# The Quaternary sediments in Gujarat

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**The Quaternary sediments in Gujarat represent three depositional environments—marine, fluvial and aeolian. The interplay of palaeoclimatic and glacio-eustasy factors controlled the shaping of the landscape of Gujarat during the Quaternary period. The landforms are broadly divisible into three geomorphic units. The Rann of Kachchh represents filled-up Holocene gulfs, the sediments having accumulated in estuarine-cum-delta environments affected by sea-level fluctuations. The Gujarat coastline is characterized by variation in trend, shoreline features, offshore conditions and sediment nature, pointing to various controlling factors like tectonic framework, eustatic sea-level changes, and climate-related aeolian, fluvial and marine processes.**

**The alluvial plains of Central and North Gujarat are made up of thick Quaternary continental deposits of fluvio-marine, fluvial and aeolian origin. Showing record of sea-level fluctuations and climatic variation, these deposits occupy the structural depressions related to continental margin rifting and graben formation (Narmada and Cambay). The Lower Pleistocene, still a 'grey area' for age data are not available.**

## Introduction

THE Quaternary sediments in Gujarat represent three depositional environments—marine, aeolian and fluvial. A major part of the landscape evolved during the Quaternary period. The sediments of the subcontinent show records of climatic changes. The glacial stages are marked by cold and arid phases while the interglacial epochs by humid and warm climate. There were sea-level changes in the coastal areas. Thus interplay of the palaeoclimate and glacio-eustasy factors significantly controlled the geomorphic evolution of Western India during the Quaternary period. Major lineament trends and the overall fracture pattern influenced the behaviour of coastline and drainage pattern. Neotectonism does not appear to have played any major role, although tectonism related to the Himalayan uplift did influence the course of events in the morphotectonic evolution of the landscape.

The information on the early Pleistocene is very fragmentary. However marine and non-marine sequences beginning with the Middle Pleistocene have been better investigated. The marine Quaternary sediments are restricted to the coastal areas, fluvial and aeolian sediments make up the plains of northern Gujarat.

On the basis of landscape characteristics, sediment types and geological history, the Quaternary areas of Gujarat, are divisible into three geomorphic units (Figure 1): 1. The Rann of Kachchh, 2. Coastlines of Kachchh, Saurashtra and mainland Gujarat, 3. Alluvial plains of Central and North Gujarat.

## Rann of Kachchh

The vast saline wastelands of the Great and the Little Rann of Kachchh, barely a few inches above the sea level recurrently experience monsoon inundation under knee-deep to waist-deep waters. The Rann is made of tectonic basins bounded by faults[1-3], representing filled up Holocene gulfs. The sediments are accumulated in an estuarine delta environment. These are then evidence of sea level fluctuations, the post-glacial Holocene transgression reaching the highest mark about 6000 yr BP when the whole of the Great and the Little Rann was invaded by sea and connected with the gulfs of Kachchh and Cambay.

The combination of late Quaternary glacio-eustatic sea level fluctuations and periodic movements along fault planes is responsible for the evolution of the Rann. The Great Rann has been tectonically unstable even during historical times. The satellite imagery and air-photos reveal that the existing relict channel of the Nara river formed the earlier course of a major river (Saraswati). The disappearance of Saraswati and westward shifting of the Indus River points to regional westward tilting of the entire NW Indian subcontinent in the late Quaternary times, and even in the historic periods. Tectonic movements took place as late as 1819 A.D. when a major earthquake finally destroyed the connection of the Kori Creek with the Indus River system[1].

The flooding of the western portion of the Great Rann is due to tidal ingress[4,5], while the eastern portion gets flooded by Luni River and other streams. The Little Rann represents the former extension of the Gulf of Kachchh during the post-glacial transgression. Even today it gets annually inundated by the tidal and river waters. During the marine incursion around 7000 yr BP (Middle Holocene) the sea transgressed and covered an earlier channel network[6-8]. Significantly, the palaeo-channels extending southwestward within the Rann formed extensions of the Banas, Saraswati and Rupen rivers in the early Holocene.

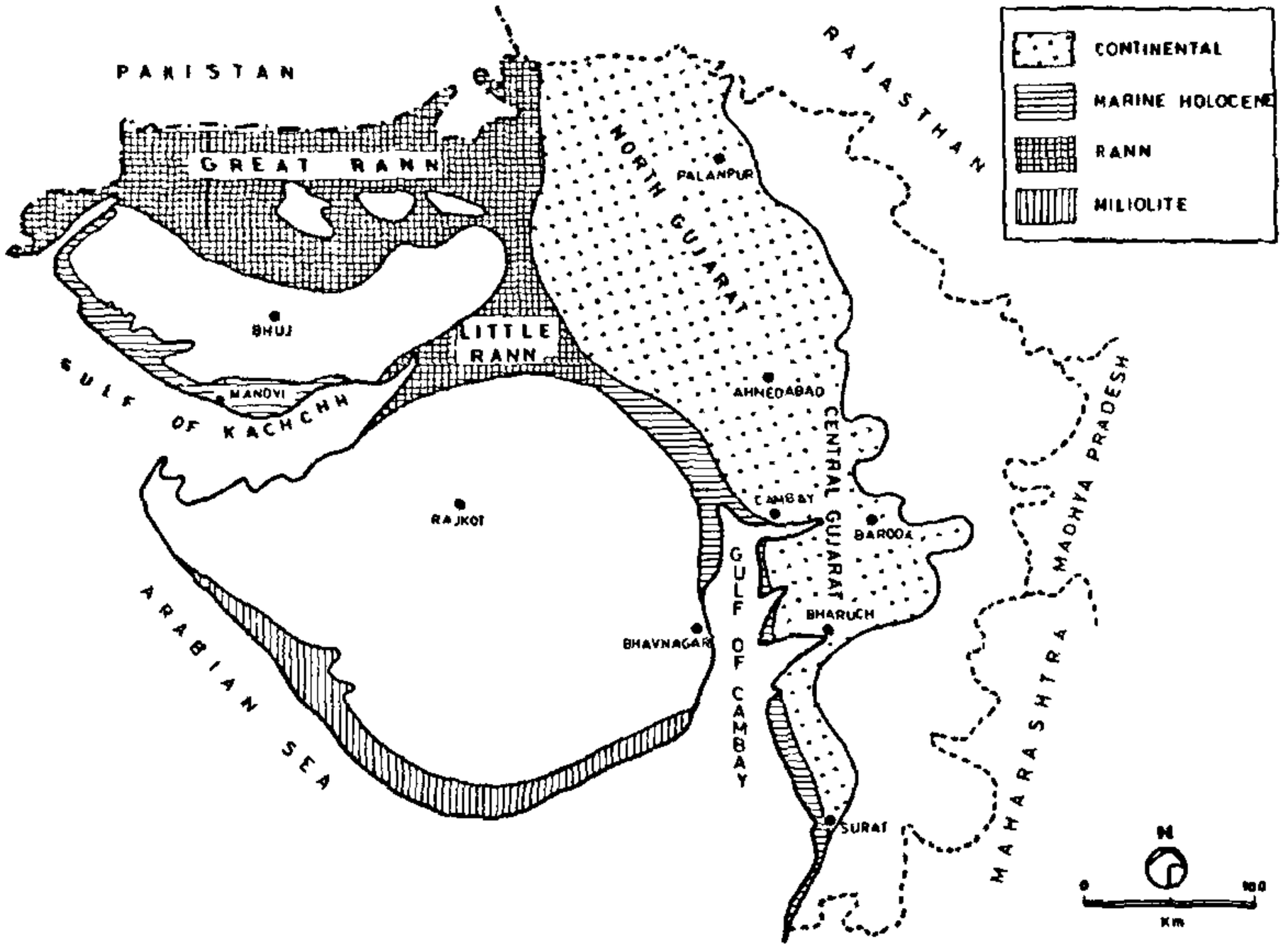


**Figure 1.** Sketch map of Gujarat showing distribution of the Quaternary deposits.

During Holocene the Little Rann was connected with the Gulf of Cambay, and the narrow strip of saline wasteland separating Saurashtra from the mainland formed the extension of the Rann. The remnants of this sea are represented by the lakes of the Nal area (Table 1)[9].

## Coastal marine sediments

Covering a length of about 1600 km, the coastline of Gujarat shows considerable variations in trend, shoreline features, offshore conditions and sediment nature, implying control of a variety of factors like tectonic framework, nature of pre-Quaternary rocks, eustatic sea-level changes and climate-related aeolian, fluvial and marine processes. The coastal Quaternary sediments represent marine, fluvio-marine and aeolian environments. The Kachchh coastline and the mainland Gujarat are dominated by tidal mud deposits and raised mud flats, whereas the Saurashtra coast has been the site of biogenic carbonate sand deposits (miliolite). Dating back to Middle Pleistocene the sediments are better represented in the Saurashtra coast (Table 2).

It may be pointed out that the lowermost part of the Quaternary is still little known and remains a 'grey area' for lack of age data. However, evidence points to the possibility of Lower Pleistocene being a period of relatively low sea level. There are a few indications of a very high sea level and related early Pleistocene marine rocks. All over the coastline continental conditions (fluvial/fluvio-marine) prevailed prior to the deposition of miliolites. The gravels and sands of Kankawati Series in Kachchh (doubtfully assigned a Pliocene-Lower Pleistocene age[10]) is equated with the fluvial gravels and sands that underlie the Miliolite Formation in the Heran valley, Saurashtra[11,12]. The absence of the Lower Pleistocene marine sediments is attributed to a low sea level at the onset of the Quaternary period. This fact calls for revision of Lower Pleistocene ages for the Miliolite rocks of Saurashtra[13,14] and the oolitic limestones and grapestone of North Gujarat[15,16].

The biogenic carbonates of the Miliolite Group of Saurashtra, referred to as Porbandar Formation[17] and Miliolite Formation[18] are assigned a *Pleistocene age*. Discrete outcrops occur inland at various altitudes. Some workers[11,19–24] described the miliolites as marine oolitic foraminiferal limestones, others consider them to be windblown coastal material occurring as aeolian dunes[10,25–30]. They are thought to have been deposited during successive high sea levels of Pleistocene[13,14]. High strandlines are attributed to uplifts subsequent to deposition[11,31,32].

The coastal miliolite are partly marine and partly aeolian, while the inland occurrences are all aeolian and do not indicate high strandline positions[29,30]. The

**Table 1.** Late Quaternary stratigraphy of the Rann of Kachchh[9]

| Age | Great Rann | | Little Rann | | Environment of Deposition |
|---|---|---|---|---|---|
| | Sediments | Thickness | Sediments | Thickness | |
| Late Holocene | Brown to dark brown silty clays with organic matter (LTZ and ZBZ) | 0 to 2 m | Brownish grey silt and clay | 0–0.5 m | *Fluvio-marine.* Deposition during progressive withdrawal of a high sea. |
| | | | 2,000 years B.P. | | |
| | Fluvial sands and silts (Bet zone and Banni plains) | 10 m | Fluvial sands and silts with intermixed clays and salt gypsum nodules | 1–2.5 m | *Fluvial.* (Indus-Luni and Banas-Saraswati delta systems) Deposition during low sea level. |
| | | | 3,000 to 4,000 years B.P. | | |
| Middle Holocene | Blue/green tidal clays | Not known | Green to blue clays with wood fragments and foraminifers | 1–9 m | *Marine.* Related to Flandrian high sea. |
| | | | 6,000 years B.P. | | |
| Early Holocene to Late Pleistocene | Sands and silts (details not known) | Not known | Coarse, gritty sands (brine bearing) with intercalated silt clay and lime-gypsum nodules | 45–50 m | *Fluvial.* Related to last glacial (W) regression. |
| | | | 10,000 to 18,000 years B. P. | | |

**Table 2.** Generalized Quaternary stratigraphy of Saurashtra

| Lithology | Thickness | Age |
|---|---|---|
| Soils, Alluvium, Beach sands, Tidal muds | – | Holocene |
| Beach rocks (Chaya formation) | 2 m | |
| Miliolite Group: Aeolianites | 12 m | Upper to Middle Pleistocene |
| Shell limestone (marine) | 5 m | |
| Gravels and sands | 8 m | Lower Pleistocene |
| Basalts, laterites, Tertiary sediments etc. | – | Pre-Quaternary |

coastal miliolites thus represent a typical beach-dune complex forming a series of dune ridges representing a retreating high strandline that had risen up to 25 m above the present level. The innermost ridge is 15 to 18 km inland. The underwater coastal dunes point to their formation during a regressive phase and were subsequently submerged by Holocene transgression.

Petrographically, the miliolite rock is a 'biopelsparite' consisting of sand-sized bioclasts cemented by a sparry calcite. There are subordinate oolites and pellets, and most of the so-called 'oolites' and pellets are peloids-abraded and micritized tests and shell fragments[14,33–35]. A substantial percentage consists of 'vadoids' and cortoids i.e. grains comprising nucleii of skeletal particles and peloids coated by envelops of alternating micrite and microspar concentric lamellae[30,36,37].

The clastics are made up of foraminiferal tests (Ammonia, Quinqueloculina, Elphidium, Amphistegina), broken molluscan shells, algal fragments, pieces of corals, ostracodes, echinoid spines and bryozoans[13,14].

The Miliolite Group appears to have evolved over a protracted period of time, ranging from 200 to 50 ky[38–40]. The Holocene rocks are encountered practically all along the coast. The marine sediments rose up 6 to 10 m around 6000 years BP.

In Kachchh the Holocene is poorly developed and is represented by raised mud flats and beaches[41]. However the Holocene deposits are quite conspicuous along the Saurashtra coast. The north coastal segment, facing the Gulf of Kachchh, is marked by prolific development of coral reefs. Along the west and south coast of Saurashtra, thick (2 m) semi-consolidated beach rocks resting over either Dwarka Formation or over miliolites occur a few meters above the high water line. These have been referred[20] to as Sub-Recent by most early workers[17,20,42] and described as 'raised beaches' 'consolidated shore sands', 'littoral concrete', 'oyster beds' and 'raised reefs' named Chaya Formation, they have been assigned a Late Pleistocene to Holocene age[18].

Along the Mainland Gujarat coast, the Holocene rocks comprise raised mudflats, raised sandy and shelly beaches occurring 8 to 10 m above the HWL[43]. Between Mahi and Narmada the alluvial coast is drowned and the raised mudflats rest over this alluvium. South of Gujarat between Dahanu and Bombay the Holocene comprising littoral shelly beach rocks rise 10 m above the sea level[44].

## Alluvial plains of Central and North Gujarat

Large areas of Central and North Gujarat are occupied by thick Quaternary continental deposits of fluvio-

marine, fluvial and aeolian origin. Showing record of sea-level fluctuations and climatic variations the deposits occupy structural depressions related to the Narmada and Cambay grabens[45]. South of Narmada, the alluvial deposits do not exceed 100 m, between Narmada and Sabarmati, the maximum thickness being 200 m, while in North Gujarat, it reaches 500 m.

A remarkable feature of these Quaternary plains from Narmada in the south to Luni in the north, is the occurrence of almost uninterrupted cover of aeolian silts and sands above the fluvial sequence. Assigned to the terminal Pleistocene to early Holocene times the dune sediments originated during the arid phase of the last glaciation.

The total exposed thickness of sediments in the three major rivers (Narmada, Mahi and Sabarmati) is about 35–40 m (Figure 2). The base of the sequence is marked by a horizon of marine bluish/mottled clays of Middle Pleistocene and equated with the coastal miliolite of Saurashtra[34]. Overlying the clays there is a 3 m thick conglomeratic gravel (Figure 2) containing Lower Paleolithic implements[21,46–48].

The exposed Quaternary sequences in the river valleys point to a composite stratigraphy[49] of three major depositional environments—marine, fluvial and aeolian. The silty sand horizon over which the red soil has developed is indicative of a late Pleistocene climatic fluctuation around 125 kyrs[49] and laid during the major arid phase of late Quaternary. The soils developed over the loessic material and the low hummocky dunes, indicate that the arid phases were followed by moist conditions. The sequences exposed in the different river sections are comparable and are indicative of the prevalence of identical climatic conditions all over Gujarat during the Quaternary.

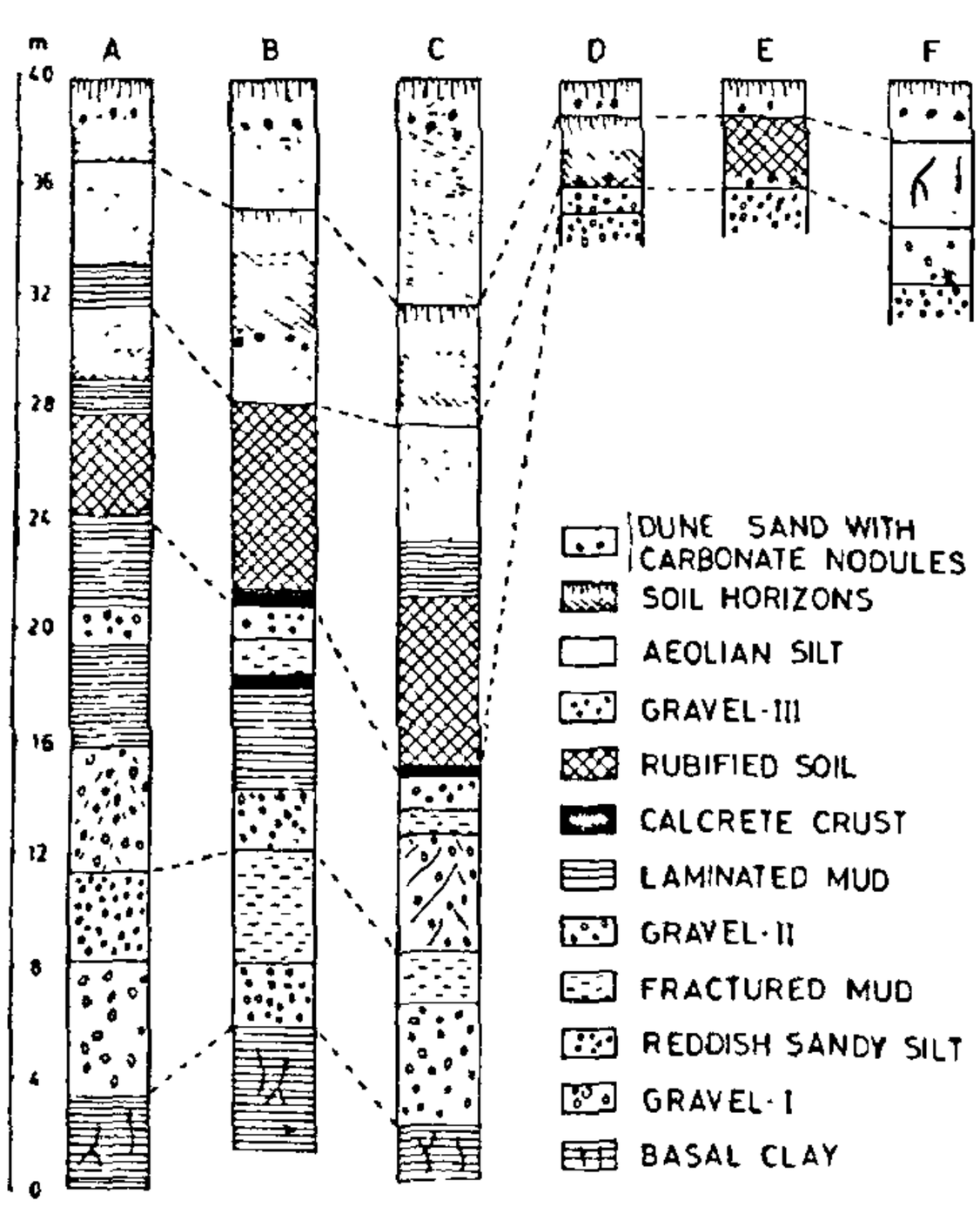


**Figure 2.** Composite Quaternary sediment profiles: (A) Narmada River Basin, (B) Mahi River Basin, (C) Sabarmati River Basin and distribution of measured Quaternary sediment profiles, (D) Near Radhanpur (Rupen River Basin), (E) At Deesa (Banas River Basin) and (F) At Sindari (Luni River Basin).


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# Slope-deviatory alignment, stream network and lineament orientation of the Sabarmati River system—Neotectonic activity in the Mid- to Late Quaternary

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**The Gujarat alluvial plain located in the semi-arid zone is bounded by the arid Thar region in the north and the coastal/estuarine zone fringing the Arabian Sea in the south. It has been built by the rivers originating in the Aravalli Hills in the northeast. The drainages, with an average length of about 300 km, generally follow the NE-SW regional slope. However, the Sabarmati River shows a flow deviating from the regional slope and follows a N-S to NNE-SSW trend in the alluvial area.**

**The slope-deviatory trend of the Sabarmati has been investigated with regard to Late Quaternary neotectonics, fluvial-aeolian interaction and sea-level change. Lineament analysis indicates an E-W to WNW-ESE trajectory of maximum principal stress, and that drainage is primarily controlled by geodynamic processes. This is obvious from the correspondence in stress trajectories obtained from the lineament and drainage orientations, respectively.**

**Sub-surface data indicate pre-Neogene faulting in the basin. It is inferred that these faults have been reactivated in the Mid- to Late Quaternary times. The slope-deviatory drainage of the Sabarmati River is, to a large extent, the result of fluvial adjustment to neotectonic reactivation in the region.**

## Introduction

THE state of Gujarat in western India consists of four physiographic micro-regions, namely the Rann, the Kachchh peninsula, the peninsular Gujarat, and the Gujarat alluvial plain. The alluvial plain has a network of drainages, emerging from the N-S to NW-SE trending Aravalli hills. Of these, the Sabarmati (Figure 1) and Mahi are the most important drainages. The Sabarmati River originating in the southern Aravalli follows, for 185 km, a nearly north-south trend up to Navapura (22° 40′ 54″ : 72° 30′ 12″). The contour map of