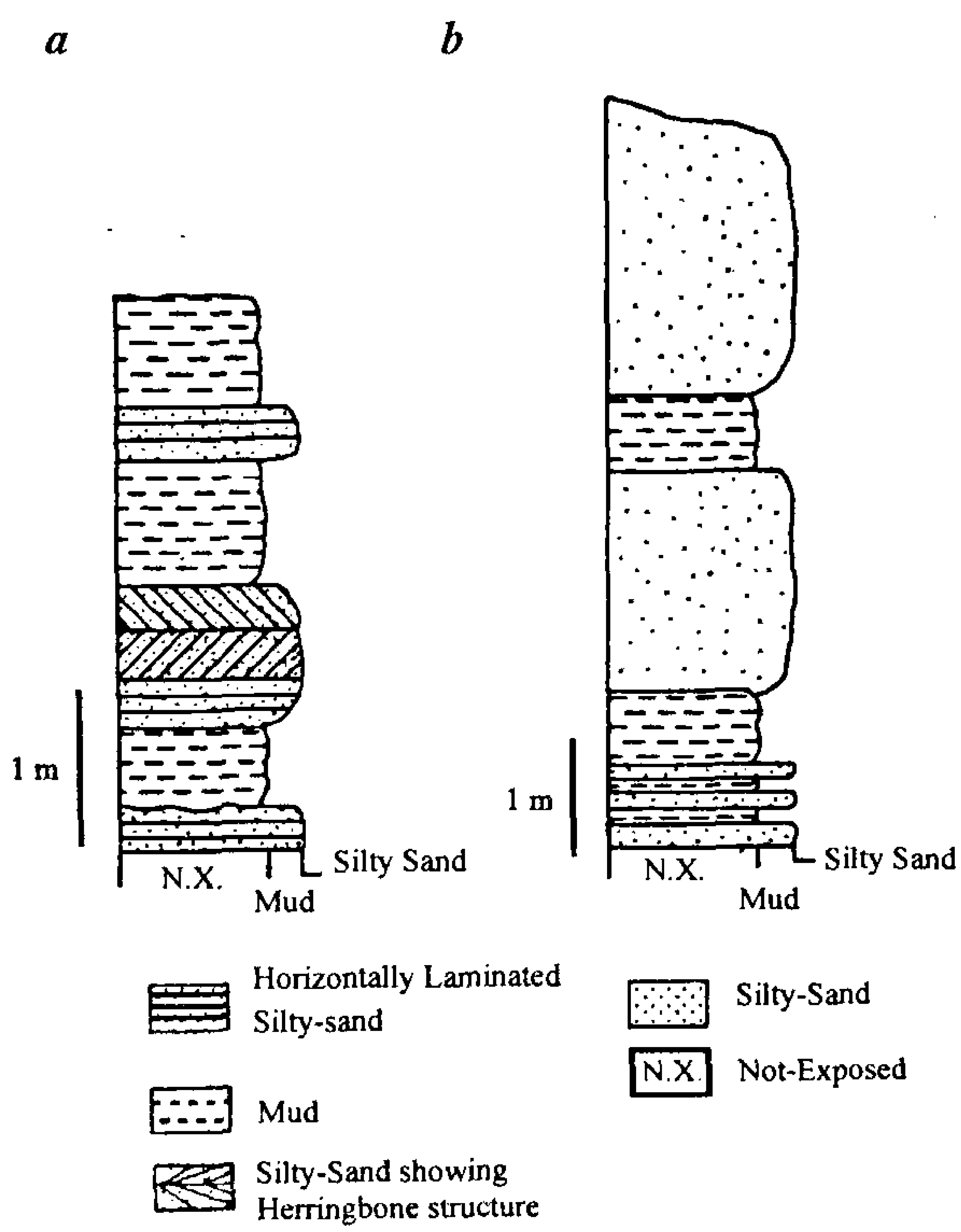

Figure 3 ***a***. Litholog of the Kothiakhadi terrace section (Surface S2); ***b***, Litholog of the S2 surface at Mujpur.

The entire thickness of the valley fill complex can be grouped in two lithofacies, tidal estuarine muds and medium to coarse sand, and fine to medium fluvial sands. The tidal estuarine facies comprise cross-stratified to rippled sand with abundant mud laminae, mud flasers and layers of estuarine mud. The present-day estuary shows a similar sedimentary facies and this facies can thus safely be interpreted as having been deposited in a tidal estuarine environment. The fine to medium fluvial sands are well sorted and exhibit parallel horizontal bedding and wave ripples, indicating a subdued tidal influence as compared to the underlying tidal estuarine sands and muds.

The younger surface (S2) has an important bearing on the evolutionary history of the lower Mahi during the Holocene. The fact that these deposits occupy the incised valley consisting of Pleistocene deposits suggests that these terraces have been deposited during the Middle Holocene high sea level. The ravine erosion and the river incision therefore pre-date the deposition of these terraces and could be safely regarded as of early Holocene age. The rise of sea level during the Middle Holocene led to the choking of the river channel resulting in the initiation of a new cycle of sedimentation within the active channel. The sediments were deposited as bars attached to the channel. The deposition never extended beyond the channel as the channel itself was confined by the steep incised cliffs.

The alluvial cliffs extend right up to the coast indicating that the extension of the fluvial deposits is well beyond the present-day coastline. The ravine erosion has affected even the youngest horizons of the older sequences, suggesting that the ravine erosion post-dates aeolian sedimentation. The ravine erosion was accompanied by fluvial incision within the main channel. The heights of the cliffs of the older sequences are directly proportional to the incision that occurred during the early Holocene. This incision is of the order of at least 35 m corresponding to the average height of the cliffs. The incisions seem to have taken place in a relatively short period of time and are not related to the fall in sea level. During this period, on the west coast, the sea rose very rapidly from 14,500 yr BP to 7,000 yr BP intervened by a still stand from 12,500 to 10,000 yr BP (ref. 9). This suggests that lower Mahi experienced tectonic uplift during early Holocene. The uplift of the area[10,11] during early Holocene resulted in the formation of extensive ravines and steep cliffs along the river valley. The uplift took place along the pre-existing Cambay basin faults.

The phase of ravine erosion and river incision ceased as the sea level reached the post-glacial maximum during the Middle Holocene[12,13], leading to the formation of a depositional wedge which extended upstream. The rise of sea level led to aggradation within the channel with deposits ranging from non-marine (fluvial), through es-

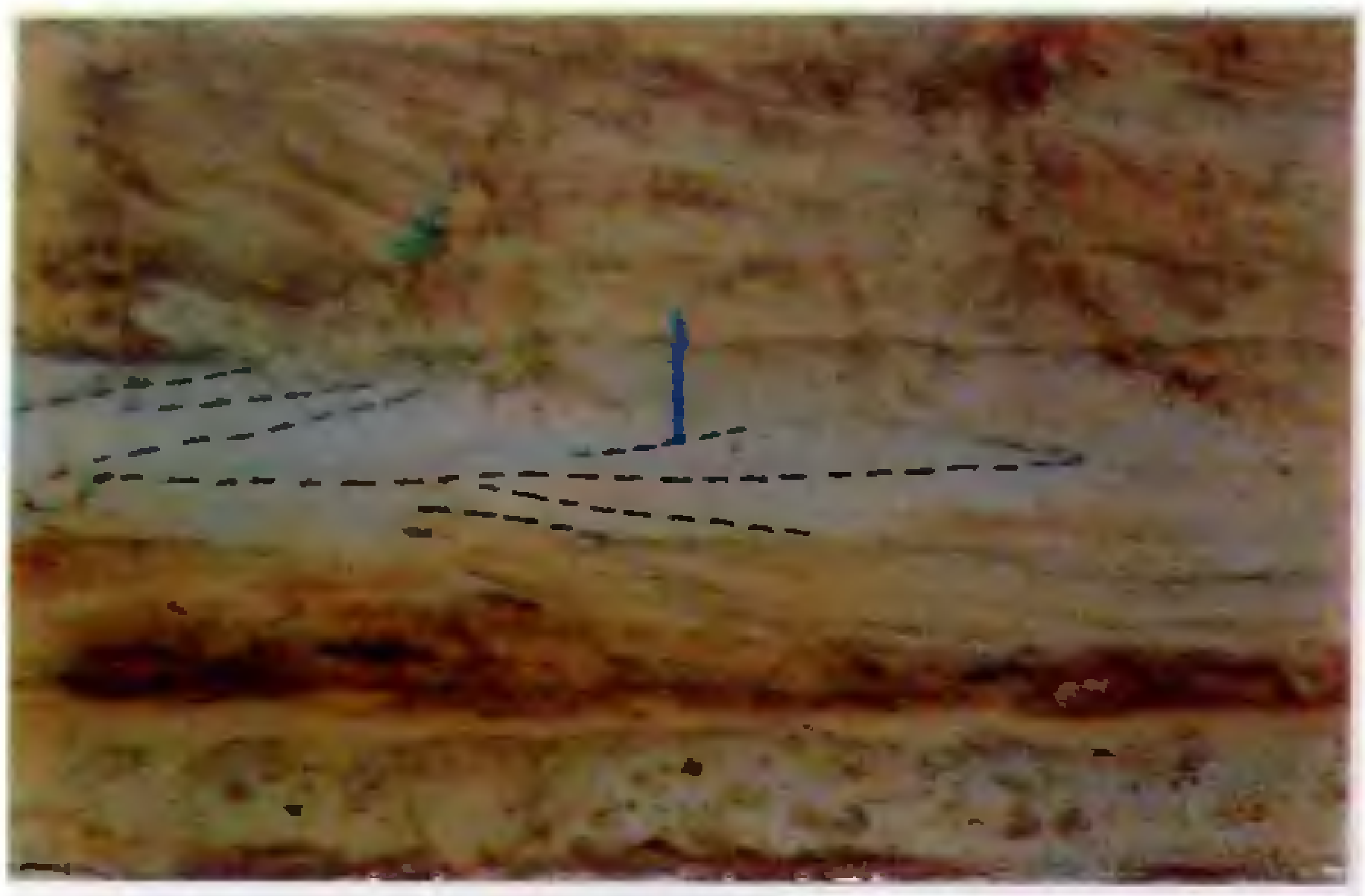

Figure 4. Field photograph showing the herringbone structures and mud flasers in the Kothiakhadi section. (Length of the pen in the picture is 16 cm).

tuarine (tidal) to open marine. The sediment fill of the incised Mahi river therefore seems to be quite complex. The rise of base level combined with landward migrating tide-limit and its associated grain size barrier effect[14], impedes transport of fluvial material downstream from the landward migrating bayline[15]. This resulted in the accumulation of transgressive tidal-estuarine sand and mud deposits onlapping the fluvial channel. However, the depositional wedge mentioned above extended well beyond the bayline as evidenced by the fluvial terraces in the upstream parts as well. This means that the rise in sea level led to the deposition of tidal sediments within the bayline and beyond it fluvial sedimentation was initiated. It should be mentioned here that the transgression was within the river channel only and even the highest tides could not reach the top of the ravinal surface. This is indicated by the younger surface made up of tidal-estuarine deposits that are incised and abut against the older sequence (Figure 2). Consequently the sediments supplied to the valley from the upstream during the Holocene were deposited as aggrading transgressive-tidal facies that overlapped the lowstand channel as the valley was transformed from a fluvial incised valley into an estuary. The younger terrace shows a maximum incision of 6 m. Since the sea level is presumed to have remained at the same level with minor fluctuations[16,17], the incision of the lower terrace can be attributed to another phase of tectonic uplift that perhaps continues even today.

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