



XXII INQUA INDIA 2027

FIELD GUIDE

INPRE - 01

EXPLORING QUATERNARY GEOLOGY OF THE KACHCHH BASIN, WESTERN INDIA: INSIGHTS INTO PAST CLIMATIC, SEA-LEVEL, TECTONIC PERTURBATIONS AND ITS SIGNIFICANCE INTO GEOARCHAEOLOGY

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बीरबल साहनी पुराविज्ञान संस्थान

Birbal Sahni Institute of Palaeosciences

विज्ञान एवं प्रौद्योगिकी विभाग के अंतर्गत स्वास्थ्य संस्थान, भारत सरकार

An autonomous institute under the Department of Science and Technology, Government of India



Published in 2026 by

XXII INQUA Congress, India
Birbal Sahni Institute of Palaeosciences (BSIP)
53, University Road
Lucknow – 226007, Uttar Pradesh
India

Website: www.inquaindia2027.in
Email: inquaindia@bsip.res.in

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Compilation and editing: Field Trips Committee in collaboration with the INQUA 2027 Secretariat.

Design and Production:

XXII INQUA Congress 2027

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INQUA INDIA 2027

Field Guide Book

INPRE-01

Exploring Quaternary Geology of the Kachchh Basin, Western India: Insights into Past Climatic, Sea-Level, Tectonic Perturbations and its Significance into Geoarchaeology

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Dr. Gaurav D. Chauhan is an Assistant Professor at K.S.K.V. Kachchh University is a field geologist whose research has significantly advanced the understanding of the structural and tectonic evolution of the Kachchh Rift Basin, western India. Integrating detailed field mapping with structural geology, active tectonics, tectonic geomorphology, and palaeoseismology, his work decodes fault evolution, Quaternary landforms, and seismic hazards in this intraplate setting. His research extends to palaeoclimate and sea-level reconstruction, geoarchaeology, and climate-tectonic interactions, linking geological archives to human-landscape history. He has also led efforts documenting and conserving Kachchh's exceptional geoheritage, advancing geoconservation, geoparks, and geotourism frameworks across Indian terrains.



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Dr. Siddharth Prizomwala has made significant contributions to Quaternary research, particularly in reconstructing past environmental and climatic changes along the Gujarat coast and western India. His research integrates palaeotsunami deposits, sea-level changes, palaeoclimate, coastal evolution and geoarchaeology to understand extreme events and their long-term impacts on human societies and landscapes. His work includes investigations of Holocene sea-level fluctuations, prehistoric tsunami evidence, coastal vulnerability and archaeoseismological records, linking geological archives with archaeological and cultural heritage. These studies provide important insights into past climate variability, extreme events and coastal hazards, contributing to improved understanding of future disaster risk and climate resilience.

Abstract

The Kachchh Rift Basin of western India is one of the most significant natural laboratories for investigating Quaternary geology, active tectonics, palaeoseismology, geomorphology, coastal evolution, climate change, and human-environment interactions. Situated along the western continental margin of India, the region preserves an exceptional record of Quaternary geological processes within a tectonically active intraplate setting. This field guide has been prepared for the INQUA India 2027 Field Excursion, to be conducted from 21-24 January 2027 in the Kachchh region of Gujarat, to provide participants with an integrated understanding of the Quaternary evolution of the Kachchh landscape through field-based observations. The excursion traverses southern, western and northern Kachchh, covering a wide range of geological, geomorphological, geoarchaeological, coastal, and geoheritage sites extending from Bhuj through Mandvi, Pingleswar, Jakhau, Narayan Sarovar, Lakhpat, Siyot, the Banni Plains, Kala Dungar, Dholavira and the Karni area. The guide integrates regional geological background with detailed descriptions of 20 carefully selected field localities, each illustrating a distinct aspect of Quaternary landscape evolution and environmental change. The field localities document the influence of active tectonics on landscape development through investigations of the Katrol Hill Fault, Khari bedrock gorge, Ratiya neotectonic fault, hanging fossil valleys and fault-generated scarps. These sites demonstrate Holocene fault reactivation, river incision, geomorphic deformation, and the continuing influence of inherited geological structures on present-day surface processes. Coastal localities at Mandvi, Layja, Pingleswar and Jakhau preserve evidence of raised beaches, tilted beach rocks, coastal dune systems, mangrove ecosystems and sedimentary records of palaeotsunami and palaeostorm events, providing valuable archives of relative sea-level fluctuations, extreme marine events and coastal environmental evolution. The excursion further examines the geomorphic and sedimentological evolution of western Kachchh through active mudflats, Meghalayan-age aeolian dunes, Late Quaternary fluvial deposits and the remarkable Karni Post section, where Jurassic bedrock is unconformably overlain by Middle Holocene marine clay, fluvial sediments and Late Holocene aeolian deposits, representing changing depositional environments within a single exposed succession. The Banni Plains, Kala Dungar escarpment and the Bandi River valley provide insights into alluvial sedimentation, basin evolution, landscape dynamics, and tectonic control on drainage development. In addition to geological investigations, the guide highlights the rich geoarchaeological and cultural heritage of Kachchh through visits to the Iron Age site at Nani Chher, the historic town of Lakhpat, the ancient Buddhist caves at Siyot and the UNESCO World Heritage Site of Dholavira, illustrating the close relationship between changing landscapes, water resources, climate variability and long-term human settlement in an arid environment. Overall, this field guide presents a multidisciplinary synthesis of Quaternary stratigraphy, sedimentology, geomorphology, neotectonics, coastal geology, palaeoseismology, geoarchaeology and geoconservation. By integrating field observations with recent scientific research, the excursion provides participants with a comprehensive understanding of the tectonic, climatic and depositional processes that have shaped the Kachchh Rift Basin during the Quaternary period. The guide is intended as both a scientific reference and an educational resource for researchers, students and professionals interested in Quaternary science, active tectonics, coastal evolution, geoheritage and sustainable geotourism in one of India's most remarkable geological regions.

Preamble

Quaternary geology provides the framework for understanding Earth's recent environmental, climatic, tectonic and human history. Globally, major research challenges include deciphering the interactions between active tectonics, climate variability, sea-level change, sedimentary processes and human occupation during the Quaternary period. Many regions preserve only fragmentary records of these processes, making it difficult to correlate terrestrial, coastal, fluvial and archaeological archives within a single landscape. The Kachchh Rift Basin of western India is exceptional because it preserves an integrated archive of active faults, fluvial systems, marine deposits, coastal dunes, mudflats, mangroves, aeolian successions, geoarchaeological sites and historical landscapes within a tectonically active intraplate setting. The INQUA India 2027 field transect has been designed to demonstrate how these diverse archives can be examined together to reconstruct Quaternary landscape evolution and environmental change. Across twenty carefully selected field localities, participants will observe Holocene fault reactivation, neotectonic scarps, bedrock gorges, raised beaches, tilted beach rocks, palaeotsunami and palaeostorm deposits, coastal dune systems, active mudflats, Meghalayan-age aeolian dunes, valley-fill successions, and the Karni Post section recording Middle Holocene marine, fluvial and Late Holocene aeolian deposition in a single vertical profile. The transect further integrates geoarchaeological evidence from Nani Chher, Siyot and the UNESCO World Heritage Site of Dholavira, illustrating the links between environmental change, water availability and human adaptation. Unlike many Quaternary excursions that emphasize either tectonics, coastal evolution or archaeology alone, this field transect provides a multidisciplinary perspective linking tectonics, climate, sedimentation, sea-level change, extreme events and cultural evolution within one rift basin. Its continuity of geological archives and diversity of landforms make Kachchh a globally significant natural laboratory for testing models of Quaternary environmental change, intraplate deformation, palaeoseismicity, coastal evolution, geoheritage and geoconservation.

Logistics

1.1 Dates and Location

The field excursion will be conducted from January 21 to January 24, 2027, in the Kachchh region of Gujarat, India. The programme will commence with the arrival of participants in Bhuj on January 20, 2027, and conclude after hotel check-out on January 25, 2027. The field traverse covers important Quaternary geological, geomorphological, neotectonic, coastal, archaeological, and geoheritage sites across southern, western, and northern Kachchh, including Mandvi, Pongleshwar, Jakhau, Narayan Sarovar, Lakhpat, Siyot, Banni Plains, Kala Dungar, Dholavira, and surrounding areas (Fig. 1.1).

Date	Field Traverse
20/01/2027	• Arrival at Bhuj • Check-in into the Hotel (after 12 PM) • Inauguration Ceremony at the Department of Geosciences, Krantiguru Shyamji Krishna Verma Kachchh University • Visit to the Geological Museum, Department of Geosciences, Krantiguru Shyamji Krishna Verma Kachchh University • Cultural Program at Krantiguru Shyamji Krishna Verma Kachchh University • Kutchi Traditional Dinner at Krantiguru Shyamji Krishna Verma Kachchh University
21/01/2027	Location 1: Katrol Hill Fault Section (Holocene Reactivation) Location 2: Khari Bedrock Gorge Location 3: Ratiya Neotectonic Fault Location 4: Hanging Quaternary Fossil Valley near Palara Village Location 5: Katrol Hill Neotectonic Scarp Morphology at Ashapura Hill
22/01/2027	Location 6: Raised Beach and Tilted Beach rocks at Mandvi Location 7: Layja Coastal Dunes Location 8: Pongleshwar Paleotsunami and Paleostorm site Location 9: Jakhau Mangrove Field
23/01/2027	Location 10: Narayan Sarovar Active Mud Flats Location 11: Pinjorpir Sand Dunes of Meghalayan Age Location 12: Nani Chher Geo-Archaeological Site- Iron Age Culture Location 13: Lakhpat Geo-Historical-Cultural Site Location 14: 5000 Years Old Siyot Buddhish Caves

24/01/2027

Location 15: Banni Plains near Tropic of Cancer (Bhuj-Khavada Road)

Location 16: Kaladongar Scarp Top

Location 17: Bandi River Section (Valley Filled multi-directional channel – Late Quaternary Deposit)

Location 18: Road to Heaven- Quaternary Geotourism

Location 19: Dholavira UNESCO World Heritage Archaeological Site

Location 20: Karni Post section of Mid- Holocene Quaternary Dynamics (Marine, Fluvial and Aolian Deposits in a single section).

VALIDECTORY FUNCTION AND CERTIFICATE DISTRIBUTION AT DHOLAVIRA and Back to Bhuj at Night

25/01/2024

Checkout from the Hotel before 12 PM.

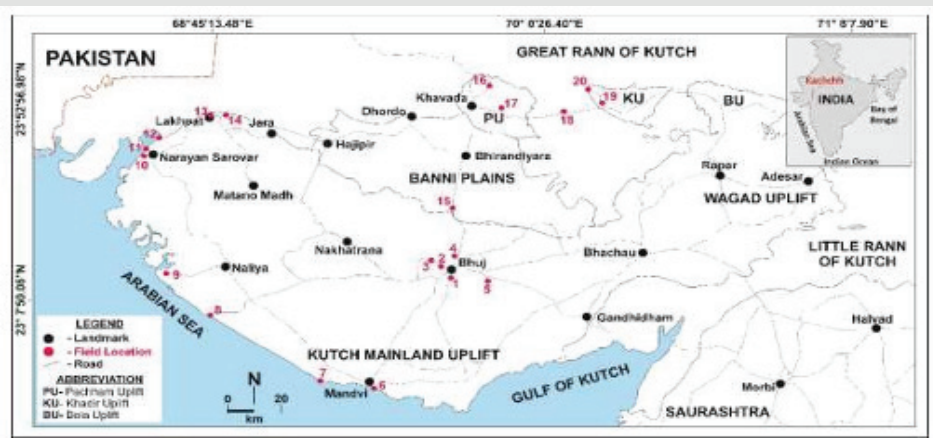


Fig. 1.1: Road Map of Kachchh Showing the Field Locations.

1.3 Travel Arrangements

Participants are requested to arrive in Bhuj on January 20, 2027, preferably before noon. Hotel check-in will be available after 12:00 P.M. The inaugural session, museum visit, cultural programme, and traditional Kutchi dinner will be hosted at the Department of Geosciences, Krantiguru Shyamji Krishna Verma Kachchh University.

Daily field excursions will be undertaken by air-conditioned buses. Breakfast, packed lunch, evening tea, and dinner will be arranged throughout the field programme. On days involving extended travel, breakfast may be served early or packed for the journey. Drinking water will be available throughout the excursion.



The field programme includes full-day traverses to several remote localities. Participants are requested to adhere strictly to departure timings to ensure smooth execution of the schedule. On January 24, following the visit to Dholavira and the valedictory function with certificate distribution, the field party will return to Bhuj during the night. Hotel check-out will be completed before 12:00 P.M. on January 25, 2027.

1.4 General Remarks

The field excursion involves extensive outdoor activities under semiarid climatic conditions. During daytime, temperatures may be warm, while mornings and evenings can be relatively cool. Participants are advised to carry a hat or cap, sunscreen, sunglasses, and sufficient drinking water during field visits.

Most traverses involve walking over rocky terrain, loose sediments, coastal deposits, sand dunes, and uneven surfaces. Comfortable trekking or sports shoes with good grip are strongly recommended. Participants should wear light, full-sleeved clothing suitable for fieldwork.

Several localities are situated near the international border and within environmentally sensitive regions. Participants must carry a valid government-issued photo identity card at all times and strictly follow the instructions of the field leaders and local authorities. Photography may be restricted at certain locations near defence establishments and border areas.

The field excursion includes visits to archaeological monuments, UNESCO World Heritage sites, mangrove ecosystems, and protected landscapes. Participants are requested to respect local customs, avoid littering, refrain from disturbing geological or archaeological features, and follow responsible geotourism practices. Collection of geological, archaeological, or biological specimens is prohibited unless specifically permitted by the excursion leaders.

Mobile network coverage may be intermittent in remote areas such as Narayan Sarovar, Lakhpat, Kala Dungar, Banni Plains, and Dholavira. Participants are advised to inform their family members accordingly before the excursion. Basic first-aid facilities will be available with the field team; however, participants should carry any personal medications they may require.

1.5 Scientific Objectives

The principal scientific objectives of the excursion are to:

- Examine the geomorphic, structural, and sedimentary evidence of Late Quaternary and Holocene tectonic activity.
- Investigate active faulting, tectonic landforms, and structurally controlled drainage evolution.
- Interpret fluvial, coastal, and aeolian depositional systems in relation to tectonics, climate, and sea-level change.

- Study modern coastal environments as analogues for interpreting Quaternary depositional processes.
- Evaluate palaeoseismic indicators, including liquefaction features and earthquake-induced deformation.
- Understand the evolution of the Banni Plains and the Great Rann of Kachchh in response to tectonic, climatic, and sea-level fluctuations.
- Explore the links between Quaternary geology, geoarchaeology, cultural heritage, and human adaptation.
- Develop skills in field mapping, sediment logging, geomorphic interpretation, sampling, geochronology, and geoconservation.
- Promote critical scientific interpretation and effective communication of geological observations for research, geoconservation, and geotourism.



Regional Geological Framework of the Kachchh Basin: Western India

2.1 Introduction

Kachchh, the largest district in India, is located in the western part of the state of Gujarat and forms the westernmost extremity of the Indian subcontinent. Covering an area larger than several Indian states, it is bounded by Pakistan to the northwest, the Arabian Sea to the south, and the Gulf of Kachchh to the southeast (Fig. 2.1). The region is, in effect, a seasonal island. During the southwest monsoon, the salt marshes of the Great Rann and Little Rann of Kachchh, which separate the district from mainland India, are inundated by both marine and freshwater. In contrast, during the dry winter months, these vast mudflats are covered by a thin veneer of salt crystals, creating a striking landscape that contrasts with the surrounding hill ranges and isolated uplands.



Fig. 2.1: Schematic map of Kachchh in western Gujarat with its major towns and roads.

2.2 Geological Setting of the Kachchh Basin

The Kachchh Basin, located in Gujarat, western India, is a pericratonic rift basin situated along the western continental margin of the Indian Plate. It is one of the most seismically active intraplate basins in the world and has experienced repeated episodes of tectonic reactivation from the Mesozoic to the present day. The present-day landscape of Kachchh is broadly divided into four major physiographic units: (i) the Great and Little Rann of Kachchh, (ii) the low-lying Banni Plains, (iii) the uplifted hilly region, and (iv) the southern coastal plains (Fig. 2.2).

The uplifted hilly region comprises three principal structural blocks: the Island Belt Uplift (IBU), the Kachchh Mainland Uplift (KMU), and the Wagad Uplift (WU) (Fig. 2.2). These uplifts are predominantly composed of Mesozoic and Cenozoic sedimentary successions that host economically important mineral resources, including limestone, bentonite, bauxite, kaolin, gypsum, and lignite.

The Kachchh Basin preserves an approximately 2,000–3,000 m thick Mesozoic sedimentary succession overlain by nearly 1,000 m of Cenozoic sediments (Biswas, 1982). The Mesozoic succession records the evolution of the rift basin through pre-rift, syn-rift, and post-rift depositional phases. The basin stratigraphy is broadly classified into three major sedimentary packages: the Mesozoic, Tertiary, and Quaternary successions. Based on lithological characteristics, the Mesozoic rocks are further subdivided into the Mainland Group, Patcham Group, and Eastern Kachchh Group (Fig. 2.2). The Late Cretaceous Deccan Trap volcanic episode marks the transition between the Mesozoic and Cenozoic successions. The Deccan volcanic flows and associated intrusive bodies are exposed mainly

along the southern peripheral plains of the Kachchh Mainland Uplift (Fig. 1.1). The overlying Tertiary succession accumulated within post-rift sag basins and records repeated marine transgressive and regressive phases along the western Indian continental margin. Quaternary deposits are extensively developed across the basin and include both erosional (degradational) and depositional (aggradational) landforms. These comprise incised valleys, strath terraces, badlands, fluvial plains, marine terraces, lacustrine deposits, coastal sediments, and aeolian dunes, reflecting the combined influence of tectonics, sea-level fluctuations, and climatic variability during the Late Quaternary.

Structurally, the basin is characterized by a series of major eastwest-trending faults that define its tectonic architecture. The principal faults include the Nagar Parkar Fault, Allah Bund Fault, Island Belt Fault, Gora Dongar Fault, Gedi Fault, Banni Fault, North Wagad Fault, South Wagad Fault, Kachchh Mainland Fault, Vigodi Fault, Katrol Hill Fault, and North Kathiawar Fault (Fig. 1.1). These regional faults are intersected and locally displaced by numerous NW-SE- and NE-SW-oriented transverse faults, reflecting multiple phases of tectonic deformation and continued neotectonic activity.

The elevation of the basin ranges from less than 10 m above mean sea level in the Rann and coastal plains to over 450 m in the upland regions, with Pachchhmai Peak representing the highest point in Kachchh.

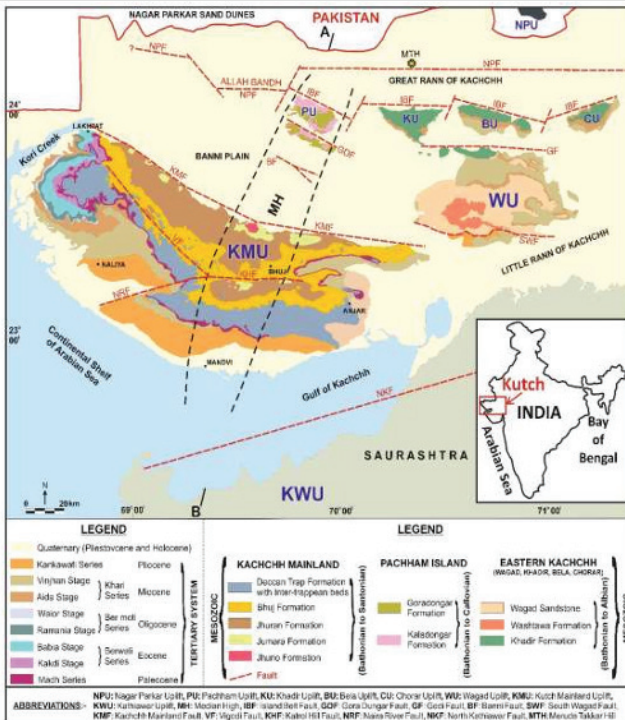


Fig. 2.2: Geological map of Kachchh (modified after Biswas, 2016) with stratigraphic succession showing the major kaolin mining areas across the three physiographic sub-divisions.

The climate is predominantly arid to semi-arid and is strongly influenced by the southwest monsoon. Mean annual rainfall is approximately 348 mm, with nearly all precipitation occurring between June and September (Juyal et al., 2006; Thakkar, 2017). Palaeoclimatic studies indicate a gradual weakening of the Indian Summer Monsoon since the Middle Holocene (Thakkar, 2017). Summer temperatures commonly range between 42 and 43°C, occasionally exceeding 48°C, whereas winter temperatures are comparatively mild, with daytime temperatures of 2830°C and nighttime temperatures often falling below 10°C owing to the moderating influence of the Arabian Sea.

2.3 Geomorphological Significance

The geomorphology of the Kachchh Rift Basin (KRB) is a direct expression of its long tectonic history and continued neotectonic activity. The landscape is characterized by isolated rocky uplands surrounded by extensive low-lying plains comprising palaeo-mudflats, salt playas, coastal mudflats with salinas, and the grassy Banni Plains (Fig. 2.3). The strong contrast between the elevated fault-bounded uplands and the surrounding plains makes Kachchh one of the finest examples of a tectonically controlled landscape in India (Biswas, 1971, 1974).

Based on relief, elevation, slope, and geomorphic characteristics, the Kachchh region can be divided into four major physiographic units: (i) the Great and Little Rann of Kachchh, (ii) the Banni Plains, (iii) the uplifted hilly terrain, and (iv) the southern coastal plains (Fig. 2.3). The hilly terrain consists of six major uplifts: the Kachchh Mainland Uplift in the south, the Wagad Uplift in the east, and the Pachchham, Khadir, Bela, and Chorar uplifts in the north. The latter four uplifts form an east-west chain within the Great Rann, collectively known as the Island Belt (Biswas, 1971). These uplands represent remnants of a once-continuous fault-bounded ridge that was later segmented by wrench faulting. During the Late Neogene and Quaternary, repeated marine inundation transformed these uplands into islands, a condition that is seasonally recreated during the southwest monsoon when the surrounding Rann becomes flooded.

The topography of the Kachchh uplands is largely controlled by major east-west-trending faults. Most hill ranges display steep fault escarpments along their northern margins and gentle dip slopes towards the south, reflecting the geometry of the underlying fault blocks. An exception is the Wagad Uplift, where the structural configuration produces a northward-tilted landscape. These fault-controlled hill ranges are characterized by narrow deformation zones containing a variety of structural features, including domes, brachyanticlines, plunging anticlines, and monoclinial flexures. Along the faulted margins, erosion has produced well-developed cuestas and fault scarps, providing excellent exposures of tectonic structures.

The interaction of tectonic uplift, climatic fluctuations, sea-level changes, and surface processes since the Mesozoic has generated an exceptional diversity of geomorphological features throughout the basin. These include active and relict mudflats, marine terraces, raised beaches, coastal and stabilized aeolian dunes, wave-cut platforms and cliffs, caves, fault scarps, incised valleys, strath terraces, gorges, knickpoints, and deformed Holocene sediments. Many of these landforms are exceptionally well preserved and provide textbook examples of active tectonics, coastal evolution, Quaternary landscape development, and Earth surface processes. Consequently, the Kachchh Rift Basin serves as an outstanding

natural laboratory for the study of tectonic geomorphology, Quaternary geology, and geohazards.

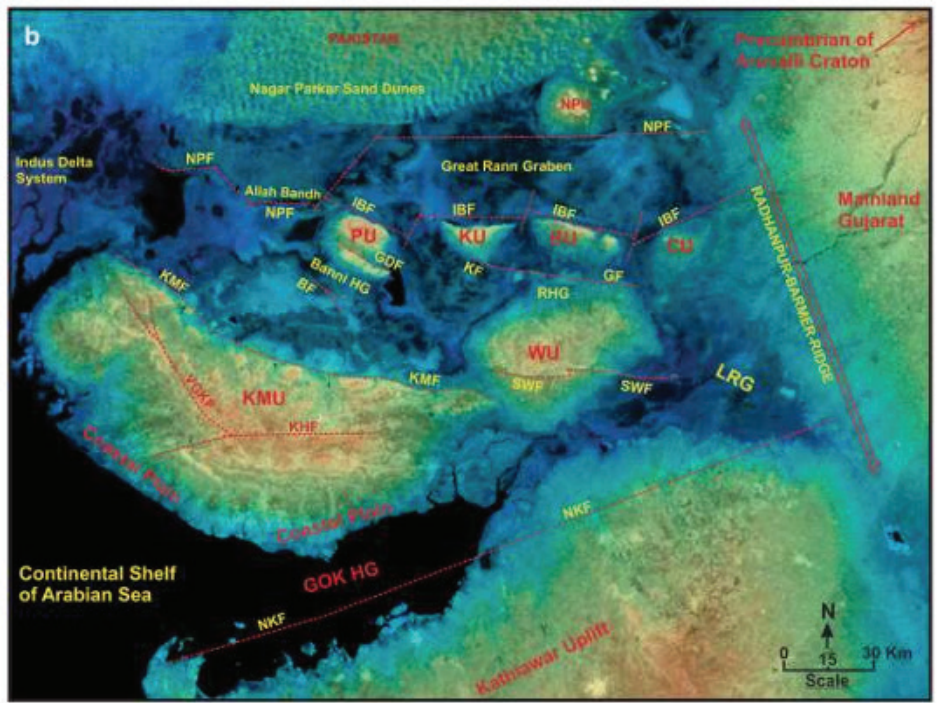


Fig. 2.3: SRTM view of the Kachchh Basin showing geomorphological features- uplands, Rann, and coastal plains correlated with uplifted and subsided blocks as controlled by major and minor structural elements in the basin (modified after Biswas 2016b).

2.4 Significance of Neotectonics and Palaeoseismology

The Kachchh Rift Basin (KRB) is one of the world's most active intraplate tectonic provinces, where Quaternary tectonic activity is expressed through a wide range of geomorphological and palaeoseismic features (Chauhan et al., 2016b). Ongoing tectonic movements have produced numerous morphotectonic markers that provide exceptional opportunities to investigate active faulting and landscape evolution. The youthful geomorphic character of the basin is reflected in a variety of erosional and depositional landforms. Prominent tectonic landforms include fault scarps, receding escarpments, deeply incised bedrock gorges, canyons, caves, triangular facets, mountain fronts, warped surfaces, deeply incised valleys, gullied slopes, offset and deflected drainage systems, anastomosing channels, meanders, and knickpoints. Equally significant are depositional features such as alluvial and colluvial fans, debris-flow deposits, valley-fill sediments, millilite deposits, coastal dunes, and extensive salt flats, all of which preserve evidence of repeated tectonic movements and Quaternary environmental change (Chauhan et al. 2021).

The Quaternary tectonic evolution of the basin has been extensively investigated using integrated approaches that combine neotectonic mapping, tectonic geomorphology, palaeoseismology, remote sensing, GIS analysis, geochronology, and sedimentological studies. These investigations consistently demonstrate repeated reactivation of the major east-west-trending faults throughout the Late Quaternary, confirming that the Kachchh Rift Basin remains tectonically active. In addition to tectonic processes, Quaternary climatic fluctuations and sealevel changes have significantly influenced landscape evolution across Kachchh. Interactions between fluvial, aeolian, marine, and lacustrine processes have produced a remarkable variety of erosional and depositional landforms, while the coastal plains and the Great Rann preserve outstanding records of Holocene shoreline migration, marine transgressions and regressions, and palaeoenvironmental change.

The Kachchh Rift Basin also preserves one of the most important palaeoseismic archives in the Indian subcontinent. Historical records document several destructive earthquakes that have affected the region, including the 1819 Allah Bund, 1845 Anjar, 1956 Anjar, and 2001 Bhuj earthquakes, along with older historical events reported from the northwestern Indian region. The 2001 Bhuj earthquake (Mw 7.7) stimulated extensive palaeoseismological investigations, leading to the discovery of numerous prehistoric surface ruptures, liquefaction features, soft-sediment deformation structures, and earthquake-induced ground deformation associated with earlier seismic events, particularly the 1819 Allah Bund earthquake. Large sand blows, liquefaction craters, fissures, and other earthquake-induced sedimentary structures are exceptionally well preserved within the unconsolidated sediments of the Banni Plains and the Great Rann of Kachchh. These features provide invaluable records for reconstructing the recurrence of large intraplate earthquakes and understanding the behaviour of active faults in stable continental regions. Consequently, the Kachchh Rift Basin serves as one of the most important natural laboratories for the study of neotectonics, active faulting, palaeoseismology, seismic hazards, and Quaternary landscape evolution.

2.5 Sea-Level Change, Climate, and Geoarchaeological Significance

Over the past two decades, research in the Kachchh Rift Basin (KRB) has significantly advanced our understanding of Quaternary sealevel fluctuations, palaeoclimate, and human-environment interactions. The basin preserves an exceptionally thick Quaternary sedimentary succession within the Great and Little Rann of Kachchh, the Banni Plains, the coastal plains, and the hinterland fluvial systems, providing one of the most complete archives of Late Quaternary environmental change along the western continental margin of India (Chauhan et al. 2021).

The Great and Little Rann, covering nearly 23,000 km², preserve extensive sequences of mudflat, evaporitic, tidal, fluvial, and aeolian sediments that record the evolution of Holocene Sea level, monsoon variability, and landscape development. The Rann represents a slowly subsiding tectonic depression that has received sediments from marine incursions, Himalayan River systems, and local drainage networks. Consequently, it provides an exceptional natural archive for reconstructing the interactions among tectonics, climate, sea-level change, and sedimentation during the Quaternary. The tide-dominated coastline of the Gulf of Kachchh exhibits a remarkable range of depositional and erosional landforms,

including tidal flats, relict intertidal deposits, spits, coastal mudflats, beaches, dunes, and marine terraces. Preserved palaeotidal-flat deposits, often interbedded with fluvial sediments, document repeated shifts between marine and continental environments in response to relative sea-level fluctuations and tectonic movements. Many of these relict coastal landforms now occur at elevations above the present tidal range, providing important evidence of Holocene shoreline migration and neotectonic uplift (Chauhan et al. 2021).

The Quaternary environmental history of Kachchh has profoundly influenced the distribution and evolution of human settlements. Nearly twenty major archaeological sites are located around the margins of the Great Rann and along the Gulf of Kachchh, indicating that Holocene sealevel changes played a critical role in shaping settlement patterns, trade routes, and resource availability. Among these, Dholavira, situated on Khadir Island, is one of the most significant urban centres of the Indus (Harappan) Civilization and is recognized as a UNESCO World Heritage Site. Its strategic location along the palaeoshoreline of the Great Rann enabled it to flourish as an important centre for inland and maritime trade.

Palaeoclimatic investigations indicate that the landscape of Kachchh responded sensitively to variations in the intensity of the Indian Summer Monsoon during the Holocene. Geological and archaeological evidence suggests that the gradual weakening of the monsoon after approximately 5 ka led to increasing aridity, reduced freshwater availability, and significant environmental stress. These climatic changes are now considered among the principal factors contributing to the decline and eventual abandonment of several Harappan settlements in the region, although tectonic activity and changing sea level may also have influenced settlement dynamics.



Fig. 2.4: Location map of the 14 geoarchaeological sites along with the major cities in the region.

There are several major archaeological sites distributed along the coast and in the Great Rann of Kachchh (GRK), and it has been suggested that Holocene Sea level exerted an important influence in sustaining ancient coastal communities (Lawler 2011) (Fig. 2.4). Recent geoarchaeological studies have further demonstrated that the Kachchh region preserves evidence of continued human occupation from the Harappan period through the Iron Age, Early Historic, and Medieval periods. Archaeoseismological investigations at Dholavira have identified multiple collapse horizons that may record large prehistoric earthquakes, highlighting the influence of active tectonics on ancient settlements. In addition, the discovery of ancient anchor stones, marine artefacts, and archaeological remains buried within the Rann sediments indicates that parts of the present-day salt desert were once navigable marine embayments connected to the Arabian Sea. The exceptional preservation of Quaternary sediments, coastal landforms, archaeological sites, and palaeoenvironmental records makes the Kachchh Rift Basin one of the most important natural laboratories for investigating the interactions among tectonics, sea-level change, climate variability, and human adaptation during the Holocene. This unique combination of geological and cultural heritage provides outstanding opportunities for interdisciplinary research in Quaternary geology, geoarchaeology, palaeoclimate, and coastal evolution.

2.6 Seismicity of the Kachchh Basin

The Kachchh region falls within Seismic Zone V, the highest seismic hazard zone in India, and is recognized as one of the most seismically active intraplate regions in the world. Despite its location far from active plate boundaries, Kachchh has experienced several moderate to large earthquakes during historical times, reflecting the continued reactivation of ancient rift-related faults (Fig. 2.5). The most devastating event in recent history was the 26 January 2001 Bhuj earthquake (Mw 7.7), which claimed nearly 20,000 lives, injured more than 160,000 people, and caused widespread destruction across Gujarat. Earlier significant earthquakes include the 1819 Allah Bund earthquake (Mw ~7.8), which produced the famous Allah Bund uplift and extensive surface deformation, and the 1956 Anjar earthquake (Mw 6.1), which caused severe damage in the Anjar region (Fig. 2.5).

Owing to its intraplate tectonic setting, the 2001 Bhuj earthquake has frequently been compared with the New Madrid Seismic Zone in the central United States, as both represent large earthquakes occurring within stable continental interiors rather than along active plate boundaries (Bodin et al., 2004; Tuttle et al., 2001). Seismological and focal mechanism studies indicate that both the 2001 Bhuj and 1956 Anjar earthquakes occurred on south-dipping reverse faults, reflecting compressional reactivation of pre-existing Mesozoic rift faults under the present-day regional stress regime (Chung and Gao, 1995; Negishi et al., 2001). Following the 2001 Bhuj earthquake, the Kachchh region has experienced a sustained increase in microseismicity and moderate earthquake activity, indicating continued crustal adjustment and active deformation within the basin (Rastogi et al., 2012). The recurrence of damaging earthquakes, together with abundant neotectonic and palaeoseismic evidence, highlights the Kachchh Rift Basin as an important natural laboratory for investigating intraplate tectonics, seismic hazards, and earthquake recurrence.

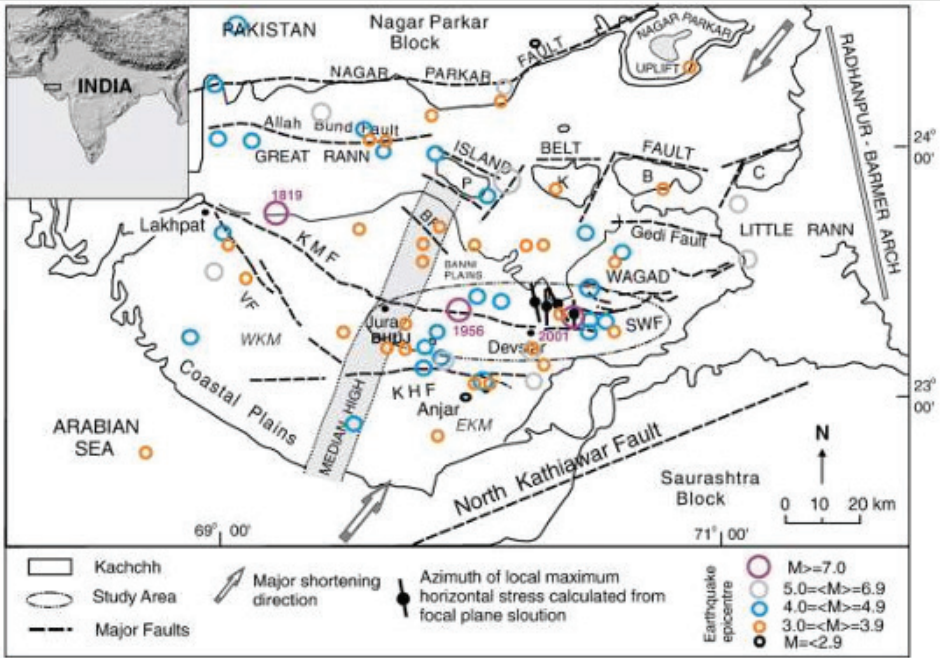


Fig. 2.5: Seismotectonic map of Kachchh showing epicenters of major and minor seismic events. KMF–Kachchh Mainland Fault, KHF–Katrol Hill Fault, VF–Vigodi Fault, BF–Banni Fault, SWF–South Wagad Fault, P–Pachham Island, KKH–Khadir Island, B–Bela Island C–Chorar Island, EKM–Eastern Kachchh Mainland and WKM–Western Kachchh Mainland (modified after Biswas and Khatri, 2002; Mathew et al., 2006; Mallik et al., 2009).

2.7 Drainage Pattern

The Kachchh Peninsula exhibits a striking geomorphic contrast between rugged uplands and extensive low-lying plains. The uplands are composed predominantly of Mesozoic and Tertiary sedimentary rocks that have been uplifted along major fault systems, whereas the intervening plains consist mainly of Quaternary alluvium, mudflat deposits, and Rann clays accumulated within tectonic grabens. The drainage network is predominantly dendritic, reflecting the relatively homogeneous lithology and structural setting of the basin (Fig. 2.6). However, radial drainage patterns are locally developed around domal structures, while meandering and braided channels occur extensively across the Quaternary plains. Several northward-flowing streams exhibit abrupt deflections, sharp angular bends, and locally offset channels, indicating structural control by the reactivation of pre-existing faults and fracture zones. Rejuvenation of these streams is further evidenced by deeply incised valleys, prominent knickpoints, active headward erosion, and significant channel downcutting.

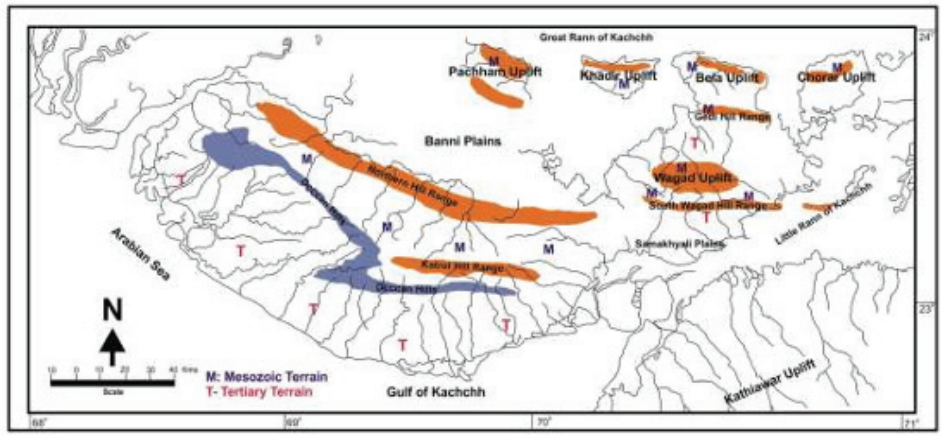


Fig. 2.6: Drainage map of the Kachchh Basin showing sub-parallel rivers across the southern and northern Mainland on either side of a central watershed. The radial drainage pattern is compatible with elliptical/domal uplifts.

The drainage pattern of the Kachchh Mainland is strongly influenced by the basin's tectonic framework. Frequent stream diversion, channel abandonment, and drainage switching across the major eastwest-trending master faults suggest recurrent strike-slip displacement along transverse faults. In addition, well-developed trellis, angular, and rectilinear drainage patterns trending NNW-SSE, NNE-SSW, and N-S reflect the strong structural control exerted by transverse lineaments. Both higher- and lower-order streams preferentially follow these orientations, indicating that these transverse structures represent the youngest tectonically active trends within the basin. The influence of active neotectonics on drainage evolution is further manifested by stream beheading, offset and deflected channels, abrupt changes in channel direction, asymmetric valley development, and differential incision across fault zones. Consequently, the drainage network of Kachchh provides important geomorphic evidence for ongoing tectonic activity and serves as a valuable indicator for understanding the neotectonic evolution of the Kachchh Rift Basin (Chauhan et al., 2021).



Field Locations

Location 1: Katrol Hill Fault Section (Holocene Reactivation), Khari River, north of the Katrol Hill Fault scarp

Coordinates: 23°11'35.36"N, 69°35'22.87"E

Description: This locality provides one of the best exposures demonstrating repeated Quaternary reactivation of the Katrol Hill Fault (KHF) and is a classic site for studying neotectonic deformation in the Kachchh Rift Basin (Fig. 3.1). The section is exposed along the left bank of the Khari River, immediately north of the fault scarp, where Quaternary sediments unconformably overlie Mesozoic rocks. The Katrol Hill Fault crosses the river at this locality and forms the lithotectonic boundary between the Bhuj Formation to the north and the Jhuran Formation to the south.



Fig. 3.1: Field photograph of the Khari River cliff section showing Holocene Quaternary sediments displaced by repeated reactivation of the Katrol Hill Fault (KHF).

The approximately 7 m thick Quaternary succession comprises five lithostratigraphic units (A–E) representing successive episodes of colluvial, fluvial, aeolian, and scarp-derived sedimentation (Fig. 3.2). The basal Unit A consists of coarse bouldery colluvium resting unconformably on Mesozoic bedrock and records the earliest preserved Quaternary deposition at the site. It is overlain by Units B–D, comprising gravelly sands, coarse fluvial sands, and well-lithified miliolitic sands that collectively represent Late Pleistocene valley-fill deposits. The uppermost Unit E consists of angular, scarp-derived colluvium deposited during the Late Holocene.

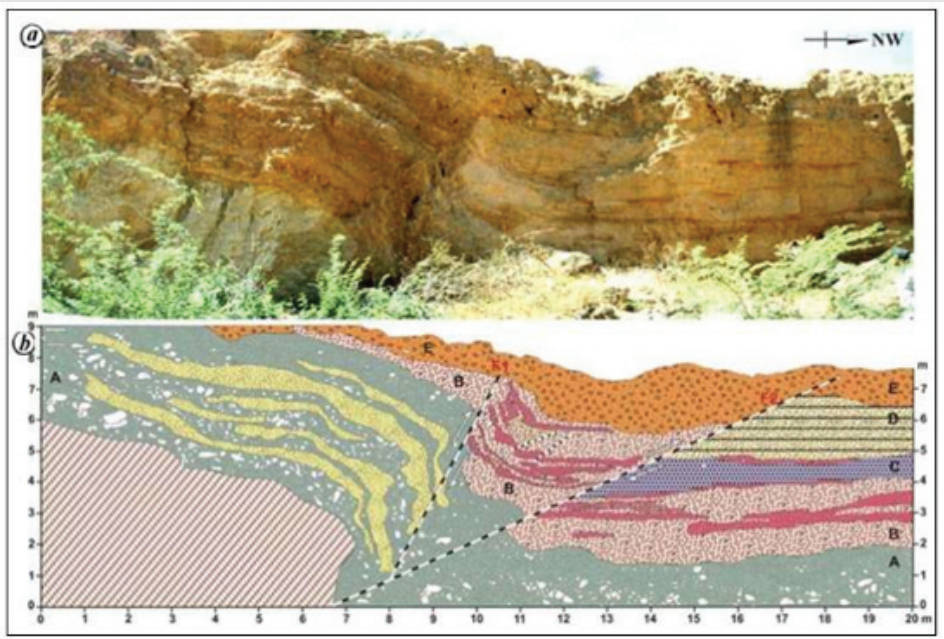


Fig. 3.2: a, Exposed cliff section along the Khari River to the SE of Bharasar showing offsetting in the Quaternary sediments along the KHF. Location of the site is shown in (c). b, overlay of cliff section showing various lithologies and faults. A, Bouldery colluvium; B, Gravelly sand; C, Coarse sand; D, Stratified miliolitic sand and E, Scarp-derived colluvium. Note the splaying nature of the KHF in Quaternary deposits (Patidar et al., 2008).

The entire Quaternary succession is displaced by two southdipping reverse faults (F1 and F2) that represent upward splays of the Katrol Hill Fault. The cumulative vertical displacement of the basal colluvial unit is approximately 7 m, providing clear evidence of repeated surface deformation during the Late Quaternary. The succession preserves two major erosional unconformities separating Units A–B and D–E, indicating alternating phases of faulting, erosion, and sediment accumulation. Detailed stratigraphic relationships indicate that fault movement occurred during at least three distinct phases. The first event displaced the basal colluvial deposits during the Late Pleistocene, followed by deposition of valley-fill sediments. A second phase of faulting occurred after deposition of the miliolitic sands during the Early Holocene, while the youngest movement displaced the scarp-derived colluvium, indicating fault activity during the Late Holocene (<2 ka). These repeated episodes of deformation demonstrate progressive upward propagation and splaying of the Katrol Hill Fault through unconsolidated Quaternary sediments.

This locality represents one of the most important field examples of Quaternary fault reactivation along the Katrol Hill Fault. The exposure clearly illustrates the interaction between tectonic deformation, erosion, and sedimentation, and provides compelling evidence for repeated Late Quaternary surface rupturing. It serves as a textbook site for

understanding palaeoseismic stratigraphy, fault-scarp evolution, tectonosedimentary processes, and the reconstruction of earthquake histories in intraplate tectonic settings.

Location 2: Khari Bedrock Gorge

Coordinates: 23°15'3.59"N, 69°37'49.27"E

Description: The Khari Bedrock Gorge, located approximately 4 km west of Bhuj along the Bhuj-Kodki Road, is one of the most spectacular examples of tectonically controlled fluvial incision in the Kachchh Rift Basin. Developed within Cretaceous sandstones on the downthrown block of the Katrol Hill Fault (KHF), the gorge provides compelling evidence of the interaction between active tectonics, river incision, and climatic variability during the Late Quaternary (Fig. 3.3).

The Khari River basin is triangular in plan, with its southern margin defined by the Katrol Hill Range and its apex extending northward towards the Banni Plains, where it terminates as an extensive alluvial fan. Although the basin generally drains northward, the main Khari River follows a northeastward course that is strongly controlled by regional structures. The basin is bounded and dissected by several active faults and fractures associated with the Katrol Hill Fault system, making it one of the best examples of a structurally controlled drainage basin in Kachchh.

The gorge is developed over an approximately 250–400 m long reach, where the river has incised a narrow canyon 10–27 m deep and only 2–3 m wide into massive Cretaceous sandstone (Fig. 3.3). Such a deeply entrenched gorge developed on an otherwise gently sloping rocky plain is highly unusual and reflects localized tectonic uplift followed by rapid fluvial incision. The gorge is bounded upstream and downstream by east-west-trending normal faults and is further influenced by N-S, NNESSW, NNW-SSE, and E-W trending fractures, transverse faults, and basic dykes, all of which have contributed to its orientation and evolution.



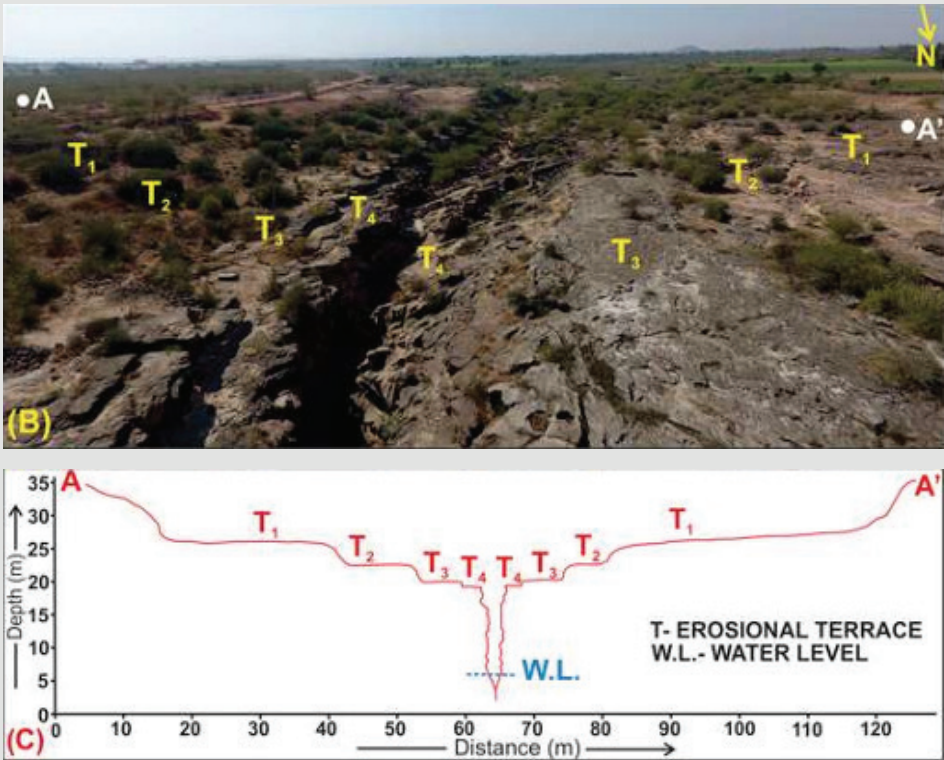


Fig. 3.3: Aerial and panoramic images of Khari River gorge showing bedrock topography with Katrol Hill Range in the distant horizon in (A). (B)-Panoramic view of the Khari Gorge site. T1 to T4 bedrock terraces along the gorge. Cross section profile between A and A' points are shown in (C).

One of the most distinctive geomorphic features of the locality is the presence of four paired bedrock (tectono-erosional) terraces preserved along the gorge walls (Fig. 3.3). These terraces represent successive phases of river downcutting following episodic uplift of the bedrock surface and record repeated cycles of incision, lateral erosion, and channel adjustment. The terrace surfaces display numerous giant potholes, flutings, longitudinal grooves, and sculptured bedrock forms, produced by high-energy turbulent flow during periods of enhanced discharge. During the dry season, groundwater is exposed at the base of the gorge, allowing close examination of its vertical walls and erosional morphology.

Immediately east of the gorge, an abandoned palaeochannel filled with Quaternary alluvium marks an earlier course of the Khari River before entrenchment into the present bedrock gorge (Fig. 3.4 and 3.5). The preservation of both the palaeochannel and the incised gorge provides clear evidence of river rejuvenation associated with tectonic uplift and changes in base level. The transition from a broad alluvial channel to a deeply incised bedrock gorge illustrates the strong geomorphic response of the drainage system to neotectonic activity.

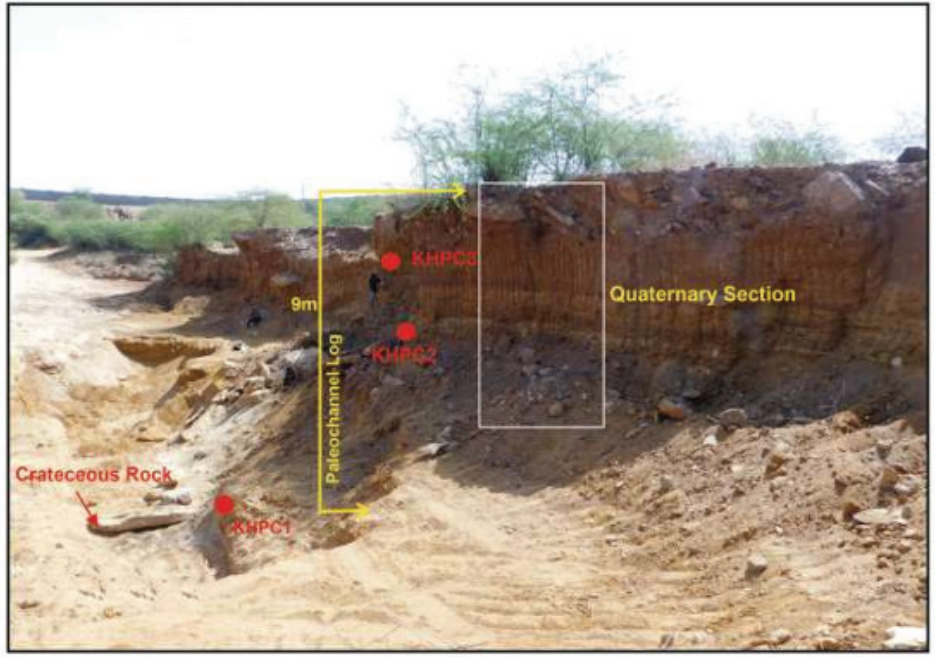


Fig. 3.4: Photograph showing abandoned palaeochannel filled with Quaternary alluvium marks an earlier course of the Khari River before entrenchment into the present bedrock gorge.

Although the Khari Gorge has long been recognized as a neotectonic landform, the precise timing of its formation remains uncertain. Nevertheless, its morphology, associated bedrock terraces, abandoned palaeochannel, and structural setting collectively demonstrate repeated Quaternary uplift and incision linked to reactivation of the Katrol Hill Fault and associated transverse fault systems.

The Khari Bedrock Gorge is one of the finest examples of a tectonically controlled bedrock river system in western India. It demonstrates how repeated fault movements, coupled with climatic fluctuations and variations in river discharge, have governed channel incision and landscape evolution. The gorge, associated bedrock terraces, and abandoned palaeochannel provide valuable insights into Quaternary uplift, drainage evolution, and neotectonic processes in the Kachchh Rift Basin, making this locality an outstanding natural laboratory for studies of tectonic geomorphology and active landscape evolution.

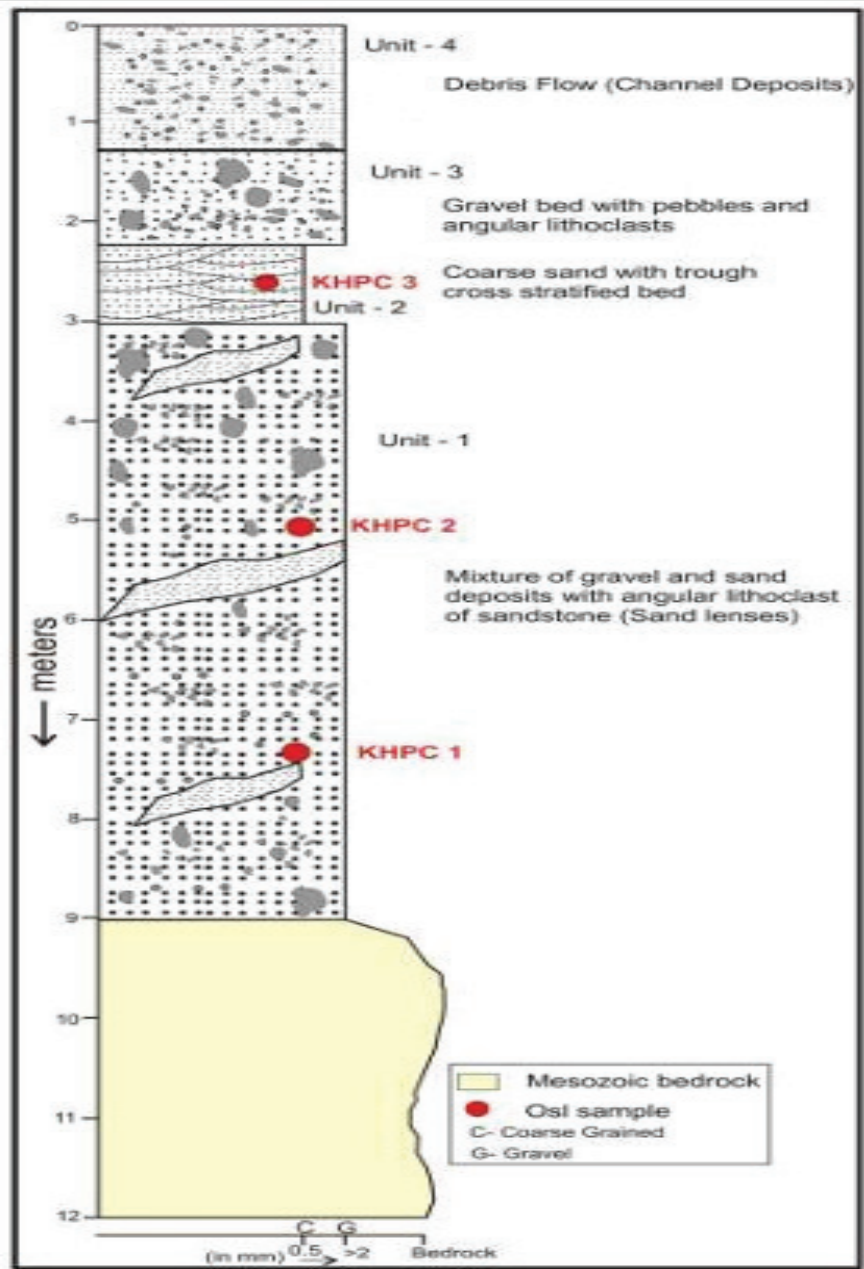


Fig. 3.5: Stratigraphy of the paleochannel deposits.

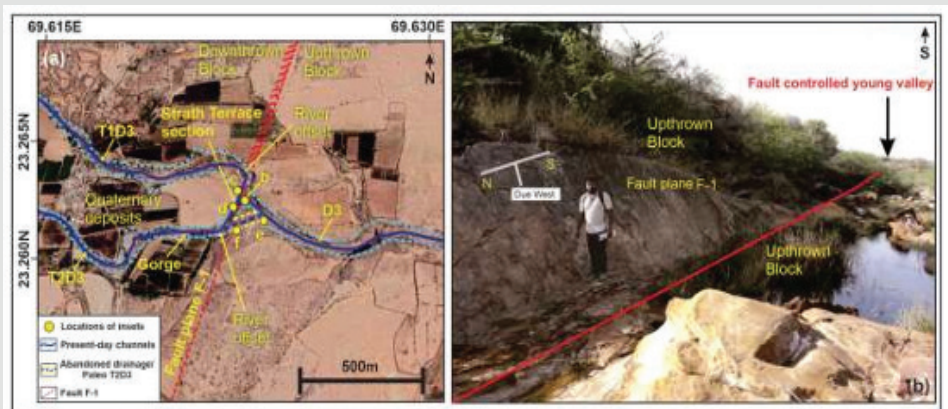
Location 3: Ratiya Neotectonic Fault

Coordinates: 23°15'45.61"N, 69°37'21.19"E

Description: The Ratiya Fault, located east of Ratiya village in the middle reaches of the Khari River basin, is one of the best exposures demonstrating Quaternary neotectonic deformation in the Kachchh Mainland. This NNE–SSW trending normal fault cuts the Cretaceous Bhuj Sandstone and has exerted a fundamental control on drainage evolution, Quaternary sedimentation, and landscape development (Fig. 3.6). The eastern side forms the uplifted block, whereas the western side represents the downthrown block where thick Quaternary sediments accumulated after fault reactivation.

The fault controls the courses of two eastward-flowing tributaries (T1D3 and T2D3), both of which display distinct channel offsets where they intersect the fault before joining the higher-order Khari River (Fig. 3.6). Reactivation of the fault produced local base-level changes, blocked the tributary drainages, and resulted in the preservation of a thick package of Quaternary fluvial deposits on the downthrown block. On the uplifted side, an abandoned bedrock channel now occurs as a hanging valley approximately 2.5 m above the present river bed, providing direct evidence of tectonically induced drainage diversion and incision.

The site preserves an exceptional assemblage of tectonogeomorphic features, including a fresh fault plane, river offsets, abandoned channels, hanging valleys, youthful bedrock gorges, strath terraces, multiple bedrock terraces (T1–T3), and entrenched meanders. These landforms collectively demonstrate repeated Quaternary uplift and incision associated with episodic fault movement. A well-exposed approximately 8 m thick Quaternary succession resting unconformably on beveled Mesozoic sandstone records sediment accumulation following fault reactivation (Fig. 3.7).



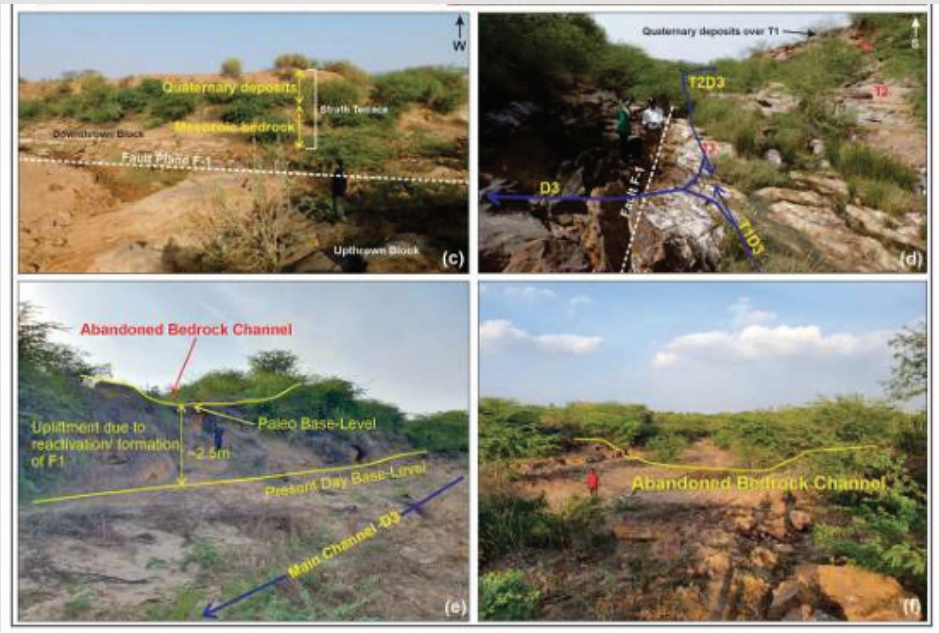


Fig. 3.6: The image shows the presence of several neotectonic features near the Ratiya Fault: (a) Satellite imagery shows the locations of neotectonic features along the Ratiya Fault and their insets; (b) field photograph shows the fault plane exposure of the Ratiya Fault near the strath terrace section; (c) shows the location of the strath terrace on the downthrown block of the Ratiya Fault; (d) confluence of tributary channels T1D3 and T2D3 in the strath terrace section along the Ratiya Fault; (e) Abandoned hanging paleochannel T2D3 and (f) shows the lateral section of the abandoned paleochannel T2D3.

The succession comprises debris-flow deposits, gritty sands with sandstone clasts, and channel-fill gravels representing fluvial aggradation within a fault-controlled depression. Optically Stimulated Luminescence (OSL) dating indicates deposition between $\sim 42 \pm 4$ ka and 32 ± 4 ka, suggesting that reactivation of Fault F-1 predates ~ 42 ka. Following sediment accumulation, renewed tectonic uplift-initiated incision of the Quaternary deposits and underlying bedrock, producing the present strath terrace and multiple levels of bedrock terraces (Fig. 3.8).

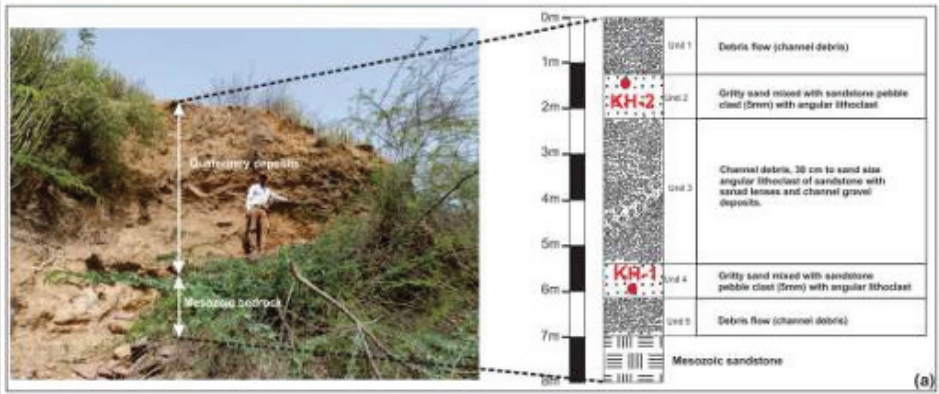


Fig. 3.7: Lithology of the strath terrace exposure and different sedimentological units.

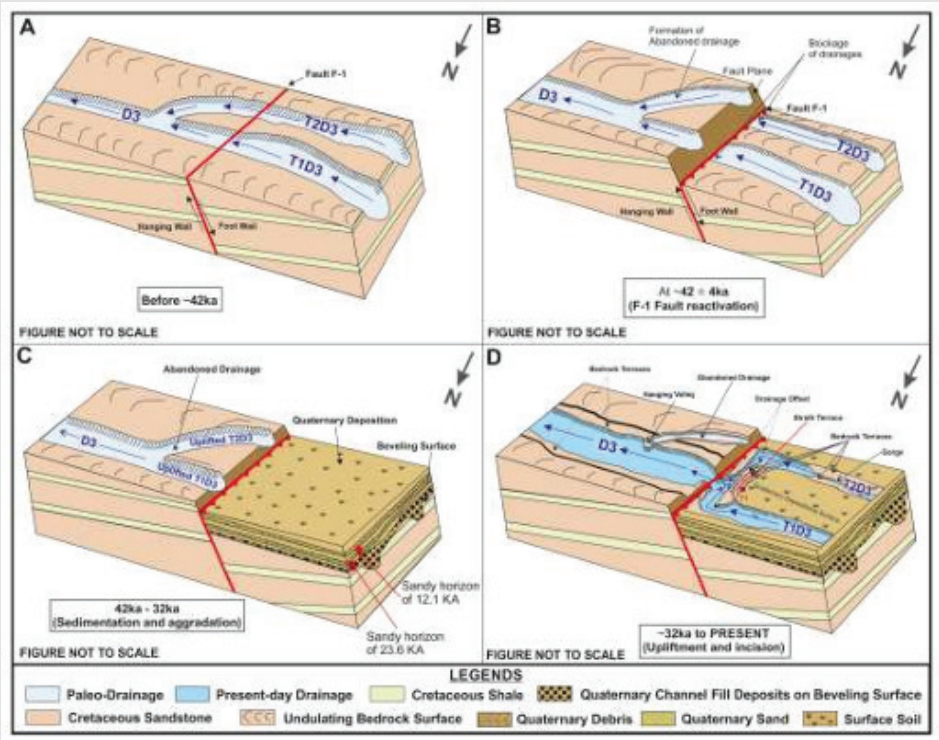


Fig. 3.8: A geomorphic model depicting the rejuvenation of the landform in the Late Quaternary period near the Ratiya Fault (F1) section. The model shows the development of the fluvial and strath terrace starting from (A) and ending at (D) based on the fieldwork, OSL dates and paleostress analysis in the particular region.

This locality provides one of the clearest field examples in Kachchh illustrating the interaction between active faulting, drainage reorganization, Quaternary sedimentation, and cyclic landscape evolution. It serves as an outstanding natural laboratory for understanding neotectonic processes, fluvial response to tectonic forcing, and the chronology of Late Quaternary landscape development in the Khari River basin.

Location 4: Hanging Quaternary Fossil Valley near Palara Village

Coordinates: 23°19'37.81"N, 69°41'8.75"E

Description: This stop exposes one of the best-preserved hanging Quaternary fossil valleys in the Khari River basin and provides exceptional evidence for the interaction between fluvial processes and neotectonic uplift. The abandoned paleochannel is perched approximately 9 m above the present Khari River, indicating a major phase of post-depositional incision driven by regional uplift and base-level lowering (Fig. 3.9).

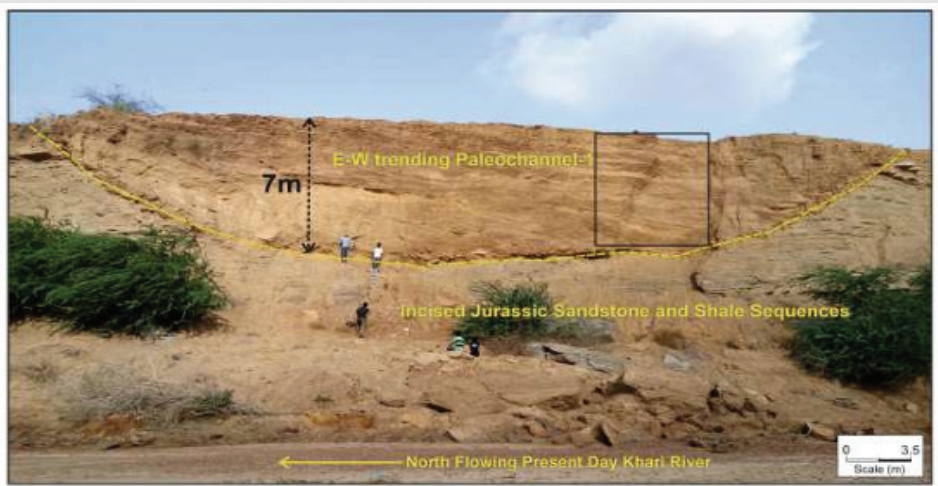


Fig. 3.9: Photograph showing paleochannel-1 incised by the Khari River. Jurassic sandstones and shales underlie the E-W trending Hanging paleochannel.

The paleochannel is incised into a beveled Jurassic (Jhuran Formation) sandstone and shale bedrock and is infilled by approximately 7 m of Quaternary alluvial sediments (Fig. 3.9). The broad, gently planed bedrock surface beneath the channel represents an ancient erosion surface produced by prolonged lateral erosion before the river became deeply entrenched. Subsequent tectonic uplift rejuvenated the drainage system, causing abandonment of the former channel and incision of the modern Khari River into both the alluvial fill and underlying bedrock. The exposed Quaternary succession records repeated changes in depositional environments under semi-arid climatic conditions. Six lithostratigraphic units are recognized. The basal unit consists of poorly sorted matrix-supported boulders, cobbles and coarse sand deposited by high-energy debris-flow or hyperconcentrated flow events (Fig. 3.10).

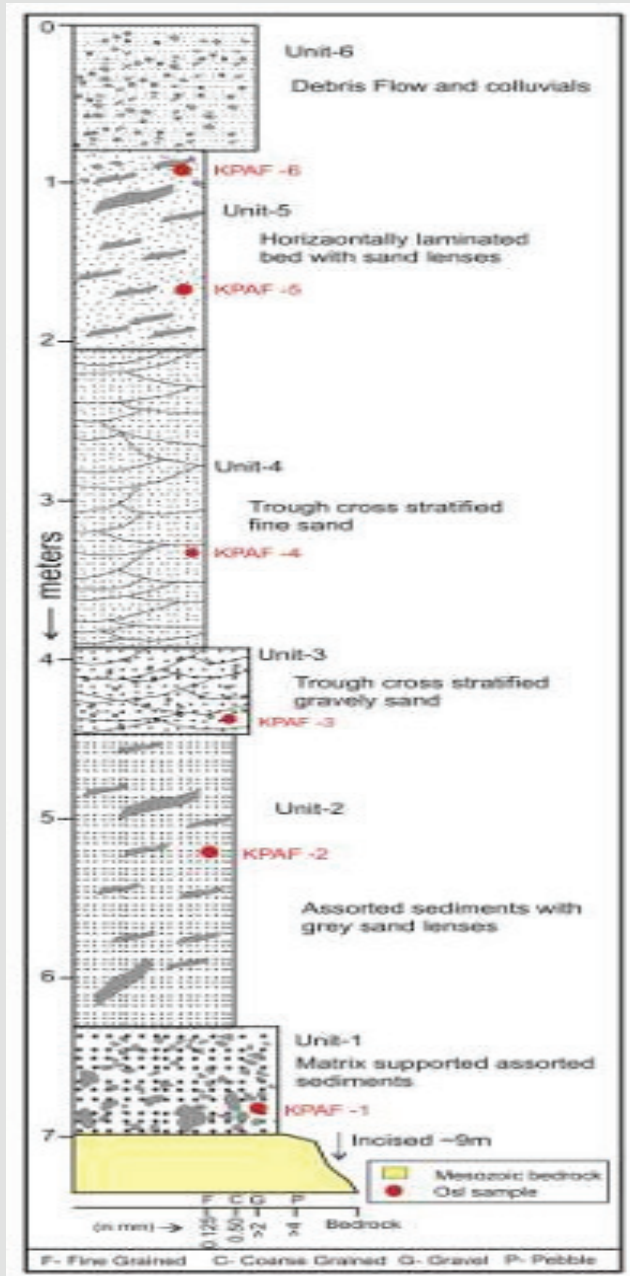


Fig. 3.10: Stratigraphy of the hanging paleochannel. The Mesozoic bedrock is overlain by six lithostratigraphic units.

This is overlain by sandy braided-river deposits composed of grey sand lenses, trough cross-stratified gravelly sand and fine sand, representing channel migration and repeated flash-flood episodes within an ephemeral fluvial system. The upper part of the sequence comprises horizontally laminated sand with floodplain deposits, capped by debrisflow and colluvial sediments derived from valley-side erosion following channel abandonment. Optically Stimulated Luminescence (OSL) dating of six samples from the paleochannel fill indicates deposition during the Late Pleistocene, providing a chronological framework for aggradation of the valley fill before incision (Fig. 3.10). After deposition ceased, renewed tectonic uplift and lowering of the regional base level caused the Khari River to abandon the paleochannel and incise nearly 9 m into the alluvial succession and Jurassic bedrock, leaving the former valley preserved as a hanging fossil channel.

This locality clearly demonstrates the evolution of a dryland river system from lateral planation and valley aggradation to rapid vertical incision associated with tectonic rejuvenation. The site also illustrates the combined influence of episodic flash floods, debris-flow sedimentation, climatic variability and active tectonics on Quaternary landscape development in the Kachchh Mainland. This stop provides one of the clearest field examples in Kachchh of how tectonic uplift, episodic flash floods and climatic variability together controlled Quaternary valley aggradation, channel abandonment and subsequent bedrock incision.

Location 5: Katrol Hill Neotectonic Scarp Morphology at Ashapura Hill

Coordinates: 23°10'50.78"N, 69°48'12.44"E

Description: The Khatrod Hill locality, situated southeast of the Kukma village along the Katrol Hill Range, provides one of the finest exposures of the mountain-front fault scarp developed along the Katrol Hill Fault (KHF). This site is an outstanding natural laboratory for examining the geomorphic expression of an active reverse fault and the long-term interaction between tectonic uplift, erosion and sedimentation in the Kachchh Mainland.

The Katrol Hill Range represents the uplifted southern block of the KHF and is composed predominantly of Upper Jurassic rocks of the Jhuran Formation, consisting of alternating sandstone and shale beds. Differential weathering of these lithologies has produced steep rock cliffs, ledges and benches that accentuate the fault-generated escarpment. The mountain front displays a remarkably preserved fault-scarp morphology, making it one of the best field examples in western India for studying active mountain-front tectonics.

From the mountain crest to the adjoining piedmont, nearly all classical geomorphic elements of a fault scarp can be recognized. These include the fault-scarp crest, steep free face (cliff), triangular facets, colluvial slope, wash slope, alluvial fan surface, and the gently sloping piedmont plain (Fig. 3.11). The triangular facets developed along the mountain front indicate repeated uplift and retreat of the fault scarp during successive tectonic episodes. Thick colluvial deposits accumulated at the base of the escarpment record repeated rockfall and debris-flow activity following fault movements, while younger alluvial fan deposits document subsequent fluvial reworking.

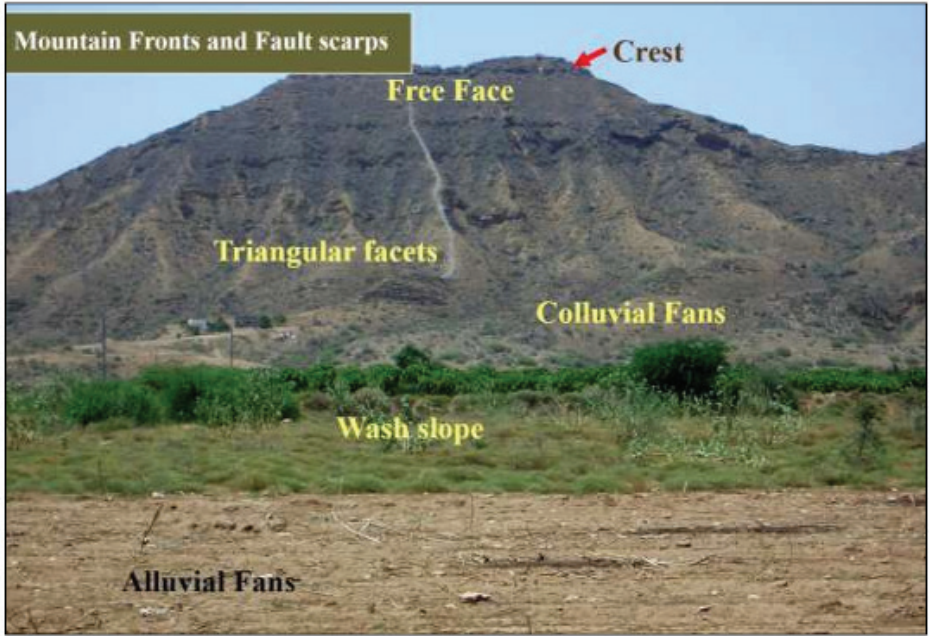


Fig. 3.11: Field photograph of the Katrol Hill Fault mountain-front escarpment showing the characteristic geomorphic elements of an active fault scarp, including the fault-scarp crest, free face, triangular facets, colluvial fan, wash slope and adjoining alluvial fan surface.

Several short ephemeral streams draining northwards across the escarpment exhibit structural control, displaying steep gradients, knickpoints, narrow bedrock gullies and locally incised channels. These streams provide excellent examples of drainage adjustment to continued uplift along the mountain front. Small rock shelters and weathering cavities developed within the calcareous sandstone beds further illustrate the combined effects of structural discontinuities, differential weathering and erosion acting on the uplifted scarp.

The locality also offers an excellent view of the Khatrod Structural Dome, an anticlinal uplift developed along the Katrol Hill Fault. Erosion has exposed older Jurassic strata in the core of the dome, providing a clear demonstration of structural inversion associated with compressional deformation. The dome illustrates the intimate relationship between folding and faulting that characterizes deformation along the KHF. The surrounding piedmont preserves Quaternary deposits recording alternating aeolian and fluvial depositional phases, reflecting repeated climatic fluctuations under semi-arid conditions. These sediments, together with the preserved fault-scarp morphology, demonstrate the combined influence of tectonic uplift and climatic processes on landscape evolution.

The Khatrod sector of the Katrol Hill Fault continues to be regarded as tectonically active. Historical seismicity in the vicinity, including moderate earthquakes during the

mid-twentieth century, together with recurrent low-magnitude earthquakes, indicates that the KHF remains an active structure capable of generating surface deformation. Although no historical surface rupture has been documented at this locality, the exceptionally preserved geomorphic features provide compelling evidence for repeated Quaternary fault activity. From the summit, where the Ashapura Temple is located, panoramic views of the Katrol Hill Range, the mountain-front escarpment, adjoining alluvial plains and structurally controlled drainage network provide an excellent opportunity to appreciate the regional geomorphic expression of the Katrol Hill Fault and its role in shaping the present-day landscape of central Kachchh (Fig. 3.11).

Location 6: Raised Beach and Tilted Beach rocks at Mandvi

Coordinates: 22°49'4.80"N, 69°22'22.25"E

Description: Mandvi, the second largest town in Kachchh district, is situated along the southern coast of the peninsula and preserves one of the finest Quaternary coastal geomorphic successions in western India. The coastline comprises a broad sandy foreshore and backshore, backed by a 2–3 m high raised beach, followed landward by a series of stabilized coastal dunes (foredunes), tidal mudflats, saline sand flats and the coastal alluvial plain (Fig. 3.12). Active longshore drift transports sand eastward along the coast, contributing to spit development between Mandvi and Mundra.

The raised beach is interpreted as the remnant of a former shoreline that now lies above the present high-tide level. The overlying stabilized coastal dunes are considered to represent mid- to late-Holocene palaeo-beach and dune deposits, formed following shoreline progradation and subsequent stabilization. Their elevation above the modern beach indicates emergence of the coastline during the Holocene.

One of the most significant features at this locality is the occurrence of tilted beach-rock exposures, where lithified beach sediments dip by more than 30° towards the southwest (Fig. 3.13). Such steeply inclined beach rocks, together with the elevated raised beach, provide compelling evidence that the coastline has undergone postdepositional tectonic uplift rather than solely recording eustatic sea-level fluctuations. The uplift is considered to be related to neotectonic deformation associated with the Median High, which has influenced the evolution of the southern Kachchh coast during the Late Quaternary.



Fig. 3.12: Field photograph of the Mandvi coast showing the Holocene raised beach (left), preserved as an elevated paleo-shoreline above the present hightide level, and the Arabian Sea (right). The raised beach records late Quaternary coastal uplift and former shoreline positions associated with neotectonic activity along the Kachchh coast.



Fig. 3.13: Field photograph of Late Holocene tilted beach rock exposed along the Mandvi coast, dipping southwestward (SW), providing evidence of coastal neotectonic uplift and relative sea-level change.

This locality therefore preserves an exceptional record of the interaction between Holocene relative sea-level changes, coastal sedimentation and active tectonic deformation. The raised beach, stabilized coastal dunes and tilted beach rocks collectively demonstrate that the present coastline is the product of repeated shoreline migration, coastal progradation and tectonic uplift (Fig. 3.12). Consequently, Mandvi is one of the most important coastal localities in Kachchh for reconstructing Holocene sea-level history and evaluating the role of active tectonics in shaping the western Indian coastline. This stop provides an excellent opportunity to examine the combined effects of Holocene sealevel fluctuations, coastal sedimentary processes and neotectonic uplift, making it one of the key coastal Quaternary sites in Kachchh.

Location 7: Layja Coastal Dunes

Coordinates: 22°50'16.02"N, 69°13'50.37"E

Description: The Layja Coastal Dunes (Layja Nana) are situated near the mouth of the Kharod River along the southern coast of Kachchh, where the river debouches into the Gulf of Kachchh (Fig. 3.14). The Kharod River originates in the Katrol Hill Range and drains a diverse geological terrain comprising Jurassic sedimentary rocks, Deccan Trap basalts, Paleogene sediments and Quaternary alluvium before entering the coast through a broad estuarine plain. The locality preserves one of the most complete Holocene coastal successions in the Gulf of Kachchh and provides an excellent record of the interaction between fluvial, tidal, marine and aeolian processes during the evolution of the Kharod estuary (Fig. 3.15). The geomorphology of the area is characterized by a modern sandy beach bordered landward by stabilized coastal dunes, an elevated estuarine tidal terrace and an extensive alluvial plain (Fig. 3.14). The exposed section lies approximately 650 m inland from the present shoreline and overlooks the modern tidal flat, which has a surveyed elevation of about 0.96 m above mean sea level (Fig. 3.16C). The elevated estuarine terrace and adjoining stabilized dunes together preserve the history of shoreline migration and coastal landscape evolution throughout the Holocene.

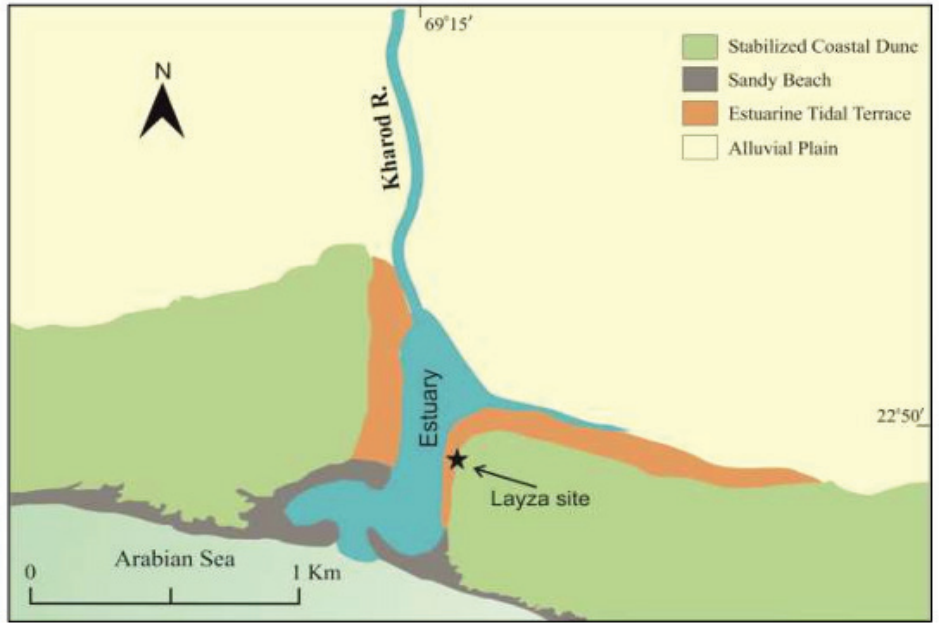


Fig. 3.14: Geomorphological map showing stabilized coastal dune, sandy beach with estuarine tidal terraces and alluvium deposits in the mouth of the Kharod River at the Layja Coastal Dunes site.

The exposed succession is divided into five lithostratigraphic units (U-I to U-V) based on lithology, sedimentary characteristics and biological features (Fig. 3.16C). The basal Unit I consists of poorly sorted gravely sand containing abundant rolled calcrete clasts, indicating deposition under high-energy fluvial or estuarine channel conditions. This is overlain by Unit II, which comprises pebbly sand with translocated clay clasts and calcrete fragments deposited in an energetic tidal-channel or estuarine environment during the early stages of post-glacial marine transgression. OSL ages obtained from this interval are 9.9 ± 0.7 ka (Unit-2) and 9.3 ± 0.4 ka (LTL-1), indicating sediment accumulation during the early Holocene as rising sea level progressively inundated the lower Kharod valley.



Fig. 3.15: Field photographs of the Layja Sand Dune section.

Upward in the section, Unit III consists of clayey sand and fine-to medium-grained sandy sediments showing abundant marine bioturbation. The unit contains a diverse assemblage of trace fossils, including *Ophiomorpha nodosa*, *Skolithos* isp., *Planolites*, *Polykladichnus* isp. and mud-lined burrows, all of which indicate deposition within a shallow estuarine to intertidal environment influenced by regular tidal inundation (Fig. 3.16A). Organic geochemical analyses of this interval, including organic carbon, total nitrogen and C/N ratios, further indicate a predominance of marine-derived organic matter (Fig. 3.16D). An OSL age of 7.3 ± 0.4 ka (Unit-3A) places this phase of deposition within the middle Holocene, when the estuary experienced strong marine influence during continued sea-level rise.

The overlying Unit IV is composed of compact, coarse biogenic sand containing abundant shell fragments and other marine skeletal debris, representing deposition on a high-energy tidal flat or nearshore environment. This unit yielded an OSL age of 4.7 ± 0.2 ka (LTL-2), indicating that marine conditions persisted until the middle to late Holocene. Unit V, forming the uppermost part of the succession, consists of friable, well-sorted biogenic sand deposited by aeolian processes. These sands represent stabilized coastal dunes that accumulated after shoreline progradation exposed wide sandy beaches suitable for wind transport. OSL ages of 4.3 ± 0.2 ka (LTL-4) from the lower dune deposits and 0.4 ± 0.03 ka (LTL-5) from the uppermost dune indicate prolonged phases of dune accumulation, reworking and stabilization extending from the Late Holocene to the recent past.

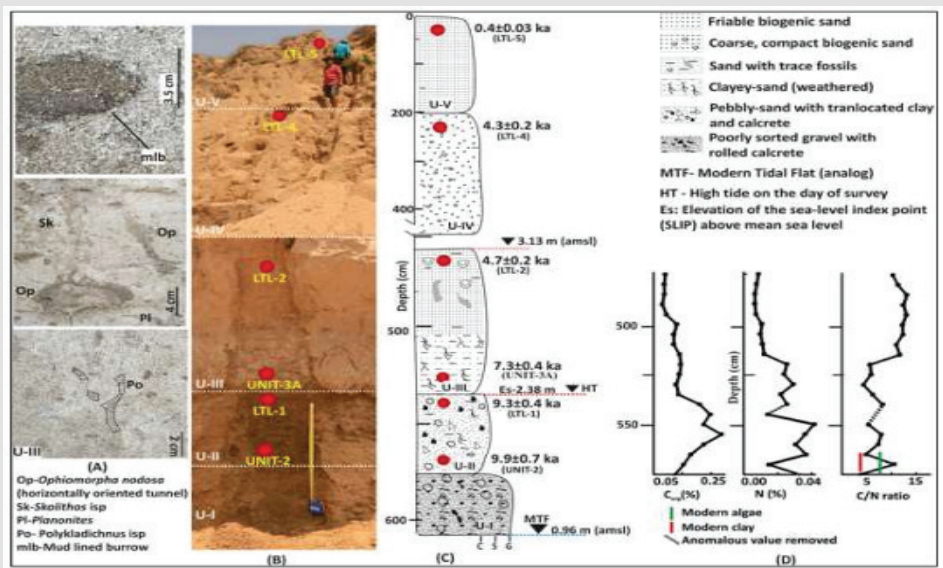


Fig. 3.16: A) Close-ups of trace fossils and mud-lined burrow (mlb), which are filled with passive sediments from the upper bioturbated section of unit-III. (B) Close-up of Kharod Estuary section with optically stimulated luminescence (OSL) sample locations (red circles). (C) The stratigraphic details along with the OSL ages. The average differential global positioning system (DGPS) elevation of the modern lower intertidal flat ($n = 30$) corresponds to Mean LowWater Spring (MLWS) and Mean LowWater Neap (MLWN) range. The high tide (HT) is the level of high tide marked on the day of survey (April). (D) Corg, Ntotal, and C/N ratio obtained on unit-II and -III indicate dominance of marine organic matter (Sharma et al., 2020).

The chronological framework established by OSL dating records the progressive evolution of the Kharod estuary during the Holocene. Initial estuarine sedimentation began shortly after 10 ka, corresponding to the early stages of post-glacial sea-level rise. Continued transgression produced extensive intertidal and tidal-flat environments between approximately 9.3 and 7.3 ka, when marine influence became dominant, as reflected by abundant trace fossils and marine organic matter. By about 4.7 ka, coarse biogenic sands accumulated on the tidal flat under energetic marine conditions. Subsequently, relative shoreline progradation and gradual emergence of the coastal plain promoted aeolian transport of beach sand, leading to the formation of stabilized coastal dunes from approximately 4.3 ka onward, with intermittent phases of dune activity continuing until at least 0.4 ka.

The Layja Coastal Dunes provide an outstanding natural archive of Holocene coastal evolution along the southern margin of the Gulf of Kachchh. The excellent exposure, well-defined lithostratigraphy, abundant marine ichnofossils and multiple OSL ages collectively document the transition from high-energy estuarine sedimentation to tidal-flat deposition and finally to coastal dune development. During the field visit, participants should examine the geomorphic relationship between the modern beach, stabilized dunes and elevated estuarine terrace, observe the vertical changes in lithology and sedimentary structures, identify the marine trace fossils preserved within Unit III, and relate the dated stratigraphic horizons to the environmental changes associated with Holocene sea-level fluctuations. The site serves as an important reference locality for understanding the interplay between sea-level change, estuarine dynamics, coastal sedimentation and aeolian processes along the western Indian coastline.

Location 8: Pingleshwar Paleotsunami and Paleostorm site

Coordinates: 23° 3'58.65"N, 68°48'2.20"E

Description: Pingleshwar, situated along the exposed western coast of Kachchh on the Arabian Sea margin, is one of the most important coastal localities in western India for investigating the geological record of extreme marine inundation events (Fig. 3.17). The site is renowned for preserving evidence of both palaeotsunami and palaeostorm deposits, making it an important natural laboratory for understanding the sedimentological signatures of high-energy coastal processes. In addition to its significance for coastal hazard studies, the modern beach at Pingleshwar contains abundant and diverse molluscan shell assemblages, providing an excellent opportunity to study recent marine invertebrates, shell taphonomy and the processes responsible for shell accumulation along wave-dominated coastlines. The locality therefore combines sedimentology, geomorphology, Quaternary geology and invertebrate palaeontology within a single accessible coastal section.



Fig. 3.17: Photograph of Pingleswar Beach.

The geomorphic setting comprises a sandy beach backed by coastal dunes, locally developed washover surfaces, tidal flats and low-lying coastal plains that are highly sensitive to marine inundation. Throughout the Holocene, these environments have repeatedly been modified by sealevel fluctuations, storm surges and extreme wave events, allowing preservation of event beds within the coastal stratigraphic record. The Arabian Sea coast of Kachchh is frequently affected by tropical cyclones and associated storm surges, while it also remains vulnerable to tsunamis generated within the Makran Subduction Zone of the northern Arabian Sea and other offshore tectonic sources. Consequently, the Pingleswar coast preserves valuable evidence for reconstructing the long-term history of coastal hazards beyond the period covered by instrumental observations (Fig. 3.18).





Fig. 3.18: Photograph showing the Dune Sediments at Pingleswar Beach.

The identification of palaeotsunami deposits requires careful sedimentological and stratigraphic investigation because tsunami deposits can closely resemble sediments emplaced by severe cyclones or storm surges. Rather than relying on a single sand layer, interpretation must integrate several independent lines of evidence. A palaeotsunami deposit is typically preserved as a laterally continuous sand or shell-rich sheet resting sharply upon soils, mudflat sediments, lagoonal deposits or older dune sands. Such deposits commonly display erosional basal contacts, rip-up clasts, multiple normally graded sand units, mud drapes deposited during waning flow, transported marine shells, and evidence for both landward and seaward sediment transport produced during successive inundation and return-flow phases. In many cases, marine microfossils, including foraminifera, ostracods and diatoms derived from offshore environments, are found well inland beyond their normal ecological range, providing further support for tsunami inundation.

Storm deposits, in contrast, generally form as washover fans, overwash sheets or channelized sand bodies that develop immediately landward of beaches and dune breaches during cyclone-induced storm surges. These deposits commonly contain abundant shell debris, heavy mineral concentrations, landward-dipping stratification, cross-lamination and inverse-to-normal grading resulting from repeated wave overwash. Because successive storms frequently rework earlier deposits, storm beds may be amalgamated and display complex internal sedimentary structures reflecting multiple overwash events. Although both tsunamis and storms generate high-energy marine inundation deposits, tsunami deposits generally extend farther inland, exhibit greater lateral continuity and preserve evidence of multiple flow pulses, whereas storm deposits are usually more localized and strongly controlled by coastal topography, dune gaps and overwash pathways.

During field examination, particular attention should be paid to the basal contacts of event beds, where erosional scour, rip-up clasts and incorporated soil fragments may be preserved. Internal sedimentary structures, including parallel lamination, cross-lamination, graded bedding, massive sand intervals and mud caps, should be examined carefully, together with shell orientation, fragmentation, abrasion and species composition. Modern beach shell assemblages provide valuable reference material for comparison with transported shell concentrations preserved within event deposits. Similarly, microfossil assemblages recovered from event beds should be compared with modern beach, tidalflat, lagoonal and offshore environments to determine sediment provenance and transport pathways. Systematic measurements of bed thickness, grain size, elevation and inland extent along shore-normal transects are essential for reconstructing the magnitude and style of coastal inundation. Mapping of event beds parallel to the shoreline further helps distinguish between broad tsunami sheets and localized storm washover deposits.

Establishing the age of coastal event deposits is equally important for regional correlation and hazard assessment. Optically Stimulated Luminescence (OSL) dating of quartz-rich sands, together with radiocarbon dating of organic material immediately above and below event beds, provides the most reliable chronological framework. Radiocarbon ages obtained from marine shells require appropriate marine reservoir corrections, while OSL ages should be interpreted cautiously because rapid transport during extreme events may result in incomplete bleaching of quartz grains before burial. Multiple age determinations from different stratigraphic levels and locations are therefore preferred over reliance on a single date.

The western Kachchh coast has experienced repeated earthquakes, cyclones, storm surges and coastal flooding throughout the Holocene, and these processes have operated against a background of changing sea level, shoreline migration, tidal-flat development and coastal dune construction. Consequently, any proposed correlation between a preserved event bed and a specific historical cyclone or Makran tsunami must be supported by compatible age constraints, sedimentological characteristics, geomorphic setting and regional stratigraphic evidence. The Pingleswar locality therefore demonstrates the importance of integrating geomorphology, stratigraphy, sedimentology, palaeontology, microfossil analysis, elevation surveys and geochronology when reconstructing prehistoric coastal hazards.

Beyond its significance for extreme-event sedimentology, Pingleswar is also one of the finest localities along the Kachchh coast for observing modern molluscan diversity. The beach preserves abundant gastropod and bivalve shells representing a wide range of ecological habitats from the intertidal and shallow subtidal zones. Variations in shell preservation, fragmentation, abrasion and sorting provide excellent examples of modern taphonomic processes and offer valuable analogues for interpreting fossil shell assemblages preserved within ancient coastal deposits. The locality thus serves both as an outstanding field laboratory for understanding Late Quaternary coastal evolution and as an important teaching site for sedimentology, coastal geomorphology, marine invertebrate palaeontology and natural hazard assessment.



Location 9: Jakhau Mangrove Field

Coordinates: 23°13'23.61"N, 68°37'34.44"E

Description: The Jakhau Mangrove Field is situated along the western coast of Kachchh, where an extensive network of tidal creeks, intertidal mudflats, sandy coastal deposits and mangrove forests forms one of the most dynamic coastal environments of northwestern India (Fig. 3.19). The coast experiences a macrotidal regime with semidiurnal tides, seasonal monsoonal runoff, saline marine water, wind-driven storm surges and continuous sediment transport by tidal and longshore currents. The interaction of these processes has created a broad intertidal landscape that is exceptionally well suited for investigating modern coastal sedimentation, geomorphological evolution and the response of coastal ecosystems to environmental change. Consequently, the Jakhau mangroves represent an outstanding modern analogue for interpreting ancient intertidal deposits preserved within the Quaternary succession of the Kachchh Basin.

Mangroves occupy low-gradient intertidal surfaces that are regularly inundated during high tide but remain sufficiently stable for vegetation to establish. Their distribution is controlled by subtle variations in elevation within the tidal frame, inundation frequency, salinity, sediment texture, proximity to tidal channels and local hydrodynamic conditions. Mangroves are highly specialized salt-tolerant woody plants adapted to waterlogged, oxygen-deficient substrates through the development of aerial roots (pneumatophores), salt-excluding or salt-excreting mechanisms, thick succulent leaves and buoyant propagules capable of dispersal by tidal currents. Although *Avicennia marina* is the dominant mangrove species throughout much of the Kachchh coast, the species composition at Jakhau should be documented during field observations rather than assumed. The distribution, density and health of mangrove communities provide valuable indicators of tidal inundation, sediment stability and environmental conditions within the intertidal zone.



Fig. 3.19: Photograph of Jakhau Mangrove Field.

The tidal creek network plays a fundamental role in controlling sedimentation within the mangrove ecosystem. Flood tides transport suspended sediment, nutrients and mangrove propagules into the intertidal platform, while ebb tides return water through an intricate network of tidal channels. Fine-grained silt and clay settle during periods of slack water within sheltered mangrove stands, whereas relatively coarser sand is deposited along active creek margins, channel mouths and wave-exposed coastal sectors. This results in a characteristic transition from sandy channel deposits to mud-dominated intertidal sediments. Mangrove roots and pneumatophores significantly reduce near-bed flow velocity, trap suspended sediment and promote the accumulation of organic matter, thereby enhancing vertical sediment accretion and stabilizing the substrate. These biologically mediated sedimentary processes gradually build the mangrove platform and enable the ecosystem to maintain its position within the intertidal zone under conditions of moderate relative sea-level rise.

From the perspective of Quaternary geology, the Jakhau mangrove ecosystem provides one of the best modern analogues for understanding ancient estuarine and tidal-flat deposits. Mangrove sediments preserve a variety of sedimentary structures, including tidal laminations, flaser and lenticular bedding, mud drapes, root traces, burrows, crab pellets, shell fragments, desiccation cracks and salt crusts, although intense bioturbation commonly modifies or obliterates primary sedimentary structures. Buried rooted horizons, organic-rich muds and peat layers preserved beneath the modern mangrove surface, together with changes in pollen, diatom, foraminiferal and ostracod assemblages, constitute valuable archives for reconstructing Holocene environmental evolution. When integrated with radiocarbon dating and sediment-core analyses, these deposits provide robust evidence for changes in relative sea level, tidal environments, salinity, sediment supply and shoreline migration through time.

The Jakhau mangrove field is particularly significant for studies of Holocene sea-level change because mangrove communities occupy a narrow vertical range within the intertidal zone and therefore serve as sensitive indicators of former sea levels. Buried mangrove deposits, fossil root horizons and organic-rich tidal sediments can be accurately dated and correlated with present-day tidal elevations to reconstruct the timing and magnitude of relative sea-level fluctuations. These records, when combined with sedimentological and geomorphological observations, contribute to understanding the Holocene marine transgression, subsequent coastal progradation and the influence of tectonic activity on the Kachchh coastline. Likewise, variations in sediment characteristics, pollen assemblages, organic carbon and microfossil communities provide valuable information on Holocene climatic variability, particularly changes in monsoonal rainfall, freshwater inflow and coastal salinity, making the locality an important archive for palaeoclimate reconstruction.

The mangrove ecosystem also plays a critical role in coastal hazard mitigation and shoreline stability. Dense mangrove vegetation attenuates wave energy, reduces current velocity and promotes sediment accumulation, thereby limiting shoreline erosion and reducing the impacts of storm surges and coastal flooding. However, the protective function of mangroves is not absolute and depends on the health, width and continuity of the mangrove belt, as well as sediment availability and local geomorphology. Extreme cyclones, storm surges, channel migration, sediment starvation and coastal erosion can damage or remove



mangrove margins, emphasizing the importance of preserving these ecosystems in the face of ongoing climate change and accelerating sea-level rise.

Ecologically, the Jakhau mangroves support one of the most productive coastal habitats along the Kachchh coast. They provide nursery grounds for fishes, crustaceans and molluscs, support numerous resident and migratory bird species, enhance nutrient cycling and act as major reservoirs of blue carbon through long-term sequestration of organic carbon within waterlogged sediments. The preservation of organic-rich mangrove deposits within the sedimentary record therefore has significance not only for palaeoenvironmental reconstruction but also for understanding long-term carbon cycling and the role of coastal wetlands in regulating the global climate system. During the field visit, participants should examine the relationship between tidal creeks, intertidal mudflats and mangrove vegetation, observe changes in sediment texture from channel margins to the mangrove platform, identify sedimentary structures produced by tidal processes and bioturbation, and document variations in vegetation across the intertidal elevation gradient. Attention should also be paid to root systems, pneumatophore density, sediment trapping around vegetation and evidence of erosion or recent sediment accumulation. These observations provide direct insight into the interactions among tidal hydrodynamics, sedimentation, vegetation and geomorphological evolution within a modern intertidal environment.

The Jakhau Mangrove Field represents one of the finest modern process analogues for interpreting Quaternary intertidal successions preserved along the Kachchh coast. By linking active sedimentary processes with the geological record, the locality demonstrates how vegetation, tides, sediment supply and sea-level change interact to shape coastal landscapes over geological time. As such, it is an exceptional field laboratory for studies of Quaternary geology, coastal geomorphology, palaeoenvironmental reconstruction, sea-level change, climate variability, blue-carbon sequestration, ecosystem dynamics and coastal hazard assessment.

Location 10: Narayan Sarovar Active Mud Flats

Coordinates: 23°40'21.88"N, 68°31'33.86"E

Description: The Narayan Sarovar Active Mud Flats are situated near the eastern margin of the Kori Creek along the northwestern coast of Kachchh (Fig. 3.20). The area is characterized by an extensive complex of active tidal mudflats, meandering tidal creeks, saline sand flats, stabilized coastal dunes, scattered mangroves and rocky Tertiary limestone outcrops, making it one of the best localities along the Kachchh coast for studying modern coastal processes and their significance in Quaternary geology. The coexistence of active depositional environments with relict coastal landforms provides an excellent opportunity to understand the evolution of tide-dominated coastlines in response to sea-level fluctuations, sediment supply and tectonic controls.

The regional geology comprises Miocene limestone that locally forms an anticline near Narayan Sarovar, creating a structurally controlled coastal landscape of rocky cliffs, wave-cut platforms and shallow bedrock surfaces. Extensive stabilized dune fields occur inland, resting on both limestone bedrock and older mudflat deposits, while modern tidal creeks dissect parts of these dunes. These geomorphic relationships indicate that the

dunes developed after phases of marine transgression and coastal planation, followed by shoreline stabilization and aeolian sand accumulation.



Fig. 3.20: Photograph Showing Narayan Sarovar Mud-flats and stabilized Dune Section.

The active mudflats are dominated by fine silt and clay deposited during tidal inundation under low-energy conditions. Repeated flooding and exposure produce characteristic sedimentary features such as tidal lamination, mud drapes, ripple marks, desiccation cracks, salt crusts and bioturbation. Coarser sandy sediments occur mainly along tidal channels and creek margins, whereas mangrove patches locally trap suspended sediment and promote vertical accretion of the intertidal surface. The sharp to gradual contacts between mudflat deposits and overlying dune sands record alternating phases of tidal sedimentation and aeolian activity associated with Holocene shoreline migration.

From a Quaternary perspective, the Narayan Sarovar mudflatdune complex provides an excellent modern analogue for interpreting ancient tidal-flat deposits and reconstructing Holocene sea-level changes along the Kachchh coast. The relationship between active mudflats, stabilized dunes, raised intertidal deposits and bedrock offers valuable evidence for past coastal evolution, shoreline migration and environmental change. The locality is also important for understanding sediment transport, coastal geomorphology and the response of arid macrotidal coastlines to climatic and sea-level variations.

During the field visit, participants should examine the geomorphic relationship between tidal creeks, active mudflats, saline sand flats, stabilized dunes and limestone bedrock, observe the transition from finegrained tidal sediments to aeolian dune sands, and identify sedimentary structures produced by tidal processes, desiccation and bioturbation. The site provides an outstanding natural laboratory for studying modern coastal sedimentation and its application to interpreting Quaternary coastal successions and palaeoenvironmental evolution along the Kachchh coast.

Location 11: Pinjorpir Sand Dunes of Meghalayan Age

Coordinates: 23°42'46.62"N, 68°33'15.19"E

Description: The Pinjor Pir coastal dune field, located along the margin of Kori Creek in western Kachchh, preserves one of the most significant Late Holocene aeolian successions on the western Indian coast (Fig. 3.21). The dunes represent an important record of coastal evolution during the Meghalayan Stage of the Holocene (beginning at approximately 4.2 ka), a period marked globally by increased aridity and weakening of the Indian Summer Monsoon. The locality provides an excellent opportunity to examine the interaction between climate change, sea-level fluctuations, coastal sediment supply, tectonic uplift and aeolian processes that controlled dune formation along the Kachchh coast.

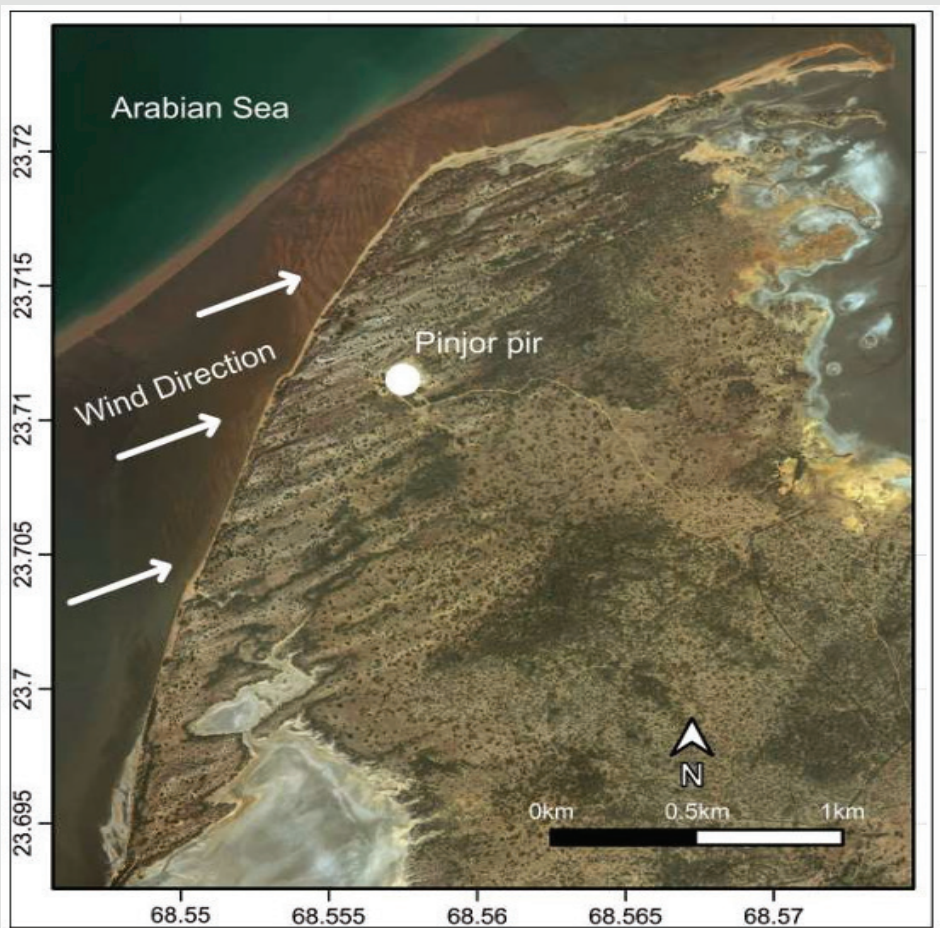


Fig. 3.21: Satellite Imagery of the Pinjor Pir dune-field showing transverse dunes aligned parallel to the wind direction.

The exposed dune succession is approximately 10 m thick and rests unconformably on Tertiary oyster-bearing limestone (Fig. 3.21). The basal part of the succession comprises poorly sorted gravelly sand overlain by well-sorted fine sand and micaceous coarse sand containing broken shell fragments, indicating the reworking of beach sediments by strong winds. The overlying units consist predominantly of massive, well-sorted aeolian sand with locally developed cross-stratification, sparse rhizoliths and root concretions, reflecting alternating phases of dune migration and stabilization. The uppermost loose sands have been modified by recent erosion and human activity, while the seaward face of the dune is actively being eroded by high tides and wave action, producing steep coastal exposures.



Fig. 3.22: Panoramic view of the Pinjor Pir coastal dune section.

Optically Stimulated Luminescence (OSL) dating indicates that the principal phase of dune construction occurred at approximately 4.4 ka, closely corresponding to the globally recognized 4.2 ka climatic event. This interval was characterized by weakening of the Indian Summer Monsoon, increased aridity and reduced fluvial discharge, resulting in enhanced aeolian activity across western India. Lower relative sea level during this period exposed broad sandy beaches and berms, providing abundant sediment for wind transport and foredune development. Subsequent sea-level rise eroded much of the former beach ridge system, bringing the present shoreline into direct contact with the older dunes, where active marine erosion continues today.

The Pinjor Pir dune field also provides important evidence for the combined influence of climate, tectonics and sea-level change on coastal landscape evolution. The Kachchh coast has experienced slow tectonic uplift throughout the Holocene, while repeated fluctuations in relative sea level have controlled shoreline position and sediment availability. The development of extensive coastal dunes during the Meghalayan reflects the coincidence of lowered sea level, increased sediment supply and strengthened aeolian processes under a drier climatic regime. These environmental changes broadly coincide with regional evidence for monsoon weakening and the widespread aridification that affected northwestern India during the Late Holocene.

During the field visit, participants should examine the contact between the Tertiary oyster bed and overlying dune sand, observe variations in grain size, cross-stratification, rhizoliths and shell-bearing horizons, and identify evidence of active coastal erosion along the modern dune face. The orientation of the dunes, their relationship with the present coastline and the ongoing marine erosion provide valuable insights into the evolution of the Kachchh coast under changing climatic and sea-level conditions.

The Pinjor Pir coastal dunes constitute one of the best-preserved Meghalayan aeolian archives in western India. They provide a valuable record of Late Holocene environmental change and serve as an excellent natural laboratory for understanding the links between monsoon variability, the 4.2 ka climatic event, coastal geomorphology, sea-level fluctuations, tectonic activity and aeolian sedimentation along the Kachchh coastline.

Location 12: Nani Chher Geo-Archaeological Site- Iron Age Culture

Coordinates: 23°47'43.86"N, 68°40'43.66"E

Description: The Nani Chher geo-archaeological site is located along the eastern margin of the Nani Chher estuary in western Kachchh, within a landscape characterized by sandy bays, relict tidal flats, tidal creeks and archaeological mounds. The locality represents an important interface between Quaternary geology and archaeology, preserving evidence of Late Holocene coastal evolution together with early human occupation. It provides an excellent opportunity to understand how changes in shoreline position, estuarine sedimentation and coastal geomorphology influenced settlement patterns during the Iron Age.

The exposed archaeological mound consists of three major stratigraphic units resting upon estuarine alluvium (Fig. 3.23). The basal Unit I, about 3 m thick, comprises pebbly coarse sand containing occasional charcoal fragments and potsherds, indicating deposition within a fluvial-estuarine environment prior to the main phase of human occupation. This unit extends beneath the adjacent modern tidal flat, whose present elevation is approximately 1.9 m above mean sea level. It is overlain by Unit II, nearly 4 m thick, which contains abundant archaeological material including iron slag, ash layers, pottery fragments, bones, marine shells and bangles. Lenticular sand bodies and clayey silt horizons within this unit indicate intermittent channel activity during occupation of the site. The uppermost Unit III consists of rubified aeolian sand that blankets the archaeological mound, recording a subsequent phase of dune activity and landscape stabilization during the Late Holocene.

Chronological evidence indicates that the site belongs to the early Iron Age rather than the Mature Harappan period. An archaeological conch shell recovered from the mound yielded a calibrated radiocarbon age of approximately 3210 ± 155 cal yr BP, while the enclosing sediment has been dated by Optically Stimulated Luminescence (OSL) to about 2.9 ± 0.2 ka, placing the occupation within the Late Holocene.



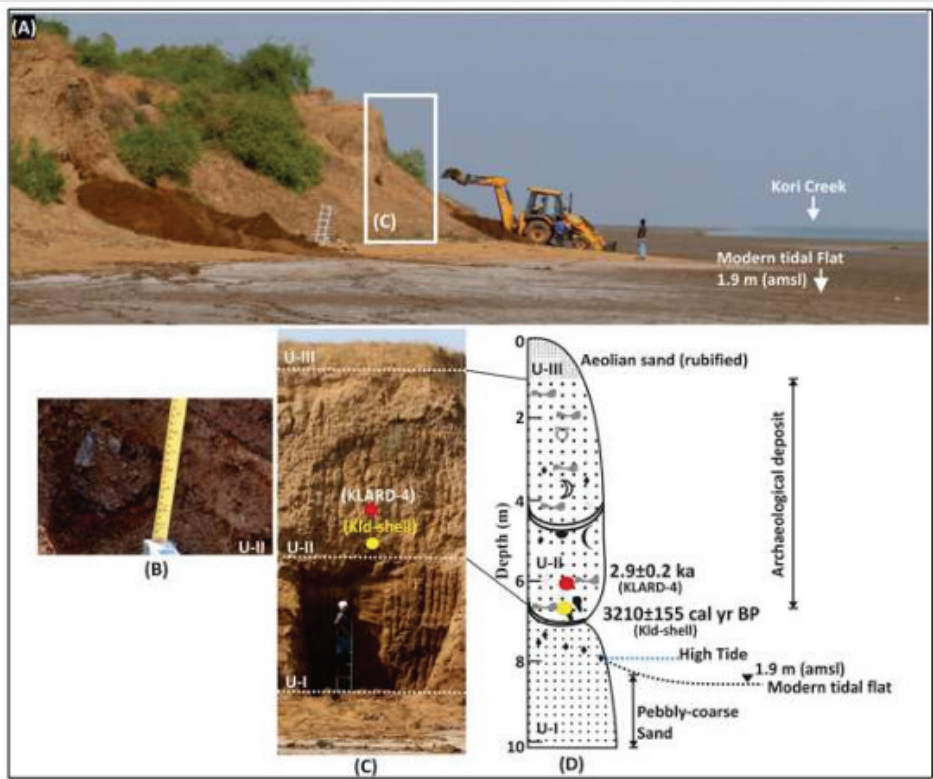


Fig. 3.23: (A) Field photograph showing the panoramic view of Nani Cher Estuary, location of the section excavated is shown by a white rectangle. (B) Close-up of unit-II showing iron slag in archaeological deposit. (C) Field photograph and (D) stratigraphic details of the section. Note that unit-I continues below the modern intertidal flat. The radiocarbon age (yellow circle) of 3210 ± 155 cal yr BP (Kid-shell) is obtained on *Turbinella pyrum* (conch shell) collected 860 cm above the high tide (HT) (May 2017), and the sediment sample (red circle) is dated to 2.9 ± 0.2 ka. (Sharma et al., 2020).

These ages suggest that human settlement developed after the establishment of the estuarine environment and during a period of relative coastal stability. The site also illustrates an important principle in geo-archaeological interpretation. Marine shells recovered from archaeological contexts should not be regarded as direct indicators of former sea level because they may have been collected, transported or traded by humans. Reliable reconstruction of palaeo-sea levels requires evidence from natural sedimentary contexts, geomorphic position and independently dated coastal deposits. Consequently, archaeological materials and geological indicators must be evaluated separately before interpreting coastal evolution.

During the field visit, participants should examine the relationship between the archaeological mound, underlying estuarine deposits and the adjacent tidal flat, observe the stratigraphic distribution of cultural materials and sedimentary units, and discuss how geomorphology, sedimentology, archaeology and geochronology together contribute to reconstructing the Late Holocene history of the Kachchh coast. The Nani Chher site is an outstanding example of how geo-archaeological investigations can link environmental change with human occupation and adaptation, making it an important reference locality for studies of Quaternary geology, coastal evolution and Iron Age archaeology in western India.

Location 13: Lakhpat Geo-Historical-Cultural Site

Coordinates: 23°49'48.79"N, 68°46'31.32"E

Description: The historic town of Lakhpat, situated on the western margin of Kachchh overlooking the Kori Creek, is one of the most remarkable localities in India where Quaternary geological processes, active tectonics, climate change and human history converge within a single landscape. Once a prosperous port town located along the distributaries of the Indus River, Lakhpat today stands isolated in an arid environment bordering extensive tidal mudflats and saline plains (Fig. 3.24). The locality provides an outstanding natural laboratory for understanding how earthquakes, sea-level fluctuations, river-course migration and climatic changes have shaped both the landscape and the history of human settlement in western Kachchh.



Fig. 3.24: View of the historic Lakhpat Fort overlooking the present barren Rann surface, which was formerly inundated by the freshwater flow of the Nara River, a major distributary of the Indus River, prior to the 1819 Allah Bund earthquake. The earthquake-induced tectonic uplift and subsequent diversion of the Indus distributary profoundly altered the regional hydrology, contributing to the abandonment of the port and transformation of the landscape.

The geomorphology surrounding Lakhpat is dominated by tidal flats, saline marshes, Kori Creek, abandoned fluvial channels, coastal mudflats and low rocky uplands. These landforms preserve evidence of repeated Holocene marine transgressions and regressions, shoreline migration and changing patterns of sedimentation. Throughout the Late Quaternary, fluctuations in relative sea level repeatedly altered the position of the coastline, while sediment supplied by the Indus River and tidal currents continually modified the coastal plain. The present landscape therefore records the combined influence of marine processes, tectonic movements and climatic variability operating over the last several thousand years.

Lakhpat occupies a unique position in the history of the Indus River. Historical records indicate that distributaries of the Indus once flowed through the Kori Creek region, supplying freshwater, fertile sediments and supporting navigation and maritime trade. The town flourished as an important commercial centre, with its name traditionally reflecting the enormous customs revenue generated through trade. However, progressive migration of the Indus distributaries toward the west, coupled with reduced freshwater inflow and increasing aridity during the Late Holocene, transformed the surrounding landscape into the saline mudflats and tidal creeks seen today. This shift fundamentally altered the regional hydrology, agriculture and economy, demonstrating the profound influence of fluvial and climatic changes on human civilization.

The history of Lakhpat was dramatically affected by one of the most significant tectonic events in the Indian subcontinent—the 1819 Kachchh earthquake (Mw ~7.7). This devastating earthquake produced widespread surface deformation across the Great Rann of Kachchh, including the formation of the famous Allah Bund, an approximately 80 km long and up to 6 m high tectonic uplift. The uplift dammed and diverted channels of the eastern Indus distributaries, while adjacent areas experienced subsidence and flooding. These sudden changes in drainage and coastal hydrology accelerated the decline of Lakhpat as an active port by reducing freshwater supply and altering navigable waterways. The earthquake remains one of the world's classic examples of surface faulting and coseismic landscape modification, illustrating how tectonic events can rapidly transform river systems, coastlines and human settlements.

The massive stone fortifications of Lakhpat, constructed during the eighteenth century, continue to dominate the landscape and stand as a testament to the town's former prosperity. Although the fort largely survived the 1819 earthquake, the changing geomorphological setting, loss of riverine connectivity and decline of maritime trade gradually led to the abandonment of the once-thriving settlement. Today, the fort overlooks a barren yet scientifically important landscape that vividly demonstrates the long-term consequences of tectonic activity, shoreline migration and environmental change.

Lakhpat also possesses exceptional historical and cultural significance. The town has long served as a gateway for travellers, traders and pilgrims moving between India, Sindh and Central Asia. It is traditionally believed that Guru Nanak Dev Ji, during his first Udasi (missionary journey), visited Lakhpat before travelling westward toward Mecca. The Gurudwara at Lakhpat preserves this important Sikh heritage. The town was also visited and documented by several British surveyors, geologists and explorers during the nineteenth century, particularly after the 1819 earthquake, when the remarkable tectonic changes in the

region attracted international scientific attention. Their observations formed some of the earliest geological descriptions of earthquake-induced surface deformation and coastal landscape evolution in South Asia.

From a Quaternary geological perspective, Lakhpat illustrates the close relationship between active tectonics, sea-level change, climate variability and human adaptation. Holocene sea-level fluctuations controlled the development of tidal flats, estuaries and coastal plains, while tectonic uplift and subsidence repeatedly modified drainage systems and shoreline positions. Climatic shifts, including weakening of the Indian Summer Monsoon and increasing aridity during the Late Holocene, further influenced freshwater availability, sediment supply and the ecological character of the region. Together, these processes transformed a fertile estuarine landscape into the saline, semi-arid environment that characterizes western Kachchh today.

During the field visit, participants should examine the relationship between the historic fort, Kori Creek, tidal mudflats and abandoned fluvial landscapes, and discuss how earthquakes, sea-level fluctuations and river-course changes influenced both the physical environment and the development of human settlements. The locality provides an exceptional opportunity to appreciate that geological processes are not confined to the distant past but continue to shape landscapes, ecosystems and societies. Lakhpat is therefore one of the finest field examples in India demonstrating the intimate connection between Quaternary geology, active tectonics, climate change, coastal evolution and the rise and decline of human civilization.

Location 14: 5000 Years Old Siyot Buddhish Caves

Coordinates: 23°46'26.00"N, 68°52'34.82"E

Description: The Siyot Buddhist Caves are situated in Lakhpat Taluka of northwestern Kachchh, about 4 km south of the Great Rann of Kachchh, and represent one of the most important rock-cut archaeological sites in the region (Fig. 3.25). Excavated into a sandstone hill, the caves form part of a larger cultural landscape that includes the Siyot habitation mound, Kateshwar Nadi, nearby temples and additional rock-cut monuments. Together, these remains demonstrate continuous human occupation and religious activity from the Early Historic to the Early Medieval period.

The caves were excavated within horizontally bedded sandstone, where natural bedding planes, joints and rock strength influenced both excavation and long-term preservation. Weathering of the sandstone by salt crystallization, thermal expansion, moisture infiltration and biological activity continues to modify the rock surfaces, making the site an excellent example of the interaction between geology and cultural heritage. The hill itself provided a stable rock mass suitable for excavation while also overlooking an important communication corridor between the Indus region, the Great Rann and the Arabian Sea coast.





Fig. 3.25: Photograph of the Siyot Caves.

Archaeological investigations suggest that the earliest rock-cut activity at Siyot may predate the Buddhist occupation. The principal cave, with its rock-cut sanctum and circumambulatory passage, differs from typical Buddhist cave architecture and has been interpreted as belonging to an earlier religious phase. During the subsequent centuries, particularly from about the 2nd century CE onward, the site was expanded into a Buddhist monastic complex comprising several rock-cut cells. Excavations yielded clay sealings depicting the Buddha, inscriptions in late Brahmi and Devanagari scripts, coins, copper objects and pottery, indicating prolonged occupation extending into the Early Medieval period.

The associated habitation mound, located about 500 m southeast of the caves, preserves a cultural sequence from approximately the 4th to the 10th century CE. Excavations have recovered Rang Mahal pottery, Red Ware, Red Polished Ware, appliqué pottery and imported West Asian ceramics, including Sasanian glazed ware and torpedo jars. These discoveries indicate that Siyot was connected to extensive inland and maritime trade networks linking Kachchh with Rajasthan, the Indus region and the Persian Gulf. Its strategic location near ancient trade routes suggests that the caves functioned not only as a religious centre but also as an important stop for merchants and travellers.

From a geo-archaeological perspective, Siyot demonstrates how geological conditions influenced the location, excavation and preservation of ancient monuments. The sandstone hill provided a suitable medium for rock-cut architecture, while the surrounding Quaternary landscape, seasonal drainage and proximity to the Great Rann supported long-term human occupation. During the field visit, participants should examine the relationship between the host sandstone, structural discontinuities, weathering features and the excavated caves, while appreciating how geology, archaeology and landscape evolution together shaped one of the most significant cultural heritage sites of western Kachchh. The Siyot Buddhist Caves provide an excellent example of the close relationship between geology and archaeology, illustrating how suitable rock types, strategic location and regional trade networks contributed to the development and preservation of an important religious centre in northwestern Kachchh.

Location 15: Banni Plains near Tropic of Cancer (Bhuj-Khavada Road)

Coordinates: 23°26'09.00"N, 69°39'42.42"E

Description: The Banni Plains, traversed by the Tropic of Cancer, represent one of the most remarkable Quaternary landscapes of the Kachchh Basin (Fig. 3.26). Situated between the Kachchh Mainland to the south and the Island Belt uplifts to the north, Banni occupies a broad tectonically controlled depression that has accumulated several hundred metres of Quaternary sediments overlying older Tertiary deposits. The present landscape appears as an almost perfectly flat plain with no exposed bedrock, making it an ideal locality for understanding the interplay of tectonics, sea-level fluctuations, sedimentation and climate during the Holocene.

Unlike the adjacent Great Rann of Kachchh, which continues to function as a seasonally inundated salt flat, the Banni Plains represent an uplifted Holocene surface interpreted as an emerged palaeo-mudflat. Tectonic uplift, together with relative sea-level fall during the Late Holocene, raised this former intertidal environment above the level of regular marine inundation, exposing older Quaternary sediments that remain buried beneath younger deposits in the Great Rann. Consequently, Banni provides an excellent opportunity to observe an ancient tidal-flat landscape that has evolved into a terrestrial plain.





Fig. 3.26: Photograph of Tropic of Cancer point at Banni Plains.

The sediments of the Banni Plain consist predominantly of fine silt, clay and micaceous sand, much of which was ultimately derived from the Himalayan catchments of the Indus River system and transported through successive distributaries before being redistributed across the Kachchh lowlands. Additional sediment contributions came from ephemeral streams draining the Kachchh Mainland and surrounding uplands. Sediment cores from Banni record a remarkable environmental succession from fluvial to estuarine, subtidal, intertidal and finally supratidal conditions during the Holocene, reflecting repeated changes in relative sea level, sediment supply and coastal configuration.



Fig. 3.27: Photograph showing grassy landscape of Banni during rainy season.

The Banni sediments also preserve one of the best continental archives of Holocene climate change in western India. High sedimentation rates permit reconstruction of centennial-scale environmental variations, recording alternating humid and arid phases associated with fluctuations in the Indian Summer Monsoon. These palaeoclimatic records demonstrate that the landscape has repeatedly responded to changing rainfall, salinity and hydrological conditions over the past five millennia. Such records are also important for understanding the environmental setting of Harappan and later settlements that occupied the Kachchh region, although cultural changes cannot be attributed solely to climatic factors.

Historically, the Banni region supported one of Asia's largest natural grasslands and sustained thriving pastoral communities through extensive seasonal grazing. However, during the past several decades the landscape has undergone significant ecological change. Reduced freshwater inflow following the construction of dams and barrages on the Indus River and its distributaries, together with geopolitical changes after the partition of the Indian subcontinent, have substantially increased salinity across the region. As a result, large parts of the Banni have become increasingly barren and saline. Nevertheless, during the southwest monsoon, seasonal rainfall transforms the plains into extensive grasslands that continue to support livestock and wildlife, illustrating the strong seasonal dependence of this unique ecosystem (Fig. 3.27).

During the field visit, participants should observe the exceptionally low-relief topography of the Banni Plain, discuss its origin as an uplifted Holocene palaeo-mudflat, examine the relationship between Banni and the adjoining Great Rann, and appreciate how tectonic

uplift, sea-level change, Indus-derived sedimentation, monsoon variability and increasing salinization have together shaped the modern landscape. The Banni Plains provide one of the finest field examples in India for understanding the evolution of Quaternary coastal plains, palaeoenvironmental change and the interaction between geological processes and human land use.

Location 16: Kaladongar Scarp Top

Coordinates: 23°56'11.73"N, 69°48'52.04"E

Description: Kala Dungar (Black Hill), the highest point in Kachchh at an elevation of approximately 462 m above mean sea level, provides one of the most spectacular panoramic views of the Great Rann of Kachchh, the Island Belt uplifts and the surrounding Quaternary landscape (Fig. 3.28). The locality is one of the best field stops for understanding the role of neotectonics, active faulting and Quaternary landscape evolution within the Kachchh Rift Basin. From the scarp top, the Great Rann appears as an extensive, nearly horizontal saline basin where sedimentation, seasonal inundation, evaporation and salt accumulation continue to operate, making it a rare opportunity to observe an active sedimentary basin and modern landform evolution.

The prominent north-facing escarpment of Kala Dungar is controlled by the Island Belt Fault (IBF), a major tectonic structure that forms the northern boundary of the Pachham Uplift. Although the fault itself is largely buried beneath the Quaternary sediments of the Great Rann, its presence is clearly expressed by the abrupt fault scarp separating the elevated rocky uplands from the low-lying Rann. The landscape provides an excellent example of how active tectonics influences topography, drainage, sedimentation and basin development. Differential uplift along the fault has elevated the Pachham block while the adjoining Rann continues to function as a slowly subsiding sedimentary basin.

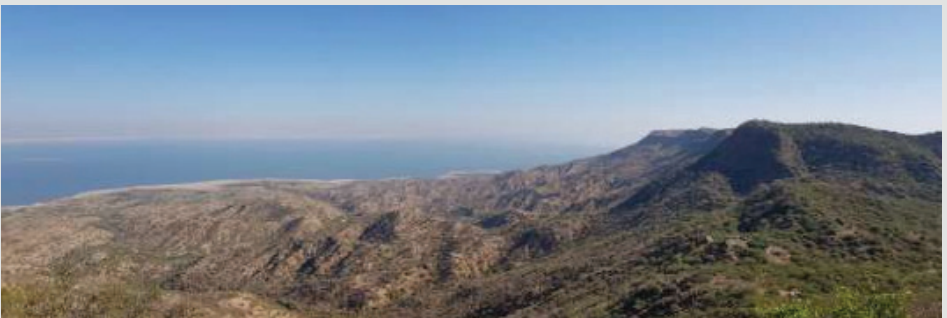


Fig. 3.28: Cross sectional view of Kala Dungar and the Rann showing morphotectonic features of Island Belt Fault.



Fig. 3.29: View of Rann surface from the Kala Dungar top.

The Great Rann visible from Kala Dungar is an active Quaternary depositional environment comprising saline mudflats, ephemeral channels, tidal creeks, seasonal wetlands and isolated bays (islands) (Fig. 3.29). The Rann records the combined effects of tectonic subsidence, sealevel fluctuations, fluvial sediment supply, aeolian processes and evaporation. Seasonal monsoon flooding transforms the basin into a shallow water body, whereas during the dry season intense evaporation leaves behind extensive salt-encrusted surfaces. The geomorphology visible from the summit provides an outstanding landscape-scale perspective of active sedimentary and geomorphic processes. The Kala Dungar region remains one of the most seismically active parts of the Kachchh Basin. Numerous small to moderate earthquakes (commonly M 3–4) have been recorded in the vicinity during the past two decades, reflecting ongoing movement along buried faults beneath the Great Rann, including the Island Belt Fault and associated structures. These earthquakes demonstrate that tectonic deformation continues to modify the Quaternary landscape and that the Kachchh Rift Basin remains an active intraplate seismic zone.

During the field visit, participants should observe the sharp geomorphic contrast between the uplifted Pachham Hills and the subsiding Great Rann, identify the fault-controlled escarpment, discuss the role of the buried Island Belt Fault in shaping the landscape, and appreciate the Great Rann as a modern sedimentary basin where depositional and geomorphic processes can be observed in real time. Kala Dungar is therefore one of the finest viewpoints in Kachchh for understanding the relationship between active tectonics,

earthquakes, Quaternary sedimentation and landscape evolution.

Location 17: Bandi River Section (Valley Filled multi-directional channel – Late Quaternary Deposit)

Coordinates: 23°51'58.69"N, 69°48'18.47"E

Description: The Bandi River section, located along the southern foothills of the Pachham Uplift near Harunwandi village, exposes one of the finest Late Quaternary fluvial successions in Kachchh. Deep river incision has revealed a thick valley-fill sequence resting unconformably on Tertiary bedrock, providing an excellent record of climatic fluctuations, episodic flooding, sediment aggradation and neotectonic influences during the Late Quaternary (Fig. 3.30). The locality is particularly important because it preserves multiple fluvial terraces and stacked channel deposits that document repeated phases of river incision and valley filling.

The exposed succession comprises coarse boulder and cobble gravels, gravelly sand, cross-bedded and massive sand, silt horizons and locally developed rhizolith-bearing palaeosols. The coarse gravel units display poor sorting, crude stratification and erosional scour surfaces, indicating rapid deposition by high-energy flash floods, debris flows and sediment gravity flows. These coarse units alternate with better-sorted sandy channel-bar deposits and finer overbank sediments that represent periods of reduced discharge, channel stabilization and floodplain development. The occurrence of rhizoliths within sandy horizons suggests intervals of landscape stability when vegetation colonized the floodplain under relatively less flashy hydrological conditions.

Three distinct river terraces (T1, T2 and T3) are preserved along the valley, each recording successive episodes of aggradation followed by incision. The repeated stacking of channel bodies with varying palaeoflow directions indicates channel migration, avulsion and reworking within the confined valley. The multidirectional sedimentary structures demonstrate that the river repeatedly shifted its course during successive flood events rather than maintaining a single stable channel.



Fig. 3.30: The Bandi River section in Pachham Island, exposing Quaternary deposits over the Tertiary rocks.



The Bandi River is an ephemeral stream draining the Kaladungar Range, and the preserved Quaternary succession indicates that runoff during parts of the Late Quaternary was considerably greater than at present. High-intensity monsoon rainfall generated powerful flash floods capable of transporting large boulders, gravel and sand over short distances. Alternating coarse debris-flow deposits and finer fluvial sediments record repeated climatic oscillations between wetter phases with high stream power and relatively drier periods characterized by channel stability and reduced sediment transport.

Neotectonic activity has also influenced the evolution of the Bandi valley. Gradual uplift of the Pachham block promoted river incision into the older valley-fill deposits, exposing the Tertiary bedrock that now forms the strath surface beneath the Quaternary succession. Downstream, the river develops entrenched meanders and locally changes course in response to transverse fault movements, illustrating the combined influence of tectonics and fluvial processes on drainage evolution.

During the field visit, participants should examine the relationship between the Tertiary bedrock and overlying Quaternary valley-fill deposits, identify erosional scour surfaces, debris-flow gravels, channelbar sands, palaeosols and terrace levels, and discuss how climatic variability, episodic flash floods and neotectonic uplift together controlled the development of this dryland river system. The Bandi River section provides an excellent modern analogue for understanding Late Quaternary valley evolution, ephemeral river dynamics and the interaction between climate and tectonics in the Kachchh Rift Basin.

Location 18: Road to Heaven – Quaternary Geotourism

Coordinates: 23°48'55.45"N, 69°58'2.49"E

Description: The Road to Heaven, located on the approach to Dholavira, traverses the spectacular Quaternary landscape of the Great Rann of Kachchh and provides one of the finest opportunities to observe the geomorphology of an active saline mudflat and salt-pan environment (Fig. 3.31). The surrounding terrain forms part of the tectonically active Kachchh Rift Basin, where long-term subsidence, Holocene sea-level fluctuations, seasonal flooding and intense evaporation have created an extensive low-relief surface composed of fine silt, clay and evaporite deposits. During the dry season, the landscape is covered by a brilliant white halite crust, whereas in the monsoon it transforms into a shallow water body, illustrating the dynamic nature of this Quaternary environment.

The Rann represents the final stage in the evolution of a former shallow marine and tidal basin into a restricted saline mudflat. Repeated cycles of marine or tidal inundation, sediment deposition, evaporation and salt crystallization have produced the characteristic flat surface, polygonal desiccation cracks, shallow brine pools and extensive evaporite crusts visible today. The almost perfectly horizontal landscape highlights the role of low-energy sedimentation, seasonal hydrology and arid climate in shaping one of the world's largest salt flats. The elevated road itself demonstrates the interaction between engineering and natural geomorphic processes. Because the Rann has an extremely low gradient, seasonal floodwaters spread over vast areas as shallow sheet flow. Roads and embankments can locally modify this natural drainage, making culverts and cross-drainage structures essential for maintaining hydrological connectivity and preventing waterlogging on either side of the roadway.



Fig. 3.31: Aerial view of the iconic Road to Heaven crossing the Great Rann of Kachchh, showing the elevated causeway traversing the vast Quaternary saline mudflat and evaporite-covered surface. The landscape illustrates the seasonal transformation of the Rann through flooding, evaporation, and salt crystallization, making it an outstanding example of active salt-pan geomorphology and Quaternary geotourism.

Beyond its geological significance, the Road to Heaven has become an internationally recognised geotourism destination, allowing visitors to appreciate the scale and beauty of the Great Rann while understanding the processes responsible for its formation. In recent years, the salt flats have also attracted the attention of planetary scientists, who study salt-crystal growth, evaporite processes and extremophile microbial communities preserved within the saline environment. These studies provide valuable terrestrial analogues for similar evaporitic environments that may have existed on Mars and other planetary bodies, making the Great Rann an important natural laboratory for both Earth and planetary science.

Location 19: Dholavira UNESCO World Heritage Archaeological Site

Coordinates: 23°53'13.34"N, 70°12'51.22"E

Description: Dholavira, a UNESCO World Heritage Site situated on Khadir Island in the Great Rann of Kachchh, is one of the most remarkable examples of the interaction between Quaternary landscape evolution and human civilization (Fig. 3.32). Occupied mainly during the Mature and Late Harappan periods (ca. 3000–1500 BCE), the site developed within a dynamic Holocene environment where changing sea level, tectonic activity, monsoon variability and sedimentation continuously reshaped the surrounding landscape. Khadir Island itself represents an uplifted structural high surrounded by the low-lying Quaternary deposits of the Great Rann, providing a naturally elevated and secure location for settlement.

The Quaternary history of Dholavira is closely linked to the MidHolocene marine transgression, when higher relative sea levels and an extensive network of tidal creeks, estuaries and shallow marine embayments occupied much of the present-day Rann. Although the open sea did not extend to the city itself, tidal channels and navigable creeks likely connected Dholavira with the Arabian Sea, facilitating trade, communication and access to marine resources. Subsequent Late Holocene regression, progressive sedimentation, tectonic uplift and increasing aridity transformed these shallow marine environments into the saline mudflats and salt deserts that characterize the Great Rann today.



Fig. 3.32: View of Fort Wall of Dholavira Archaeological site, a UNESCO World Heritage.



Dholavira flourished during a period of changing climate and entered the Meghalayan Age (beginning at ~4.2 ka) when the Indian Summer Monsoon weakened and arid conditions intensified across northwestern India. Multiproxy palaeoclimate records from Kachchh indicate alternating humid and arid phases during the last five millennia, with the 4.2 ka climatic event marking a major regional drought. Rather than a sudden collapse, archaeological evidence suggests that the inhabitants adapted through remarkable water-management strategies, including large rock-cut reservoirs, dams, channels, storm-water diversion systems and carefully planned rainwater harvesting structures. These engineering achievements demonstrate how ancient societies successfully responded to climatic uncertainty in an increasingly water-stressed environment.

The Dholavira landscape also illustrates the influence of neotectonics on Quaternary evolution. Khadir Island forms part of the tectonically active Kachchh Rift Basin, where repeated earthquakes, slow uplift and fault reactivation have modified drainage patterns, relative elevation and sedimentation throughout the Holocene. Regional studies indicate that Mid-Holocene relative sea level stood approximately 1.45 ± 0.33 m above present mean sea level (after correction for tectonic uplift), and subsequent uplift, sediment infilling and shoreline migration progressively isolated the island within the expanding Rann. Historical earthquakes, including the 1819 Allah Bund event and the 2001 Bhuj earthquake, demonstrate that crustal deformation continues to shape the geomorphology and hydrology of the region.

Dholavira is therefore an outstanding geoarchaeological site where archaeology, Quaternary geology and palaeoenvironmental studies converge. The site records the interplay between Holocene sea-level change, monsoon variability, tectonic activity, sedimentary landscape evolution and human adaptation. It demonstrates that the success and eventual transformation of one of the world's earliest urban civilizations resulted from a complex interaction of environmental change, resource management and societal resilience rather than any single climatic or geological event. As such, Dholavira remains one of the finest natural laboratories for understanding the relationship between Quaternary Earth processes and the evolution of ancient civilizations.

Location 20: Karni Post section of Mid- Holocene Quaternary Dynamics (Marine, Fluvial and Aeolian Deposits in a single section)

Coordinates: 23°56'9.88"N, 70°10'27.53"E

Description: The Karni Post section, situated along the northwestern margin of Khadir Island in the Eastern Great Rann of Kachchh, is one of the most significant Quaternary exposures for understanding the landscape evolution of the Rann during the Mid- to Late Holocene. The section preserves, within a single vertical profile, the transition from Jurassic bedrock to marine/intertidal deposits, overlying fluvial sediments and an upper aeolian sand cover, providing an exceptional record of changing depositional environments controlled by sea-level fluctuations, monsoon variability and sediment supply (Fig. 3.33).

The exposed succession rests on the Jurassic Khadir Sandstone, which forms the bedrock of the island. Above this occurs a clay-rich horizon interpreted as deposition in a low-energy intertidal to shallow marine environment during the Mid-Holocene marine transgression. This unit is overlain by fluvial deposits composed of alternating sand, silt and clay, including

repeated fining-upward sequences that record episodic flooding and sediment aggradation by ephemeral streams draining Khadir Island. The nature of the sand, its moderate sorting and sedimentary structures indicate relatively long-distance transport and repeated reworking under fluvial conditions. The succession is finally capped by well-sorted aeolian sand, representing dune formation under increasingly arid Late Holocene conditions. OSL dating of the sedimentary succession indicates that these depositional events occurred mainly during the last ~5,000 years, corresponding to the Mid- and Late Holocene, including the Meghalayan Stage.



Fig. 3.33: Photograph of the Karni Post Quaternary section showing MidHolocene intertidal to shallow-marine clay resting unconformably on the Jurassic Khadir Sandstone at the base. The clay is overlain by a fine-grained fluvial succession of Mid- to Late Holocene age, representing episodic river aggradation, and is capped by Late Holocene aeolian sand, recording increasing aridity and dune development in the Great Rann of Kachchh. This vertical succession preserves the transition from marine to fluvial and finally aeolian depositional environments during the Holocene landscape evolution of Khadir Island.

The repeated alternation of marine, fluvial and aeolian deposits reflects changes in relative sea level, Indian Summer Monsoon intensity and aridification of the Great Rann. Gypsum horizons, desiccation features and aeolian sands record the progressive transition from a tidally influenced coastal setting to the present hyper-arid saline landscape. The Karni Post section is also of considerable geoarchaeological importance because it records the environmental evolution during the period of Harappan occupation at nearby Dholavira. Provenance studies of the fluvial sediments help identify sediment sources and improve our understanding of palaeodrainage patterns, regional connectivity and the possible role of tidal creeks and navigable channels in supporting movement, trade and communication during the Harappan period. Rather than indicating a large Himalayan-fed perennial river, the available evidence suggests that sediment was derived mainly from local catchments and transported by episodic high-discharge events associated with stronger monsoon phases. This locality provides an outstanding field example of how marine inundation, fluvial aggradation and aeolian reworking operated successively during the Holocene to shape the modern Great Rann of Kachchh. It demonstrates the complex interaction between sea-level change, climate variability, sediment transport and human occupation, making Karni Post one of the most important Quaternary and geoarchaeological sections in western India.



Acknowledgement

The preparation of this field guide and the successful organization of the INQUA India 2027 Field Excursion have been made possible through the generous support, cooperation, and contributions of numerous institutions and individuals. We express our sincere gratitude to all those who have directly or indirectly contributed to the development of this guide and the planning of the field excursion. We gratefully acknowledge the International Union for Quaternary Research (INQUA) for providing an international platform that promotes collaboration and advances research in Quaternary science. We are especially thankful to the INQUA Congress Organizing Committee for their encouragement, guidance, necessary funding and support in facilitating this field excursion as part of the scientific programme of the Congress. We express our profound gratitude to the Director General (DG) and the Director, Institute of Seismological Research (ISR), Gandhinagar, for their continuous encouragement, scientific support and institutional cooperation. Our sincere thanks are extended to the Hon'ble Vice-Chancellor and the Registrar, Kachchh University, Bhuj, for their unwavering support, encouragement and for providing the academic environment and institutional facilities necessary for organizing this international field excursion. Their commitment to promoting geoscience research and international scientific collaboration has been invaluable. We are grateful to the District Administration, Kachchh, for their cooperation, administrative assistance and support in facilitating access to the field traverse and ensuring the smooth conduct of the excursion.



across diverse geological and geoheritage locations within the district. We sincerely acknowledge the Border Security Force (BSF) for granting the necessary permissions and extending logistic support for visits to sensitive border areas. We also thank the Gujarat Forest Department for permitting access to protected forest, mangrove and coastal ecosystems and for their cooperation in ensuring environmentally responsible field activities. We gratefully acknowledge the Archaeological Survey of India (ASI) for granting the required permissions to visit protected archaeological monuments and heritage sites, particularly the UNESCO World Heritage Site of Dholavira and other protected monuments included in the field excursion. We also thank Gujarat Tourism for providing valuable information, logistical assistance and promotional material that enriched the cultural and geoheritage components of this field guide. We express our heartfelt appreciation to all members of the Organizing Committee, scientific advisors, field coordinators, research scholars, students, technical staff, volunteers, drivers, photographers and supporting personnel whose dedication, enthusiasm and hard work contributed significantly to the planning, reconnaissance, documentation, logistics and successful preparation of this field guide and field excursion. We also acknowledge the invaluable contributions of the numerous researchers whose pioneering investigations on the Earth Science, Quaternary Geology, geomorphology, tectonics, palaeoseismology, sedimentology, palaeoclimate, coastal evolution, geoarchaeology and geoheritage of the Kachchh Rift Basin have laid the scientific foundation upon which this field guide has been developed. The published work cited throughout this guide has greatly strengthened its scientific content and we sincerely appreciate the contributions of all those researchers whose efforts have advanced our understanding of the Quaternary evolution of Kachchh. Special appreciation is extended to the local communities across the Kachchh region for their hospitality, cooperation and continued support during field reconnaissance and scientific investigations. Finally, we gratefully acknowledge all institutions, organizations, colleagues, collaborators, reviewers, well-wishers and individuals who have contributed in any manner, scientifically, technically, administratively, or logistically, to the preparation of this field guide and the successful organization of the INQUA India 2027 Field Excursion. We also extend our sincere apologies to anyone whose name or contribution may have been unintentionally omitted. Their support is deeply appreciated and gratefully acknowledged.



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Annexure

Field Excursion Guidelines: Do's and Don'ts

To ensure the safety of all participants and to promote responsible scientific field practices, all participants are requested to adhere to the following guidelines throughout the field excursions.

Keep a valid passport (for international participants) or a government-issued photo ID (for Indian participants) with you at all times during the field excursion.

Do's	Don'ts
1. Follow the instructions of the excursion leaders, coordinators, and local authorities at all times. 2. Remain with the group and inform the excursion leader before leaving the designated route. 3. Wear appropriate field attire, including sturdy closed-toe footwear, full-length trousers, a hat or cap, and weather-appropriate clothing. 4. Carry sufficient drinking water, personal medications, sunscreen, insect repellent, and other essential field supplies. 5. Keep a valid photo identification and your excursion registration details with you during travel. 6. Respect local customs, religious sites, cultural heritage, and private property. 7. Follow the Leave No Trace principles by carrying back all waste and helping to keep field sites clean. 8. Use designated trails and approved observation areas to minimise environmental disturbance.	1. Do not collect rocks, fossils, archaeological artefacts, biological specimens, or any other materials without prior authorization. 2. Do not damage, deface, or remove material from geological outcrops, caves, monuments, heritage structures, or other natural features. 3. Do not wander alone or separate from the excursion group without informing the field leaders. 4. Do not climb unstable slopes, cliffs, rock formations, or enter hazardous areas unless specifically instructed or supervised. 5. Do not swim or enter rivers, lakes, lagoons, or coastal waters unless expressly authorized by the excursion leaders. 6. Do not consume alcohol, recreational drugs, or engage in unsafe or irresponsible behaviour during the excursion. 7. Do not operate drones or other restricted equipment without obtaining the necessary permissions.

9. Observe geological, ecological, archaeological, and cultural features carefully without causing any damage.

10. Record field observations systematically and collect samples only with prior permission from the excursion leaders and the relevant authorities.

11. Exercise caution near cliffs, riverbanks, caves, unstable slopes, road cuts, and other potentially hazardous terrain.

12. Respect wildlife by maintaining a safe distance from animals, birds, reptiles, insects, and their habitats.

13. Immediately report any illness, injury, emergency, or hazardous situation to the excursion organizers.

14. Be prepared for changing weather conditions and comply with all safety advisories issued by the excursion leaders.

8. Do not photograph restricted installations, sensitive locations, or local residents without prior permission.

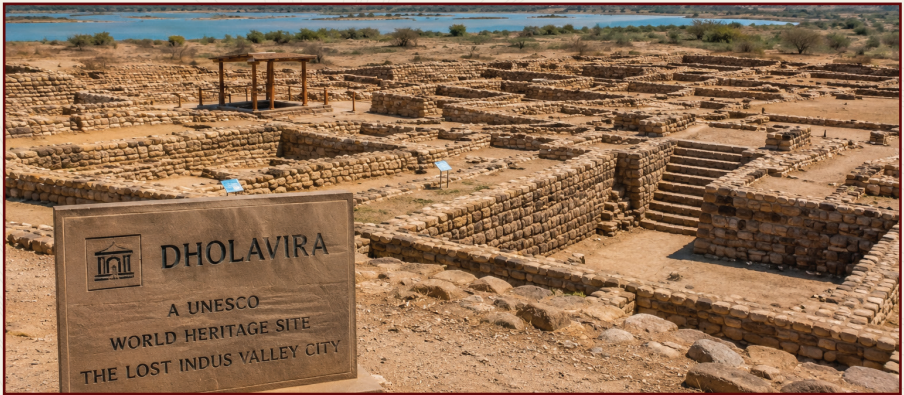
9. Do not create excessive noise or disturb local communities, religious activities, wildlife, or natural habitats.

10. Do not leave valuables unattended or rely solely on mobile phone connectivity in remote areas.

11. Do not undertake any activity that may compromise your safety, the safety of fellow participants, or the conservation of the area's geological, ecological, archaeological, or cultural heritage.

Disclaimer

Participation in the field excursions is entirely at the participant's own risk. While the Organising Committee and excursion leaders will make every reasonable effort to ensure participant safety and provide appropriate guidance, they shall not be held responsible for any personal injury, illness, loss of personal belongings, property damage, delays, or unforeseen incidents arising during travel or field activities. Participants are expected to act responsibly, follow all instructions issued by the excursion leaders, and comply with applicable local laws and regulations throughout the excursion.





Scan for
Field Guide Book



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