CHAPTER III

QUATERNARY GEOLOGY

QUATERNARY GEOLOGY

INTRODUCTION

The arid and semiarid terrains of Western Rajasthan are characterised by rich assemblages of Quaternary sediments. These sediments are of residual fluvial, lacustrine and aeolian nature and have been deposited by a combination of surficial processes, under the prevailing climatic conditions during the past. The Quaternaries exhibit an aggregate thickness of more than 300 m. deposited over the pre-Quaternary basement rocks.

PREVIOUS WORK

Since the beginning of the twentieth century, the Thar Desert has attracted number of scientific workers. However, in their works, the Quaternary sediments merited only passing references. A few noteworthy are La Touche (1902), Holland and Christie (1909), Auden (1952), Ghosh (1952), Krishnan (1952), etc. However, in the last two decades, the arid terrain of Rajasthan has become a centre of attraction from the point of view of understanding the early Pleistocene-Holocene climatic vicissitudes. Resultantly, voluminous data have been generated on the numerous aspects of Quaternary period. Few important aspects on which valuable

contributions are made include: archaeology, palynology/palaeoclimate, geomorphology and neotectonism.

The accumulation of a thick pile of varied Quaternary sediments in the Thar desert can be attributed to numerous factors related to the pre-Quaternary topographic and structural configuration, Neogene-Quaternary tectonism and the past climatic changes. These factors in turn were responsible for controlling the intensity of various surficial processes, governing an overall modification in the terrain. The studies of these sediments have established that the climatic changes in the Thar region were fluctuating between humid and arid (Misra *et al.*, 1988).

Singh *et al.*(1974), analysed the lithostratigraphy and palynostratigraphy from core sediments of the Lunkaransar, Sambhar, Didwana and Pushkar lakes, and described five phases of vegetation and climatic development during the past 12,000 years in the Northern Thar.

Phase I (before 10,000 yrs) : an extremely arid period when sand dunes were deposited. This process was responsible in creating the lake basins at Sambhar, Lunkaransar and Didwana (Verstappen, 1970; Allchin & Goudie, 1971).

Phase II (10,000 yrs - 9500 yrs B.P.): characterised by a freshwater condition in the lakes as shown by the presence of *Typha agunstata.*

Phase III (9,500 yrs - 5,000 yrs B.P.): period of relatively high rainfall as indicated by the presence of pollen assemblages characteristic of humid climate.

Phase IV (5,000 yrs - 3,500 yrs B.P.): characterised by high values of sedges, trees and shrubs indicative of moist conditions. During this period the lakes began to dry up followed by a desiccation phase that continued to prevail for about 1,500 B.P.

Phase V (3,500 yrs - Present): a period with present day conditions of vegetation and climate.

These derived sequences of humid and arid periods as indicated by the vegetation history show consistency with the climatic events in parts of tropical Africa.

Allchin *et al.*(1978), have demonstrated the rich potential of sand dunes for reconstructing the palaeoenvironment and human history of the Thar. The sequence of Quaternary climate and cultural events for the Thar desert suggest (i) major dry phase (pre-Middle Stone age), (ii) major wet phase (Middle Stone age), (iii) major dry phase (Upper Palaeolithic, pre-10,000 yrs B.P.) and (iv) a moist phase (10,000 yrs - 9,500 yrs B.P.).

Ghose (1982) has worked out the geomorphic evolutionary history of Eastern Thar and correlated it with the various Quaternary geological units.

Agrawal *et al.* (1980), in their integrated studies on the palaeoclimate, stratigraphy and pre-history of Thar desert have stated that the Quaternary formations in Western Rajasthan are of fluvial, lacustrine and aeolian origin. Their detailed studies on the fossil gravel ridges of Jayal in Nagaur district conclude that these gravels are of early Pleistocene age, so far recorded in the region.

Wasson *et al.* (1983), have provided a detailed account on the geomorphology, late Quaternary stratigraphy and palaeo-climatology of the Thar dune field. They had opined that the dune sands are largely derived from a local source, i.e., the reworked fluvial sands. The dune building activities have started at least 20,000 years B.P. and stabilised by the Middle to Late Holocene. The lacustrine sedimentation history shows hypersaline conditions which prevailed at about the last glacial maximum (LGM). The period between LGM and 6000 years B.P. is characterised by a fluctuating water level upto the onset of freshwater conditions.

Misra *et al.*(1988) have worked out the Quaternary stratigraphy of exposed surficial deposits of the Thar and have divided these fluvial, aeolian and lacustrine sediments into three formations, *viz.*, Jayal, Amarpura and Didwana Formations ranging in age from Early Pleistocene to Holocene (Table 3.1) which is described briefly in the section on the Quaternary Geology of the study area). However, recent studies (Gangadhar and Tiwari, 1995) on the gravelly ridges of

Jayal have revealed that these gravelly pavements of Jayal area represent basal unit of Nagaur Group of rocks i.e. the Khichan conglomerates. These conglomerates due to upliftment got loosened and only the resistant component is now left out as lag-deposits.

Wadhawan (1991), while proposing the Quaternary stratigraphic model for Western Rajasthan, has suggested that the deposition of these Quaternaries has taken place in four major sub-basins. *viz.*,

(i) the **Shahgarh-Kishangarh** sub-basin,
(ii) the **Sanchor-Shergarh-Dechu** sub-basin,
(iii) the **Ganganagar-Churu** or the **Ghaggar** sub-basin, and
(iv) the **Luni** sub-basin.

In **Shahgarh-Kishangarh** (Jaisalmer) sub-basin, the basal Quaternary sequences include fluvial or fluvio-lacustrine deposits of Shumar Formation resting unconformably over the marine middle Eocene limestones (Narayanan, 1964). These continental deposits comprise gravels, sandstones, grits, variegated clays, lateritic concretions and calcretised pseudo-conglomerates and sandy loams. Their thickness increases westwards and southwestwards to over 300 metres and are buried under thick cover of aeolian deposits (Singh, 1982).

The **Sanchor-Shergarh-Dechu** (Barmer-Jodhpur) sub-basin comprises mostly clusters of parabolic dunes and superimposed multi-layered transverse and linear dunes. Three distinct aeolian episodes have been inferred in this tract (Wadhawan, 1988). This upper Quaternary litho-association rests disconformably over the aggradational fluvio-aeolian deposits (basal Quaternary or Neogene) which in turn lies unconformably over the Malani rhyolites and the Marwar Supergroup of rocks.

The basal Quaternary-Neogene deposits in the **Merta-Degana-Jayal-Didwana** sub-basin are made up of open framework polymictic conglomerates and arkosic grits along with coarse sands and sandy clays. The upper part of the conglomeratic horizon is calcretised. The older fluvial aggradational deposits consist of intensely pedocalcified greensish grey and reddish brown

mottled, medium to coarse, poorly sorted sandy loams/clayey sands. Reddish brown, very fine. well sorted sands occur at the top of these deposits. The oldest aeolian sediments with illuviated kankars rest with a sharp contact over the fluviatile and fluvio-aeolian mixed deposits (Wadhawan, 1990).

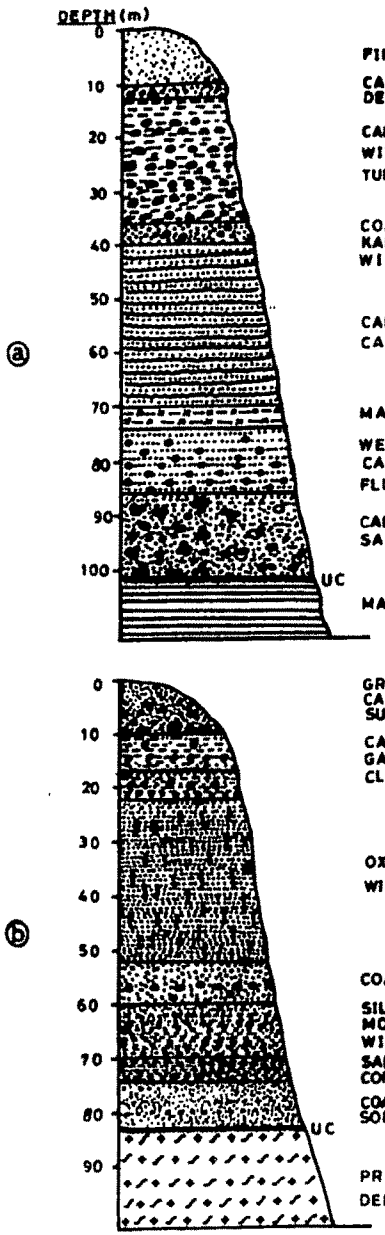
The **Ganganagar-Bikaner-Churu (Ghaggar)** sub-basin consists of 'drowned' Quaternary fluviatile and fluvio-aeolian deposits of the lost Saraswati. The older fluvial sequences are confined to the palaeochannels and showed progressive northerly shifts, ending as evaporite pans of calcrete and gypsites of lacustrine sub-environment (Rakshit and Sundaram. 1990). Superimposed transverse, oblique and complex linear/parabolic and star shaped dunes dominate the dunal forms of second generation of aeolian activity.

The generalised Quaternary lithostratigraphy of southwestern and northeastern Thar as worked out by Wadhawan (1988) is shown in Fig. 3.1.

Dhir *et al* (1992) have suggested a stratigraphic framework for the Quaternary and Neogene sediments on the basis of their detailed studies on the aspects of nature of sediments. geochronology, etc. (Table 3.2).

QUATERNARY GEOLOGY OF THE STUDY AREA

The study area exhibits vast accumulation of Quaternary sediments of fluvial, aeolian, lacustrine and residual origin. Distribution wise, the aeolian sediments cover a large expanse of the northern, northeastern and northwestern parts of the study area. The fluviatile sediments are well exposed within the river valleys of the present day drainage systems. The continuity of these fluviatiles in the form of flood plains is concealed under a thick cover of wind blown sands of recent to sub-recent period. The lacustrine sediments are predominantly associated with the present day active pluvial lakes, interdunal playas and the older playas concealed under the thick cover of aeolians. The residual deposits are represented by a variety of duricrusts (calcretes. gypsicretes, palaeosols, etc.), developed under the influence of episodic climatic perturbations and are widespread in all other surficial formations.



	LITHOSTRATIGRAPHY	MAJOR PROCESS	PROBABLE CLIMATE
ⓐ	FINE SAND WITH ALLUVIUM / COLLUVIUM.	AEOLIAN / SEASONAL FLUVIAL	ARID
	CALCAREOUS SAND AND SILT WITH WEAKLY DEVELOPED KANKAR	FLUVIAL	SEMI ARID
	CALCAREOUS / NON CALCAREOUS FINE SAND WITH KANKAR, CROSS BEDDING AND BIO-TURBATION STRUCTURES	AEOLIAN	ARID
	COARSE SAND, SHEETFLOW - RUNOFF DEPOSITS KANKAR CALC / NON CALC FINE SAND - SILT WITH KANKAR	FLUVIAL / FLUVIO-LACUSTRINE	SEMI ARID
	CALC SAND - WELL SORTED MASSIVE WITH CALCRETE CRUSTS	AEOLIAN	ARID
	MARLY CLAY, CALC-SAND AND SILT.	FLUVIAL/LACUSTRINE	SEMI ARID
	WELL SORTED CONSOLIDATED CALC-SANDS, CALCRETE NODULES, COARSE SUBANGULAR FLUVIAL SANDS	AEOLIAN - FLUVIO-LACUSTRINE	ARID
	CALCRETISED GRITTY CONGLOMERATE COARSE SAND WITH FINE SAND AND CLAY BANDS	FLUVIAL	SEMI ARID
	MALANI RHYOLITE AND JODHPUR SANDSTONE		
ⓑ	GRAVELS, PEBBLES AND BOULDERS WITH COARSE CALCAREOUS POLYMICTIC CONGLOMERATE WITH SUBROUNDED TO ANGULAR FRAGMENTS	FLUVIAL	SEMI ARID
	CALCAREOUS SILTY SAND AND CLAY WITH GASTROPODS, ALTERNATE SAND, BLACK SILT/ CLAY LAYERS WITH SOME HALITE BEDS	LACUSTRINE / FLUVIO-LACUSTRINE	SUB-HUMID
	OXIDISED WELL SORTED FINE SAND WITH PEDOCALCIC HORIZON	AEOLIAN	SEMI ARID
	COARSE SAND WITH CALCAREOUS HORIZON	FLUVIAL	SEMI ARID SUB-HUMID
	SILTY SAND AND CLAY WITH KANKAR PAN, MODERATELY OXIDISED WELL SORTED SAND WITH PEDOCALCIC HORIZON	FLUVIO-LACUSTRINE AND AEOLIAN	SUB-HUMID
	SAND WITH SILT AND CLAY, UNOXIDISED CONSOLIDATED AEOLIAN SAND	FLUVIAL WITH MINOR AEOLIAN EPISODE	SUB-HUMID SEMI ARID
	COARSE TO FINE SAND WITH SILT, WELL-SORTED FINE SAND, ALTERNATING SILT CLAY	AEOLIAN / LACUSTRINE	SEMI ARID
	PRECAMBRIAN METASEDIMENTS OF DELHI SUPERGROUP		

Fig. 3.1. QUATERNARY LITHOSTRATIGRAPHY IN ⓐ SOUTHWESTERN THAR AND ⓑ NORTHEASTERN MARGIN OF THAR (After Wadhawan, 1988)

Table 3.1. Quaternary stratigraphy of exposed surficial deposits (after Misra *et al.*, 1988)

Formation	Dominant Lithology	Approximate Age
Didwana	Stabilised aeolian sands pedocalcic palaeosols and playa sediments	Late Middle Pleistocene to Holocene
Amarpura	Calc pans, calcretised alluvium and pedocalcic palaeosols	Late Middle Pleistocene to Late Pleistocene
	Disconformity	
Jayal	Calcretised bouldery gravel	Late Tertiary to Early Pleistocene

Table 3.2 Lithostratigraphic framework of the Quaternary and Neogene sediments in Thar (Dhir *et al.*, 1992)

Lithological Units	Geological Period	Approximate Chronology
Aeolian sands and salines	Late Quaternary (Late Pleistocene-Early Holocene)	4-50 ka. B.P.
Alluvial sediments, calc-pans, calcrete bands, calcretised gravels and aeolian sands	Middle Quaternary (Late Middle-Early Phase of Late Pleistocene)	50-200 ka. B.P.
	Disconformity	
Lithic calcretes, bouldery, cobbley gravel beds	Early Quaternary (Early-Middle Pleistocene)	> 200 ka. B.P.
	Disconformity	
Ferricretes, Fluvial sands and gravels	Neogene (Miocene-Pliocene)	-
	Unconformity	
Bedrock	Precambrian-Palaeogene	-

Studies on the aspects of Quaternary deposits in the study area have been attempted by large number of researchers from different angles. This has resulted in the generation of voluminous information which has provided much insight in understanding various processes and factors responsible for an overall evolutionary history of the area. However, owing to difficulties in observing continuity of various lithostratigraphic units due to the vast area being buried under aeolian cover, the available information is full of gaps and embroilment.

In the present study, the author has realised this fact and has made an attempt to understand the varied aspects of Quaternary sedimentation records by way of (i) critical appraisal of the available information, (ii) collection of first hand information by mapping various exposed Quaternary sections in the study area, and (iii) collection of bore hole records drilled by the government agencies and their evaluation from the point of view of nature and sub-surface extent (vertical and lateral) of the Quaternary sediments.

AEOLIAN FORMATION

The aeolian sands cover nearly two-third parts of the study area and are predominantly confined to the northern and northeastern parts. These wind-blown sands, which generally overlie the alluvium, exhibit high variation in their thickness and seem to have the control of pre-existing topographic configuration. In the study area, these aeolians form a thick sheet over the residual plains in the eastern parts of the Upper Luni basin; while in the northwestern, northern and northeastern parts they exhibit various dune patterns. These wind blown sands are characterised by their non-stratified, very fine to medium-grained, sub-angular to sub-rounded nature. Compositionally, these aeolians are dominated by quartz, with subordinate proportions of ferruginous, calcareous and micaceous impurities. The different types of dunes observed in the study area are parabolic, barchans, longitudinal, transverse, seif, shrub-coppice (obstacle), star and complex dunes.

The blown sands, on their surface, commonly exhibit light to yellowish brown colour. However, in the area around Tivri, Osiyan, Khimsar, Nagaur and Didwana, they are slightly to deeply reddish in colour. This reddish colouration in the dunal sands is attributed to the predominance

of ferric oxide released by the action of weathering from the sedimentary sequences of the Marwar Supergroup of rocks, seen occurring as isolated inselbergs within the vast dunal plain. However, the reddening of these dunal sands due to earlier warm and humid climate has also been advocated by Raghavan (1987).

The fluctuating depth distribution of the aeolian cover in the region around Nagaur, Sikar, Churu, etc., precludes the possibility of their reworked nature from the earlier as well as present day riverine sediments. The localised thicker accumulations can be ascribed to the pre-existing topographic lows, manifested by the neotectonic phenomenon.

Sedimentation History

Important contributions have been made on this aspect by Dhir (1977), Dasgupta *et al.*(1983), Wadhawan and Sural (1991) and Dhir *et al.*(1994). Dhir had recognised a sequence of three aeolian formations around Jodhpur, *viz.*, from bottom to top,

(i) the *Pal Series,* comprising reddish brown non-calcareous formation,
(ii) the *Khatawas Formation* with yellowish brown sand, and
(iii) the *recently activated sands* covering patches at the surface.

Dasgupta *et al.*(1983) observed a sequence of four aeolian and three fluvial morphostratigraphic units in the Quaternary sequence near Jaipur. Wadhawan and Sural (1991) have suggested four aeolian lithostratigraphic units, the first and oldest unit comprises sand-sheets and buried dunes, while the barchans and the shrub-coppice hummocks constitute the fourth and the youngest unit. The present day parabolic and obstacle dunes constitute the second unit and the longitudinal, reticulate, superimposed and transverse dunes the third unit. For the purpose of evaluating the overall aeolian stratigraphy of the study area, the author has relied upon the available information as well as his own data collected during various field visits. Some of the important aeolian sections (Fig. 3.2) recorded by others as well as personally studied by the author are discussed as under:

(a) **Belwa** (N 26° 30' : E 72° 45')

This site is located in Belwa village just adjacent to the western part of the study area on the left bank of a small ephemeral stream flowing through the terrain comprising sedimentary sequences of the Marwar Supergroup of rocks with intermittent wind-blown sands. This section exhibits an intercalated sequence of aeolian and fluvial sediments with two very conspicuous bands of calcretes (Plate III.1). The entire sequence is developed over the sandstones seen occurring 1 to 2 m in subsurface. The section (Fig. 3.2a), which constitutes an aggregate thickness of more than 8 metres, exhibits three aeolian cycles, separated by two well defined calcretic beds indicating an intermittent warm and humid phase. Occurrence of thin unit of fluvial sands between these calcretic horizons is indicative of a minor wet phase. However, the occurrence of pedogenetic features in almost the entire sequence is suggestive of overall semi-arid climatic conditions.

(b) **Sardarshahar** (N 28° 30' : E 74° 30')

This site is located on the left side of the entry point to Sardarshahar town at the highway crossing. The pit section exhibits almost 4.5 m to 5 m thick aeolian sequence. This section in all displays five units (Fig. 3.2b). These are, from bottom to top, (i) greenish yellow loose silts, (ii) pedogenised mottled sand with occasional caliche nodules, (iii) hardpan calcrete, (iv) compact calcified sand with caliche nodules, and (v) dunal sand with burrows and pedogenetic features. This is overlain by present day dunal sand cover. This section illustrates two aeolian cycles, separated by a well defined calcretic unit.

(c) **Bhalera** (N 28° 25' : E 74° 45')

This section is located within an interdunal depression in a roadside pit. The exposed thickness, which is more than 5 metres, depicts different degrees of pedogenesis (Plate III.2). The different units observed within the section from bottom to top are described as under:

Plate III.1 A view of the stream-cut section at Belwa showing an intercalated sequence of aeolian and fluvial sediments with two conspicuous calcrete horizons.

Plate III.2 A view of the dunal section at Bhalera showing palaeosol, calcrete, bentonite layers.

(i) The exposed basal part comprises loose silty material with burrows and yellowish clayey granules, (ii) pedogenised silts with caliche nodules, (iii) Hard honey-comb calcretic bed. (iv) nodular calcrete, (v) greyish black, blocky silty clay (palaeosol?), and (vi) pedogenised silts. Overall profile (Fig. 3.2c) depicts two aeolian cycles, followed by a palaeosol horizon indicating warm and humid climate.

(d) **Pachlagi** (N 27° 44' : E 75° 40')

A cliff section of the Kantli river at Pachlagi village (Plate III.3a), with an aggregate thickness of more than 15 m represents exclusively aeolian sediments. This section (Fig. 3.2d) exhibits three aeolian cycles, separated by two well defined calcretic horizons. The top aeolian horizon consists of lenses of colluvial sediments derived from the neighbouring rocky exposures of Delhi Supergroup (Plate III.3b).

(e) **Ghatwa** (N 27° 19' : E 75° 09')

This section of about 2 m thickness is located in an interdunal plain and comprises mainly pedogenised clayey and silty horizons (Plate III.4a). The lowermost silty horizon of the exposed section is devoid of caliche nodules and is overlain by a 0.30 m thick horizon of calcretised silts (Fig. 3.2e). The overlying 0.20 m thick greyish black blocky and fractured siltyclay horizon (palaeosol ?) also contain the bone fragments (Plate III.4b). This is overlain by 0.55 m thick pedogenised silts with oxidised iron clots (Plate III.4c), followed by 0.35 m thick pedogenised sticky clay with caliche nodules. The litho-units overlying this is 0.11 m thick pedogenised silt with calcareous matter, a 0.30 m thick laminated silty horizon and a topmost 0.35 m thick stabilised aeolian silt. This section in general is indicative of ameliorating warm and humid climatic conditions and a sub-aerial environment which prevailed at a later stage.

Plate III.3.a A view of the Kantli river cliff section representing three aeolian cycles separated by well defined calcretic horizons. Location: Pachlagi village

Plate III.3.b A closer view of the Kantli river cliff section at Pachlagi showing well marked colluvial horizon (C).

Plate III.4.a Aeolian section showing top laminated silty horizon and a palaeosol horizon at its base. Location: Ghatwa

Plate III.4.b A close view of the palaeosol horizon containing bone fragments in the Ghatwa section.

Plate III.4.c Closer view of the pedogenised silts and oxidised iron layers and wood charcoal in the Ghatwa section.

(f) **Surpalia** (N 27° 28' : E 75° 02')

A roadside pit at the outskirts of the Surpalia village (Nagaur district) exhibits 4 to 5 m thick section of calcretised dunal material. In all, five horizons are recognisable within the section (Fig. 3.2f). The section reflects semi-arid to warm-humid climatic conditions.

(g) **Budha Pushkar** (N 26° 31' : E 74° 35')

Dunes within the intermontane valleys in the Aravalli hills near Budha Pushkar (about 10 km northwest of Ajmer), had been studied by Allchin *et al.* (1978), Agrawal *et al.* (1980) and Wasson *et al.* (1983). A composite stratigraphic section (Fig. 3.2g) reveals a surface horizon made of yellowish brown present day aeolian sand, followed by 1 to 3 m thick calcareous pale brown fine sand with carbonate nodules and root pseudomorphs. The oldest unit is a palaeosol consisting of yellowish brown fine sand. This unit has a dark brown 'A' horizon having a higher content of organic matter and iron compared to that of the underlying calcareous yellowish brown sand. The lower parts of the profile show the development of calcrete nodules.

Based on archaeological evidences, Allchin *et al* (1978) had dated this aeolian unit. Contradicting ages were worked out by Agrawal *et al.* (1980) on the basis of the microliths found within the aeolian units. They reported radiocarbon dates of 2000 yrs to 4000 yrs for the upper horizons, i.e. the pale brown sand.

The subsequent studies by Singhvi *et al.* (1994) based on the obtained TL dates have concluded that the dunal activity in this part has been confined to two epochs around ca. 25 and ca. 15 ky These workers have further ruled out the earlier concept of Middle Palaeolithic wet climatic conditions put forward by the archaeologists *viz.*, Allchin *et al.* (1978).

(h) **Didwana** (N 27° 24' : E 74° 33')

The only excavated aeolian section studied in great detail by Misra and Rajaguru (1986), Misra *et al.* (1988) is the 16R dune section near Didwana. This 20 m thick section (Fig. 3.3) comprises

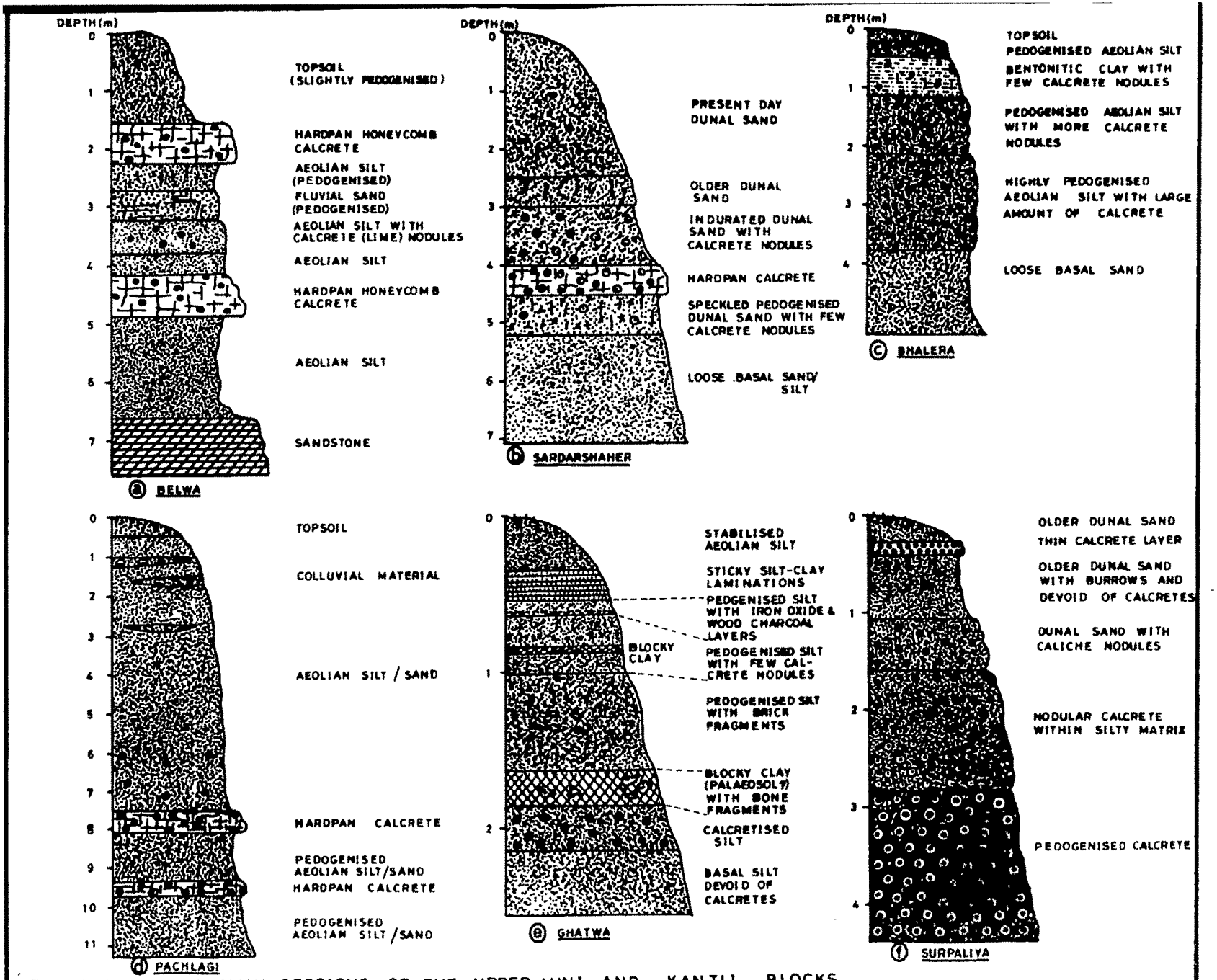


Fig. 3.2. TYPICAL AEOLIAN SECTIONS OF THE UPPER LUNI AND KANTLI BLOCKS

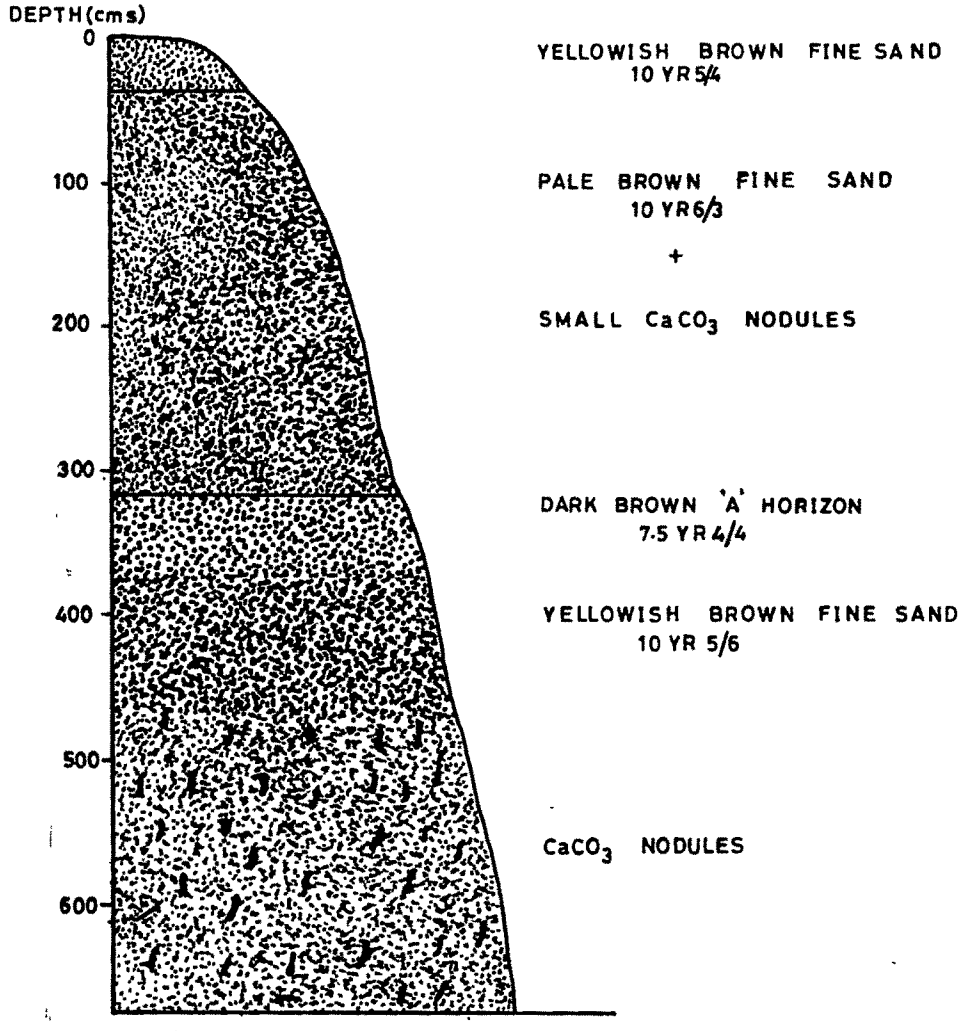


Fig 3.2.g. COMPOSITE STRATIGRAPHIC SECTION OF DUNAL MATERIAL AT BUDHA PUSHKAR
(After Wasson et al. 1983)

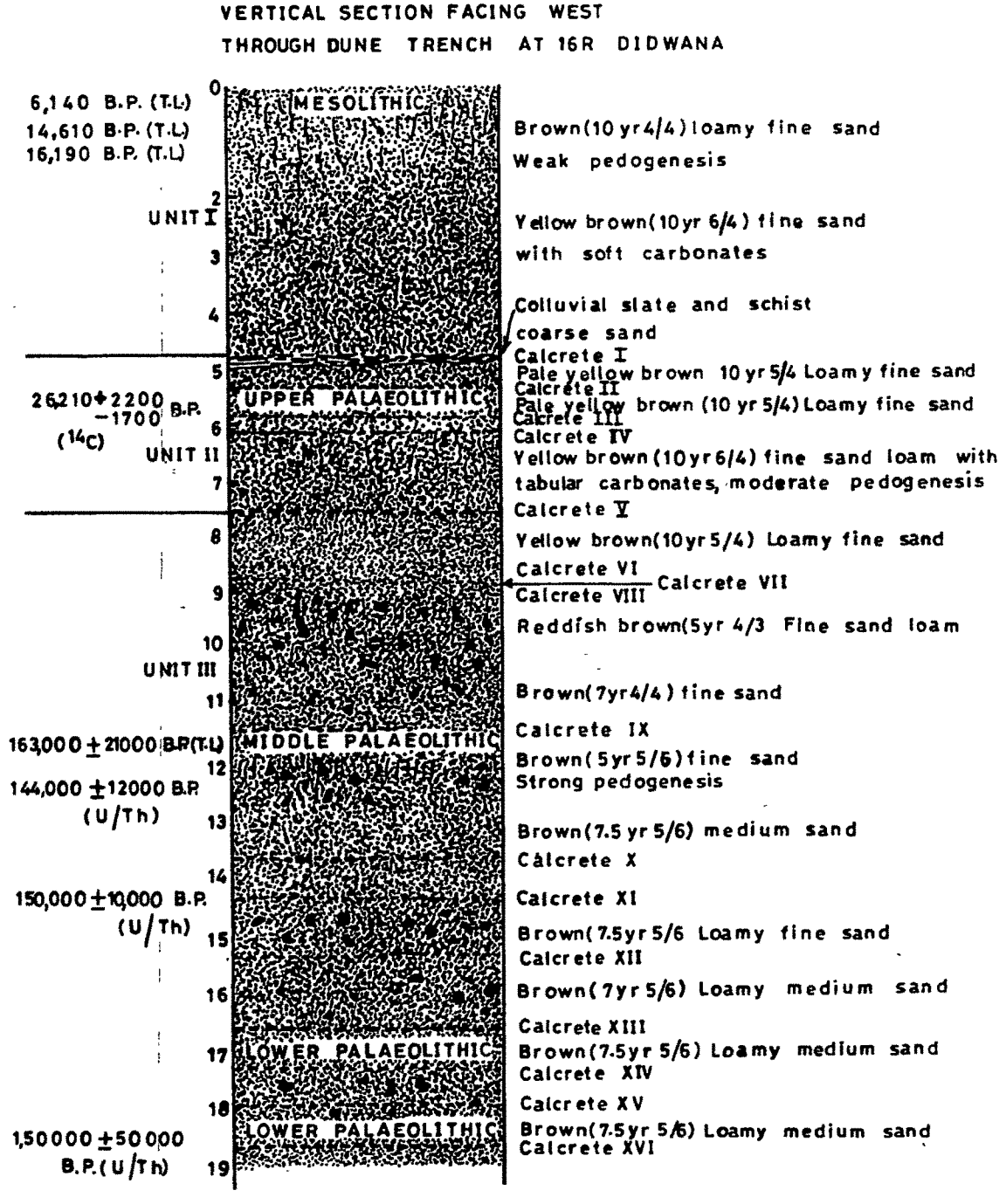


Fig.3.3. DEEP SECTION OF THE 16R DUNE AT DIDWANA
(After Misra and Rajaguru, 1986)

three major litho-units, *viz.*, litho-units I, II and III. The litho-unit I with microliths (TL date 6.1 ky B.P.) at the top is separated from litho-unit II by a thick colluvial layer with a well defined calcretic horizon, containing (C^{14} age - 26 ky B.P.). The litho-unit III is also characterised by lime nodules and calcretic bands, comprising middle and lower Palaeolithic tools (U/Th age - 131 ky B.P.). Extension of this unit to the deepest calcretic band shows the antiquity to 390 ky B.P. However, the lack of pedogenesis, induration characteristics and related features question the antiquity of this aeolian section.

Studies on the dunal sections of the study area have thrown significant light on the arid-semi arid patterns of past climate that prevailed in the Thar. The eastern parts of the study area had witnessed a semi arid to sub-humid type of climate during the Quaternary period, the degree of aridity increasing towards the western parts as indicated by well developed calcretic horizons in the different sections.

ALLUVIAL FORMATION

The study area is characterised by a rich assemblage of Recent to sub-Recent alluvial materials comprising admixtures of silt, sand, gravel and pebbles. These alluvial deposits are distributed over a vast stretch of area all along the present day active fluvial systems (Newer alluvium) and the buried flood plains of the defunct and buried palaeochannels (Older alluvium).

The studies on satellite imageries, available information and author's fieldwork have revealed that the thickness of present day alluvium does not exceed 10 m except in the central parts of the area. Here the alluvia are distributed as narrow flood plains along the rivers Sagarmati, Saraswati, Lilri and Luni in the Pushkar valley.

Alluvium varies from a highly angular bouldery gravels near the hills to coarse sands which is mostly reworked under aeolian action. The alluvium of fluviatile origin consists of boulder, gravel, pebble, coarse sand and clay. The older alluvium (Krishnan, 1956) is found at depths and also in the river beds as strongly cemented basal conglomerate, but the younger alluvium is found near the land surface along the present river channels and is devoid of any cementing

matrix. The absence of kankar formed in-situ in the younger alluvium also distinguishes it from the older alluvium Clay forms only a minor ingredient of alluvium in the present day stream channels. Raghav and Grover (1991) divided the Quaternary fluvial sediments of the Kantli river basin into three litho-units *viz.*,

i) the younger fluvial unit (F_0) confined to either banks of the present day Kantli channel and comprising the present day river sands.
ii) the older fluvial unit (F_1), comprising pedoclastic, pedogenised coarse to fine grained sand and silty sand with gravels and pebbles, and
iii) the oldest fluvial unit (F_2), comprising calcareous conglomerate with sand and silty sand.

Dhir *et al.*, (1994) described typical fluvial sequences at Silari within the Luni river basin as under:

Silari (N 26° 17' : E 73° 31')

This section is located in a granitic terrain overlain by a moderately thick alluvium. The 20 m thick alluvial strata comprises loamy, calcareous material with pebbles of quartz, gneisses, schists and chert (Fig. 3.4). The lithic calcrete horizon consists of coalesced lime nodules. The occurrence of calcareous horizons in the surficial and underlying sediments in a fluvial section reflects fluctuating climatic conditions between arid and semi-arid during the Quaternary period.

It could be very well seen through the sub-surface geological profiles in the study area that the sediments are predominated by the sandy material with intermittent coarse and fine fractions, i.e., gravel, silts and clays respectively, pointing towards a well-knitted and active drainage system in the past which has later on been disrupted due to the intense tectonic activities.

The alluvial sediments are mostly loamy and generally calcareous. The lime in the sediments had undergone reworking and redistribution to form lime nodules, kankars, pipe or tube calcretes, lithic hardpan calcretes, etc., that are indicative of the various stages of development of

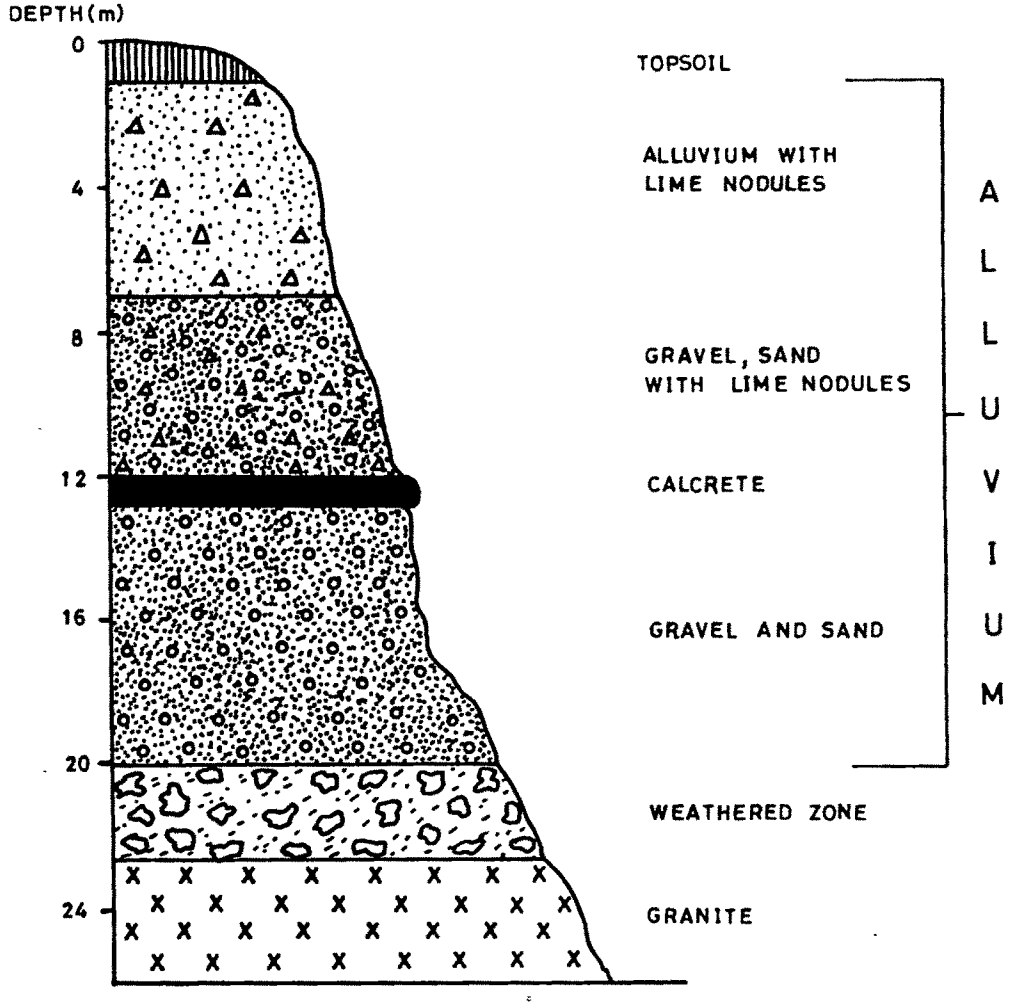


Fig. 3.4. ALLUVIAL SECTION AT SILARI (Dhir et al., 1994)

calcretes, indirectly pointing to the fluctuating arid and semi-arid climatic conditions of the past which prevailed in the area.

In order to obtain the sub-surface basement configuration, nature, thickness and distribution pattern of these fluviatile sediments in the study area, the author has constructed and studied several cross sections by taking into account available bore hole records. A few important cross sections covering the Luni and Kantli watersheds and relevant to the studies on the Quaternary geology are discussed below.

i) **Ransigaon-Thakurwas-Barr section.**

This NW-SE section (B-B' in Fig. 6.2) across the Luni river between Ransigaon in the NW and Barr in the SE clearly shows thick accumulation of Quaternary alluvial deposits in the area (Fig. 6.2.2). The area around Ransigaon is mostly a limestone terrain. Towards SE, i.e., in the areas around Nimbol, Malpuriya, Thakurwas, Khinwari, Nimaj, etc., Quaternary sediments of about 100 m thickness occur. These consist of horizons of gravels, pebbles, clay, sand and kankar. The depth to the bedrock decreases towards SE, i.e., around Nimaj and Barr. At Barr the bedrock, comprising mica-schist, occurs very near to the ground surface.

ii) **Jhak-Kalu-Badauli section.**

This NE-SW section (C-C' in Fig. 6.2) along the Luni river course between Jhak in the SW and Badauli in the NE shows relatively thick accumulations of fluvial deposits comprising sand, gravels and boulders along with thick horizons of silty clay and clay (Fig. 6.2.3). The thickness of these sediments ranges between 60 m and 100 m The occurrence of thick subsurface gravel bouldery sediments (100 - 120 m) in the Nimbol area attains a considerable significance At Jhak in the SW, the limestone basement occurs at a depth of about 15 metres, whereas at Badauli in the NE, mica-schist occurs at a depth of about 70 metres. Younger alluvium ranging in thickness from 2 to 8 metres is present all along the section. Kankar horizons occur at Kalu and Kaulia-Kalan.

iii) **Section across the Kantli river at Chaonra.**

This EW section reveals the existence of an alluvium filled buried channel of palaeo-Kantli, deposited in a nearly 2.6 km wide basinal depression (Fig. 3.5). These alluvial deposits are 40 to 50 m thick and comprise admixtures of sand, pebbles/gravels, kankar, clays and silts. The pebbles and gravels (20 - 30 m) in a sandy matrix are concentrated in the bottom parts of the basin. Few clayey intercalations are also present in this horizon. Overlying this gravel horizon is a 10 - 15 m thick continuous clayey horizon with silty admixtures. The sand above these silty clays is 10 - 15 m thick.

iv) **Section across Kantli river at Jodhpura.**

This section depicts a 2 km wide palaeochannel of the Kantli river consisting of 30-40 m thick alluvial deposit of gravels, pebbles, sand and silt (Fig. 3.6). Basal conglomerate/gravels of about 10 m thick occur in the middle portions of the basinal structure. Overlying this is a 20 - 25 m thick horizon of sand and silt with lenses of clay (8 - 15 m thick).

Based on the above obsevations a tentative chronological classification of the fluviatile formations and their characteristic landforms in the study area has been prepared and is given in Table 3.3.

LACUSTRINE FORMATION

The study area inhibits numerous continental salt lakes and playas with typical internal drainage systems. Sambhar, Didwana, Kuchaman, Tal Chhapar and Sujangarh are the important salt lakes and Pushkar and Budha Pushkar are the fresh water lakes in the study area. The Sambhar lake is the largest of all these lakes with a lacustrine sediment thickness of about 25 metres.

The lacustrine records of these above mentioned lakes/playas have been studied by a number of workers *viz.*, Singh *et al.* (1974), Bryson and Swain (1981), Wasson *et al.*(1983, 1984) and Rai

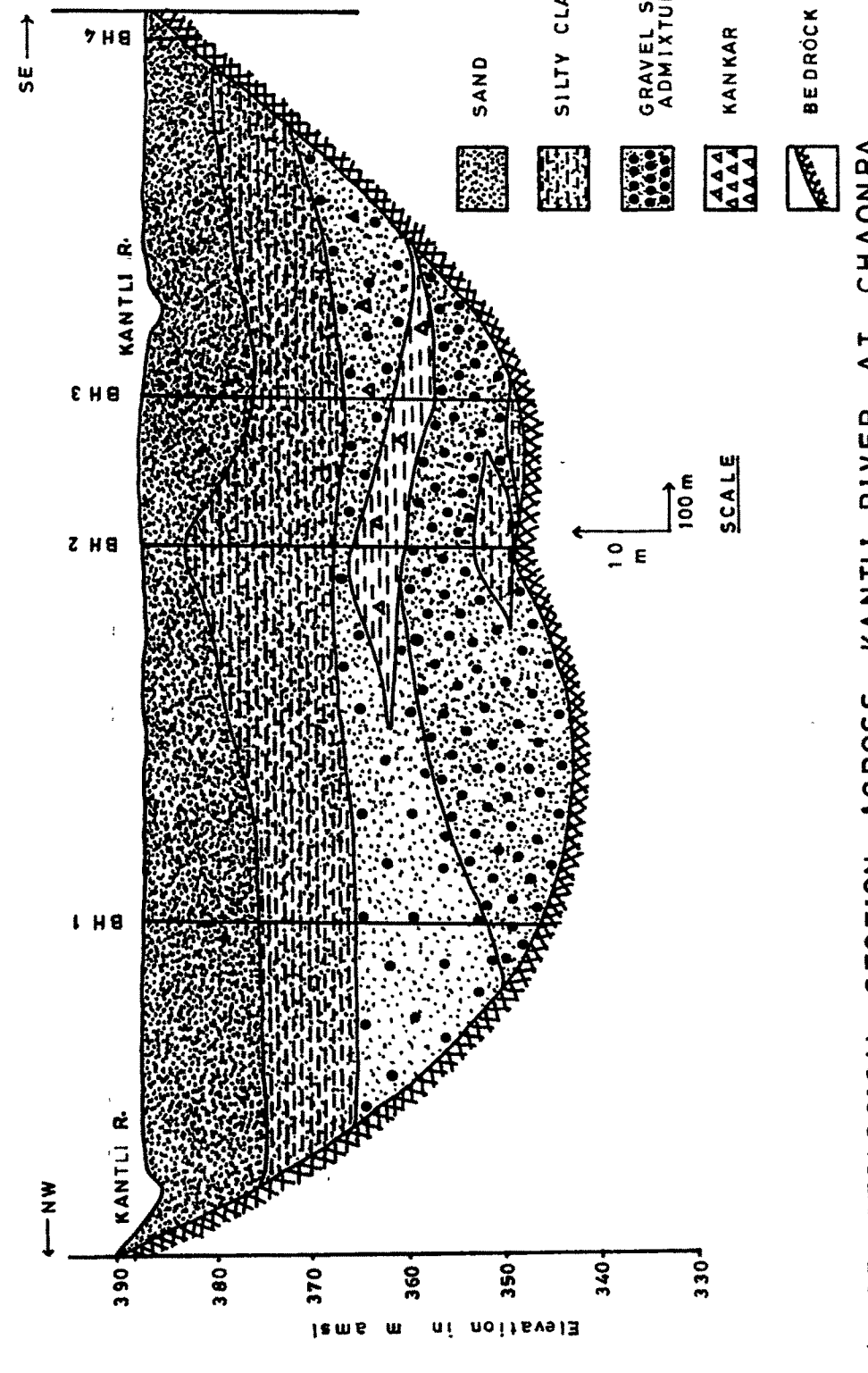


Fig. 3.5. GEOLOGICAL SECTION ACROSS KANTLI RIVER AT CHAONRA
(Based on CGWB bore hole data)

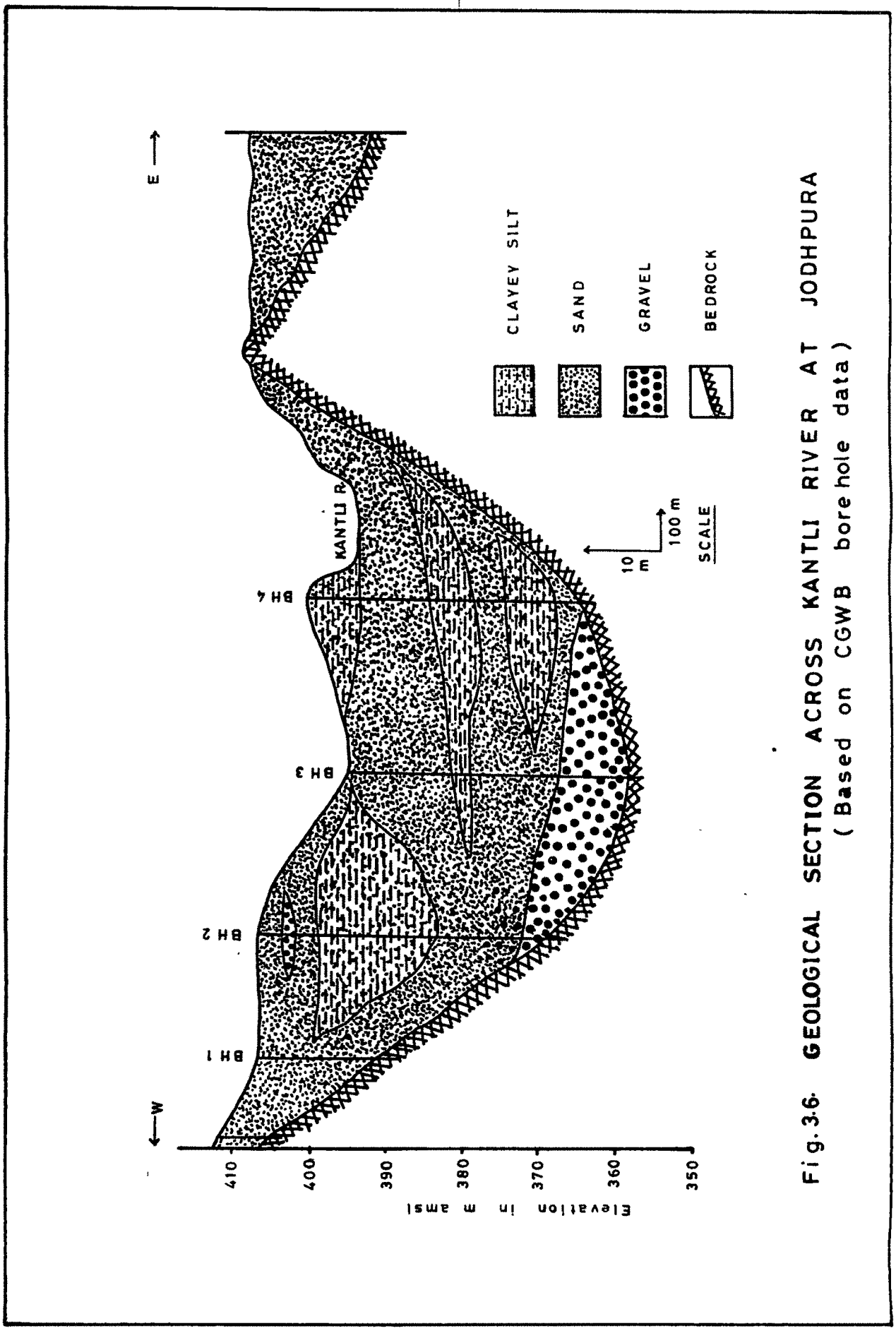


Fig. 3.6. GEOLOGICAL SECTION ACROSS KANTLI RIVER AT JODHPURA
(Based on CGWB bore hole data)

Table 3.4 Chronological classification of the fluviatile formation and the typical landforms of study area (Modified after Ghose 1982, and Raghav and Grover 1991)

Geology	Type of sediments and occurence	Nature of landform
Younger alluvium (F_0)	Present day fluvial, gravel sands and silts in the river channel and braids. Present flood plains	Depositional
Older Alluvium (F_1)	Pedoclastic, pedogenised coarse to fine grained sand and silty sand in Backswamps, Left out channels, older flood plains and terraces	Depositional
Oldest Alluvium (F_2)	Calcareous riverine conglomerate with sand and silty sand	Depositional
Older colluvium, talus and Pediment hillwash	Peneplain	Initially erosional, later depositional. Initially depositional, later erosional
	1st Peneplanation	
Delhi Supergroup of rocks with post-Delhi intrusives	Hill ranges, discontinuous hills and outcrops	

(1989), Rai and Sinha (1990). The inferences on the sedimentation records for selected lakes are given as under:

Sambhar Lake: The detailed analysis of the bore hole records of the Sambhar lake showed the dominance of clay/mud and silt sequences. Kankar is mostly concentrated as nodules in the upper horizons. Layers of gravel and coarse sand also occur within the sediment. A typical lacustrine litholog of the Sambhar lake is given in Table 3.4.

Fence diagrams depicting the distribution pattern of lacustrine sediments in the Sambhar lake at Sambhar and Nawa, based on the geoelectric records (GMICC, 1986) are shown in figures 3.7 and 3.8. The fence diagrams at the two locations show the occurrence of basal gravels and kankars. This is followed upwards by laminated clay and silt sequence of 25 m thickness Lenses of clay are seen to occur in this horizon. Overlying this horizon is a sequence of thick black clay ranging in thickness from 5 m to 10 m The surface sand/silt above this clay horizon is about 3 m thick.

Kuchaman Lake: Rai and Sinha (1990) worked out the sedimentation history of the Kuchaman saline lake and concluded that the formation and evolution of this lake is largely controlled by the climatic variation in a denudational basin along a palaeodrainage course. The generalised stratigraphy of the Kuchaman lake is given in Table 3.5. Figure 3.9 represents the fence diagram of the typical lacustrine lithology of the Kuchaman lake.

Didwana Lake: Wasson *et al.* (1983, 1984) were the first to carry out a detailed study on the salinity and lake level history at Didwana based on the variation of texture of clastic sediments, mineralogy of evaporites and precipitates and the relative chemical activity of the major precipitates (Fig. 3.10). They inferred a hypersaline condition at the last glacial maximum followed by widely fluctuating lake levels between 13,000 yrs and 6000 yrs B.P. and a high water level between 6000 yrs and 4000 yrs B.P.

Talchhapar Lake: The lacustrine sequence of the Talchhapar salt lake has been studied in detail by Achyuthan and Reddi (1992). The lacustrine sequence from bedrock is calcrete (<1 m).

Table 3.4. Typical lacustrine lithlog of Sambhar lake (bore well near Hindustan Salt Co. office, Sambhar lake) [Total depth drilled: 128 m]

Lithology	Depth range (m)	Thickness (m)
Surface sand	0 - 11.6	11.6
Fine sand with kankar	11.6 - 17.1	5.5
Coarse sand (Brown)	17.1 - 20.8	3.7
Clay and Kankar	20.8 - 27.5	6.7
Medium sand and kankar	27.5 - 32.1	4.6
Bedrock	32.1 onwards	

Table 3.5. Generalised stratigraphy of the Kuchaman lake (after Rai and Sinha, 1990)

Litho-unit	Shallower portion bounded by merging rocky pediment	Deeper portion	Shallower portion bounded by sand dunes
Unit A	Grit/Colluvium	Silt	Silt
Unit B	Intercalated silt/clay sequence with occasional grit	Dark Clay	Silt/clay inter laminations
Unit C	Hard lithified carbonate layer	Hard lithified carbonate layer	Hard lithified carbonate layer
Unit D	Pebble/Sand	Laminated clay with carbonate intercalation	Silt/clay inter laminations
Unit E	Colluvium with calcareous cement (Calcrete)	Reddish sand/silt with calcareous cement	Reddish silt with calcareous cement

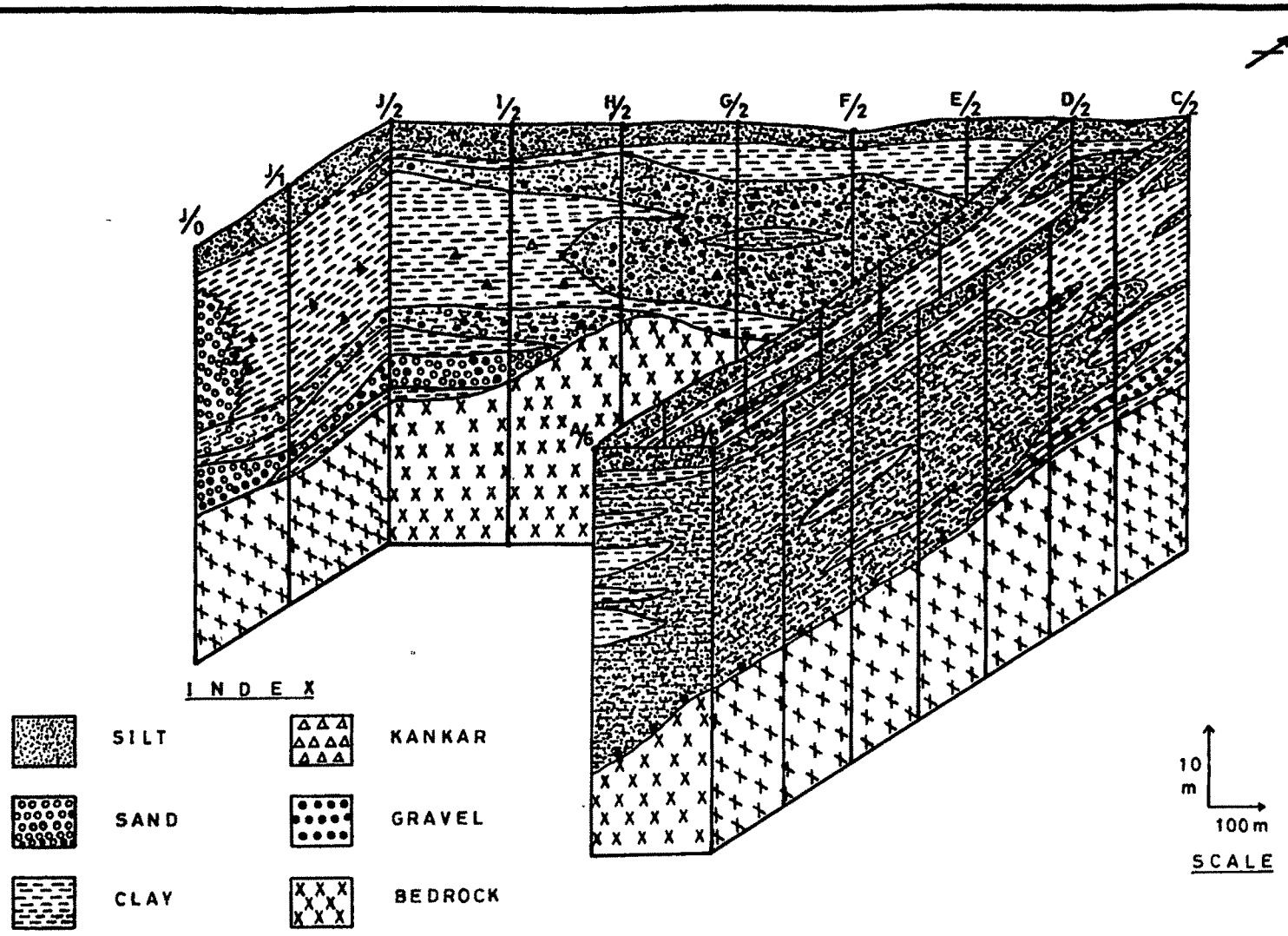


Fig. 3.8. FENCE DIAGRAM DEPICTING DISTRIBUTION PATTERN OF LACUSTRINE SEDIMENTS IN SAMBHAR LAKE AT NAWA. (After GMICC, 1986)

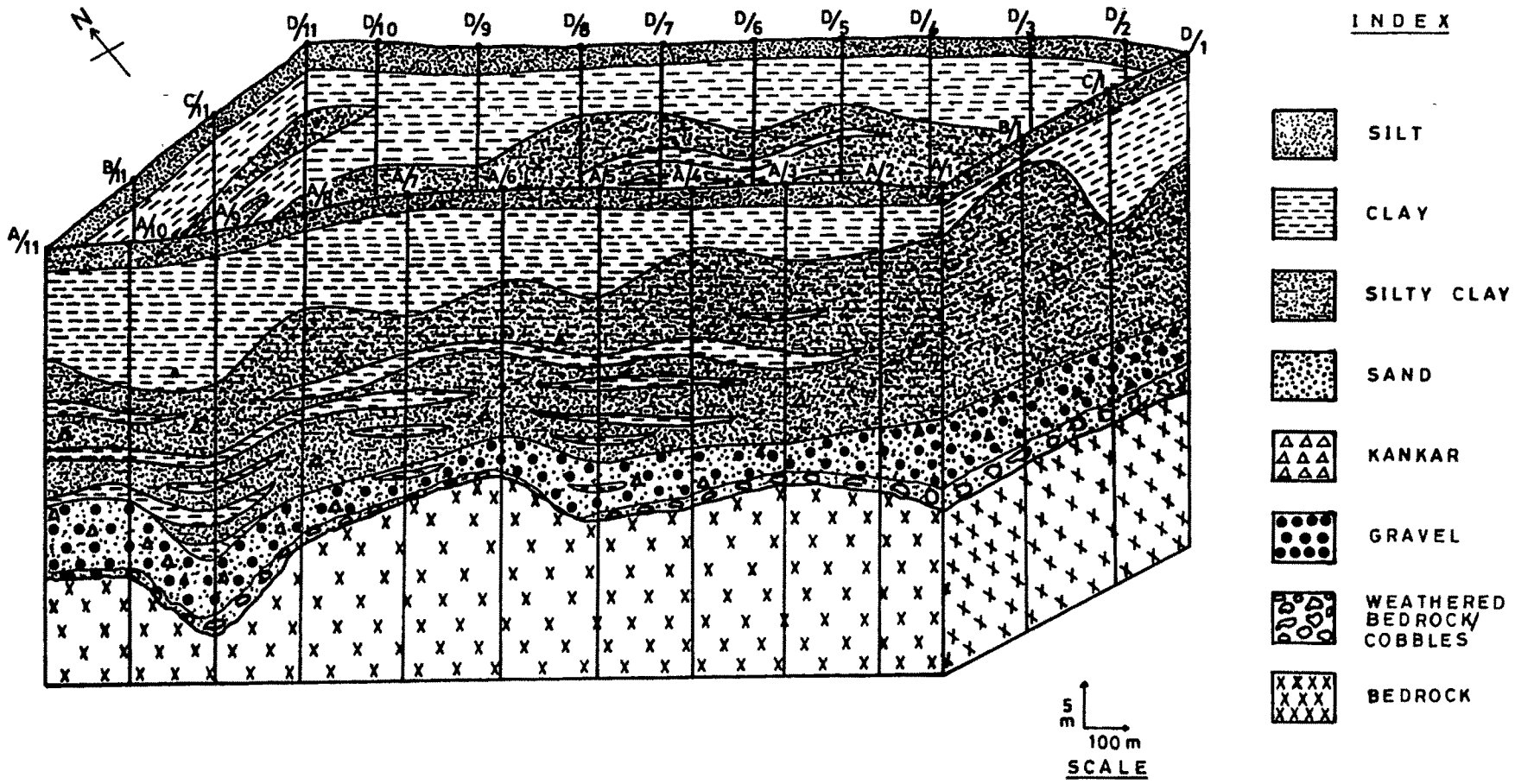


Fig. 3.7. FENCE DIAGRAM DEPICTING DISTRIBUTION PATTERN OF LACUSTRINE SEDIMENTS IN SAMBHAR LAKE AT SAMBHAR (After GMICC, 1986)

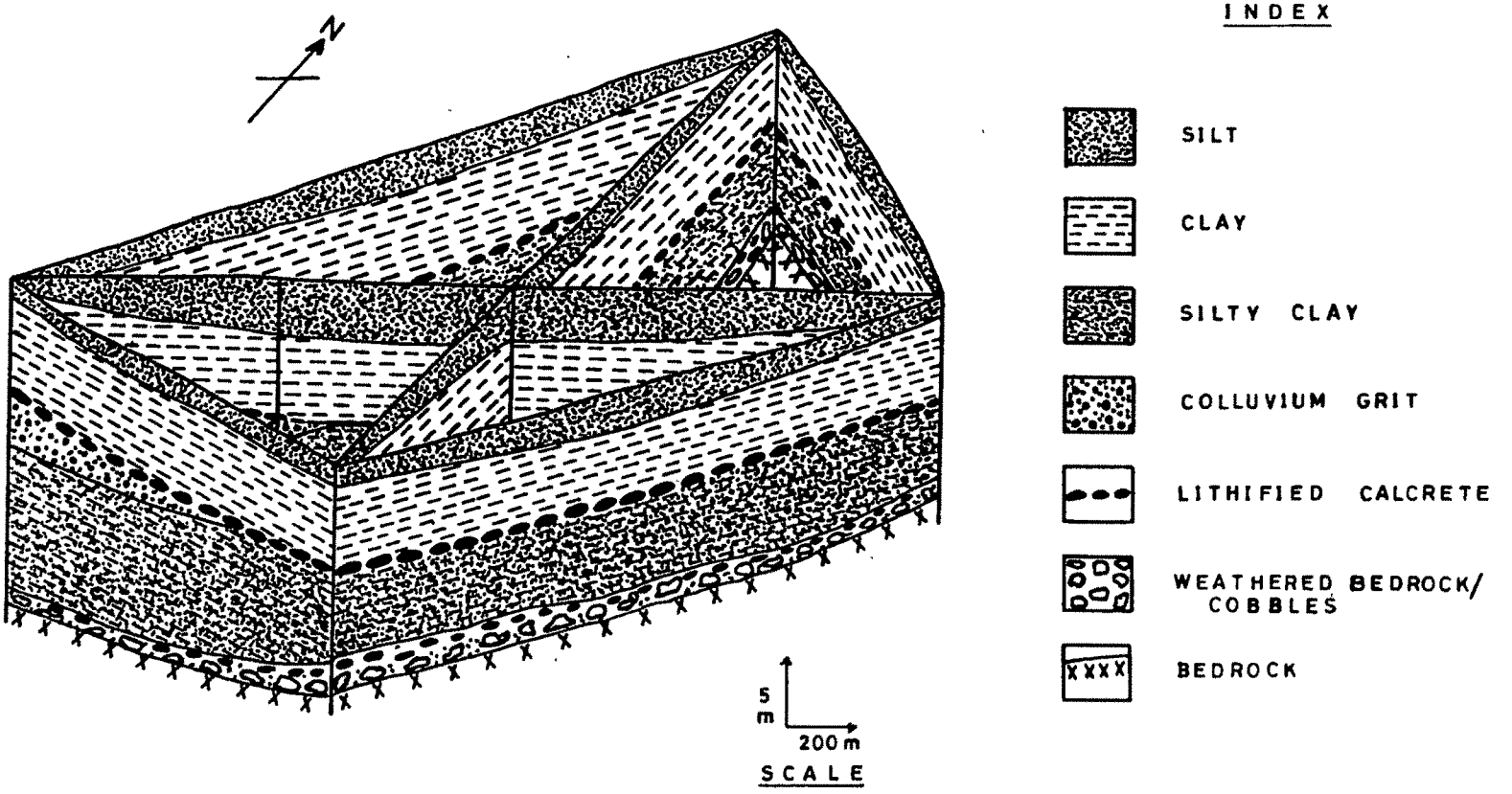


Fig. 3.9 FENCE DIAGRAM DEPICTING DISTRIBUTION PATTERN OF LACUSTRINE SEDIMENTS IN KUCHAMAN LAKE

(Based on Rai and Sinha, 1990)

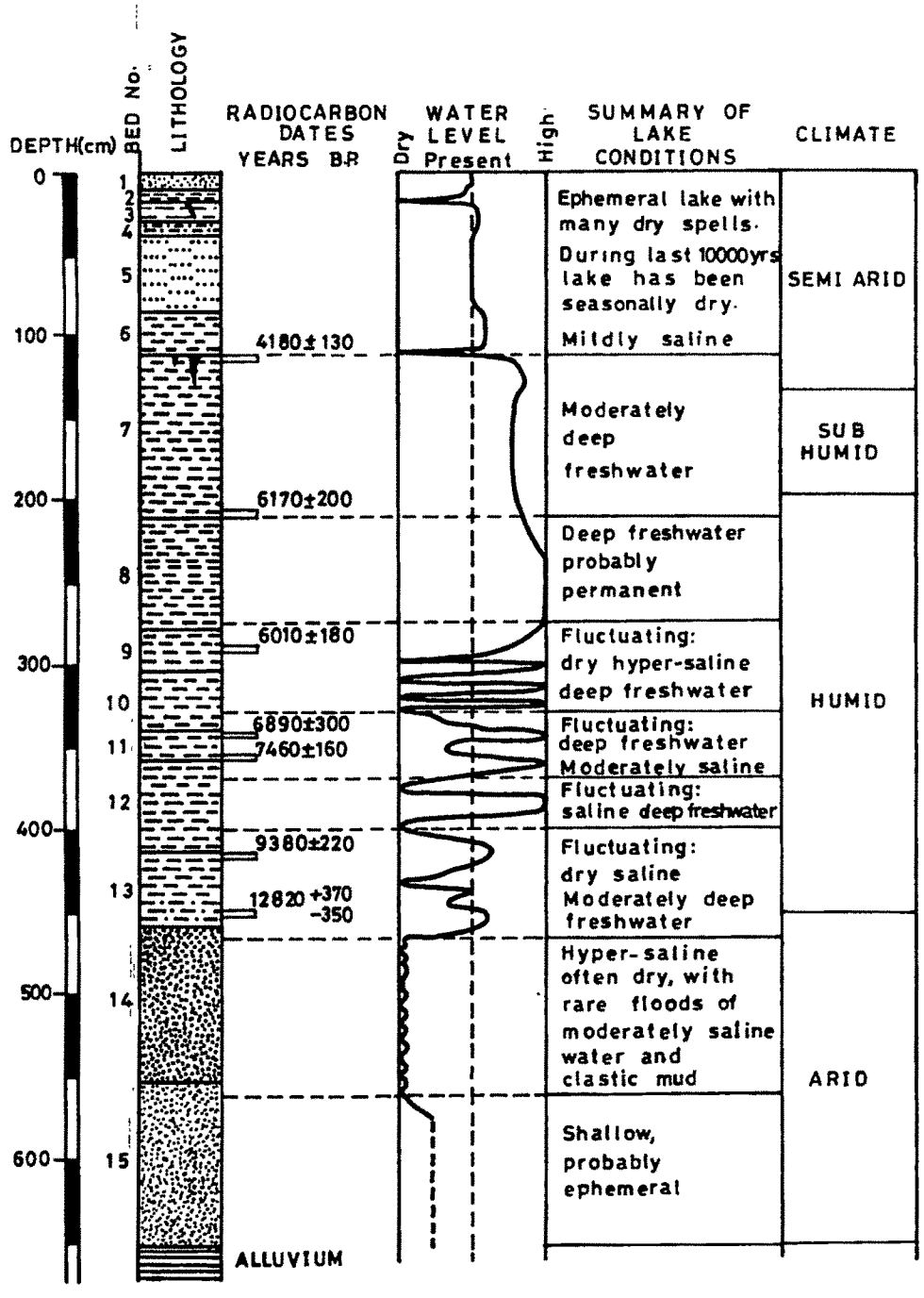


Fig. 3-10. STRATGRAPHY, LAKE WATER LEVEL CURVE, SUMMARY OF LACUSTRINE HISTORY AND RELATED CLIMATIC CHANGES AT DIDWANA.
(After Wasson et al., 1983 and Singh et al., 1990)

fluvio-aeolian sediments (5 m) and clay (2 m). They viewed that the few iron precipitates in the form of segregations and dendritic patterns within the clay horizons indicate reducing and anaerobic micro-environmental conditions for the precipitation of iron oxides that was a resultant of climatic changes from semi-arid to sub-humid conditions.

A comparative account on the subsurface records (Rai, 1989), highlighting the sedimentation history of the Sambhar, Kuchaman and Didwana lakes have revealed the following facts:

(i) Sambhar-Kuchaman lake system exhibit the development of lithified calcrete, marking the beginning of sedimentation.
(ii) Sediments in all three lakes are dominated by the clayey-muddy sequence.
(iii) Sandy sediments are proportionately less.
(iv) These lakes do not show any consistency in the sedimentation records.

The lacustrine sediments encountered in the lake sections can be assigned to specific environments of deposition and also to the past climatic conditions. Neotectonic activities which resulted in the drainage disruption, formation of sag ponds, etc., have played a major role in the evolution of these lakes. The fluctuating environments and climate through time has left its imprint on the nature and lithology of the lacustrine deposits.

DURICRUSTS

The duricrusts and kankar form part and parcel of the Quaternary fluviatile, lacustrine and aeolian sediments.

Calcretes and Ferricretes: Calcrete is the most conspicuous duricrust formation in the study area. The calcretes mostly lie at or close to the surface, although at places, they are concealed by aeolian sediments. Calcretes exhibit a large range in the degree of development and morphological appearance, depending on the age of the landform and local physiographic setting. In the study area, soft nodular calcretes, lithic hardpan calcretes, pipe or tube calcretes, etc. are seen within the Quaternary sediments. The hard, nodular calcrete is most extensive and forms

a thick horizon below the surface soil in the old aggraded plains of the Luni basin and also at other places (Plate III.5).

In the aeolian sandy plains, the calcretes occur mostly in the late Quaternary sediments. These calcretes may also occur as reworked deposits of fluvial activity. Successive overgrowth rings in nodular calcretes indicate alternating arid and semi-arid conditions that prevailed in the past.

The ferricretes, probably of Tertiary period are rarely seen in the study area. Few occurrences are reported from the Nagaur and Bikaner districts. These must have formed under the strong influence of fluctuating water table in a humid environment. The ferricretes are usually overlain by calcretes of a subsequent arid phase.

Gypsicretes and Gypsum Beds: In the study area the development of gypsicretes and thick gypsum beds are very characteristic of the aeolian terrrain. These are usually seen within the interdunal depressions and in the areas around the playas and salt lakes. Local mining of these gypsum deposits is common in the northern, central and western parts of the study area (Plate III.6).

PRESENT DAY SOILS

Apart from fluvial, aeolian, colluvial sediments and various duricrusts, present day soils, a veneer of associated parental materials (consolidated and unconsolidated both) constitute an important unit of Quaternary stratigraphy. In the study area these soils are of lateritic (red) and arid types characteristics of residual rocky peneplains and residual aeolian plains respectively.

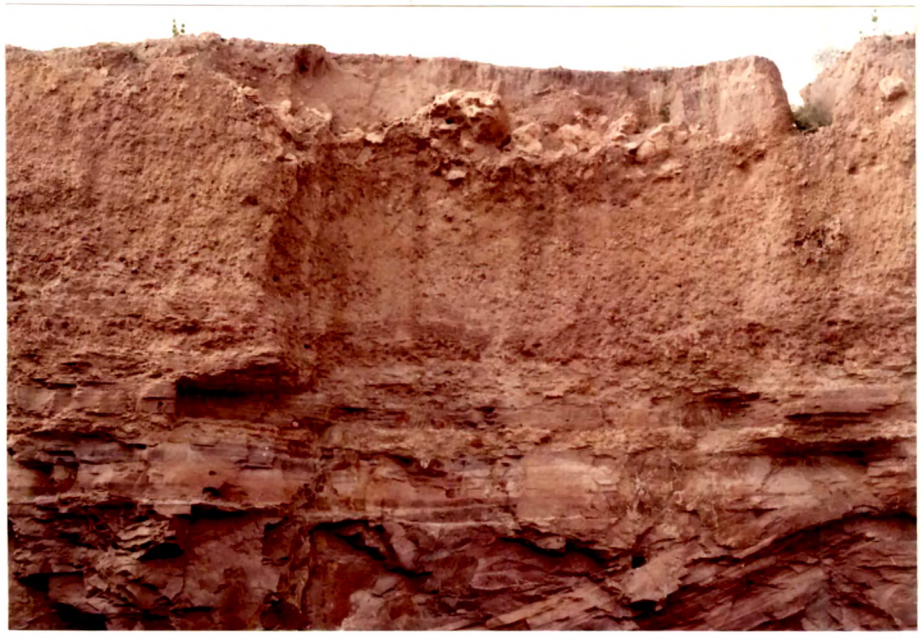


Plate III.5 Field photograph showing calcretic crust developed over Jodhpur sandstones. Location: Nimbi Jodhan

Plate III.6 Field photograph showing development of sub-horizontal gypsicretes in vast interdunal plain. Location: Bhilari Dhani