7

PALAEOCLIMATES

CHAPTER 7

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GENERAL

The Gujarat alluvial plains which form the SE margin of the Thar desert, provide an opportunity to assess the nature of past climatic changes in Western India. The margins of the deserts are the areas that have preserved significant imprints of the climatic fluctuations. Though fairly detailed account of the palaeoclimatic changes during Quaternary is available from other parts of western India, such studies in Gujarat alluvial plains have been lacking. A big gap thus exists in the available palaoeclimatic record of western India in the absence of any information from this promising area. The sediments exposed in the various semi-arid basins in this part have preserved a complete record of the palaeoclimatic changes during Late Quaternary. The Mahi river flowing across these plains, has exposed the Quaternary sediment successions in the form of cliffs ranging in height from 5 m - 35 m.

The sediment sequences provide complete record of the palaeoclimatic changes in the basin during late Quaternary. The exposed sequences comprise sediments deposited under three major depositional environments viz. fluvial, aeolian and marine. The sediment record is frequently interspersed with several buried soils which mark the periods of non-deposition and soil formation. These reveal dominant pedogenetic activities, changing amplitudes of desertification through distinct changes in channel planforms, change in mode of sediment transport, change in fluvial regime and sediment size. Thus the study of the stratigraphic record of such a desert margin was found promising for providing evidences of past climatic ameliorations.

The present day Mahi flowing across these alluvial plains has a mean annual precipitation ranging from 650 to 800 mm in the lower reaches and 1000 to 1150 mm in the upper catchment area (Merh, 1995), and marks sub-humid to semi-arid climate. Earlier workers (Allchin and Goudie 1971; Goudie 1973; Allchin *et al.*, 1978; Pant and Chamyal 1990, Merh 1992; Merh and Chamyal 1993; Chamyal 1995; Chamyal and Merh 1995; Khadkikar *et al.*, 1996) have provided tentative chronology of palaeoclimatic events based on archaeological studies and by comparing the sediment succession with global climatic events. Zeuner (1959) and Fairbridge (1961) attempted to correlate the interglacial stages with various high sea-levels of the Quaternary. None of the subsequent studies has offered convincing alternative sea levels for major part of the early Quaternary, and details of sea levels and related climatic fluctuations till the advent of Middle Pleistocene are not available. In this connection the works of Emiliani (1955), and Chappel and Shackleton (1986) do provide some information on Quaternary sea levels and palaeoclimates but as will be seen in figure 7.1, their postulations differ in respect of ages and durations. An attempt has been made to correlate the exposed succession in Mahi valley with global sea-level curves (Fig. 7.1). In the lines to follow, the present author on the basis of the tentative thermoluminescence dates (provided by Physical Research Laboratory, Ahmedabad), has made an attempt to reconstruct a broad chronology of the climatic events that influenced the sedimentation pattern in the Mahi basin. The samples for TL-dating

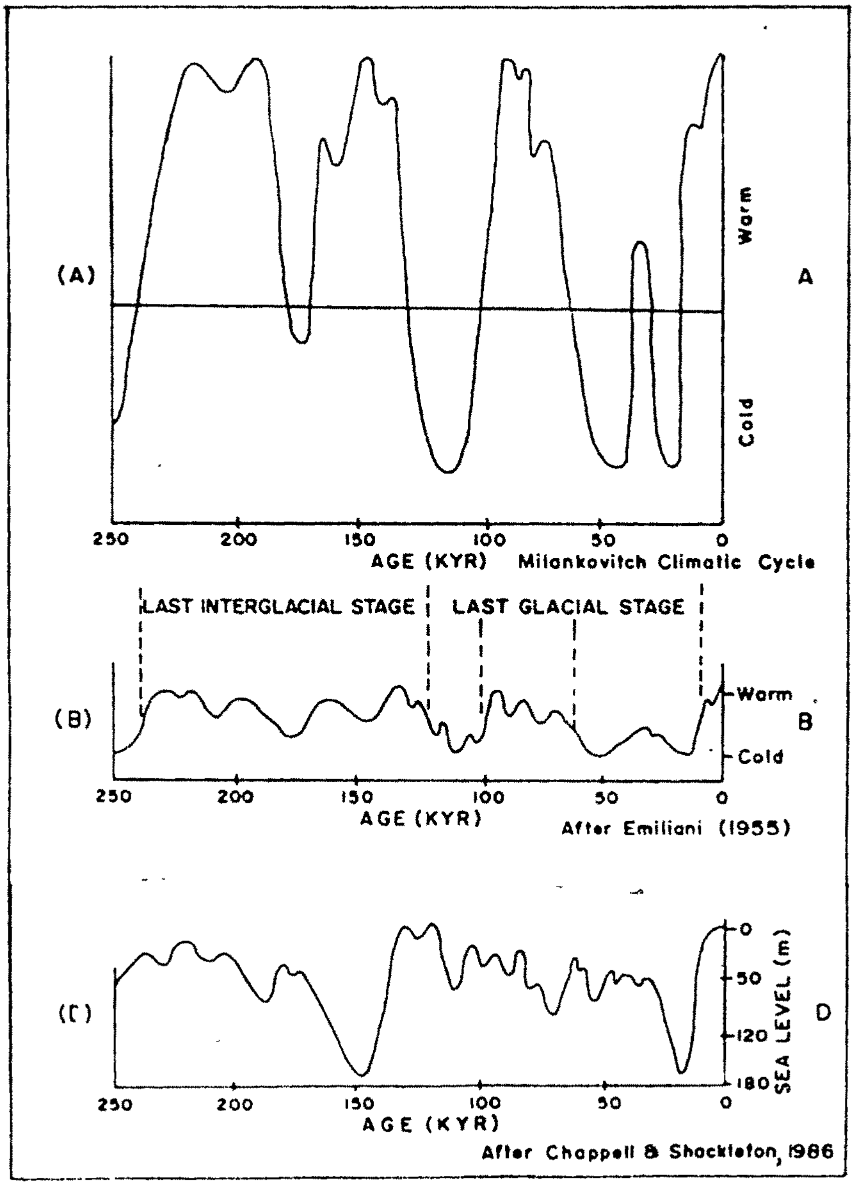

Fig. 7.1 Palaeoclimatic and sea-level curves.

were collected from the best exposed section located 22 kms NW of Baroda on the left bank of Mahi at Rayka (type section).

A broad scenario of the climatic changes during the entire sedimentation of Quaternary succession in Mahi basin has been worked out by taking into account (a) lithostratigraphy, (b) change in lithofacies, (c) change in channel planforms, (d) geomorphology, (e) grain size variations, change in mode of transport and (f) palaeosol horizons. These parameters are significantly influenced even by small changes in climatic conditions. The subtle changes in these parameters have been documented from the exposed sediments and critically evaluated to arrive at the climatic variations as revealed by the sediments. The parameters mentioned above and observed in the field have been supplemented by lab data which include clay mineralogy and granulometric analysis. However these studies have been used as supporting evidences to the field observations to get a more accurate picture of the climatic conditions. For reconstructing the palaeoclimatic record, all the evidences were analysed and following assumptions have been made while doing so :

(1) fluvial sedimentation must have taken place during humid to sub-humid climate alongwith the intervening relative dry phases.

(2) pedogenic changes in the succession are indicative of sub-humid to semi-arid climate, that marks the period of non-deposition and sub-aerial weathering.

(3) thick pile of aeolian sediment suggests onset of aridity, during this period high wind activity deposited fine sands and silts from the nearby floodplain areas.

(4) well preserved dunal topography is indicative of stabilization of aeolian sediments. This suggests increase in relative humidity in the area.

(5) the younger surface comprising fluvial and estuarine sediments suggests onset of humid climate in the area marking the high sea-level or transgression of sea after the aeolian phase.

ROLE OF CLIMATE ON SEDIMENTATION PATTERN

The sediment succession mapped in the Mahi basin, ideally reflect the role played by climate in their deposition and post-depositional diagenetic changes. Earlier workers, on the basis of indirect evidences viz. archaeological and global sea-level curves had tried to construct the palaeoclimatic sequence of the Gujarat alluvial plains and have assigned tentative dates to some of the marker lithounits in the various basins (Pant and Chamyal, 1990; Merh, 1992; Merh and Chamyal, 1993; Chamyal and Merh, 1995; Khadkikar *et al.*, 1996). Recently Tandon *et al.*, (in press), based on luminescence dates have assigned ages to some of the marker horizons in the Sabarmati basin located on the western fringes of the study area.

The exposed sediment succession in the Mahi basin comprises coarser as well as finer lithounits. Overall four major aggradational phases in the basin have been identified, phases 1 and 2 are the fluvial events, phase 3 represents aeolian aggradation and phase 4 fluvial as well as marine (estuarine) aggradation. The aggradation 1, 2, and 3 marks the older aggradational surface (S_1), while the phase 4 marks the younger aggradational surface (S_2).

CHRONOLOGY OF PALAEOCLIMATE IN MAHI BASIN

The Mahi flows through varied terrain, cutting across the rocky uplands, alluvial plain and coastal zone. The sediments exposed in the lower reaches (in alluvial and coastal plain) reveal complete sequence compared to the uplands. To construct the palaeoclimatic sequence, studies were mainly concentrated in the alluvial and coastal zones.

The late Quaternary sediment succession in the lower reaches of Mahi is marked by a thick vertisol horizon at the base (Plate 5.11). The vertisol horizon is indicative of several dry and wet spells (Weaver, 1989). The intense fracturing and desiccation in this unit suggests considerably long dry period. This lithounit according to Merh (1992) was deposited under tidal environment and marks the high strandline of Middle Pleistocene. Recently on the basis of micro-palaeontological studies it has been emphasized that the sedimentation of this unit took place under estuarine to marginal marine environment (Raj and Chamyal, Comm.). This suggests the deposition of vertisol sediments during humid to sub-humid climate. The high concentration of montmorillonite (smectite) in vertisol is indicative of low leaching and poor drainage condition (Singer, 1984) and suggests a change in climate from humid to semi-arid. This change in climate alongwith intervening wet and dry phases is well evidenced by pedogenesis, intensive fracturing, desiccation, occurrence of rhizoliths; and high concentration of calcrete nodules (Birkeland, 1984; Weaver, 1989; Mack *et al.*, 1993 and Coulombe *et al.*, 1996). The entire phenomenon of sub-aerial changes is an indication of time interval before the start of fluvial sedimentation and an onset of humid phase. This could be taken as an evidence of a climatic change, pointing to increased precipitation in the area.

The main bulk of sediments of aggradation phase 1 comprise two coarse lithounits (Gp and Gt) and finer lithounits (Sh and St) which separates the Gp and Gt. The author has tried to reconstruct a tentative chronology of the sediment succession from the basal Gp-lithounit to the St-lithounit. The fluvial sedimentation commenced in the basin with the deposition of planar cross-stratified conglomerate (Gp). On the basis of lower Paleolithic artifacts from this lithounit (Subbarao, 1952), an age of around < 200 ka B.P. has been assigned to these lithofacies. This suggests that the climate changed from semi-arid to humid to sub-humid around 200 ka B.P. The deposition of this lithounit during major phases of semi-arid to sub-humid suggests a short humid phase around < 200 ka B.P. which is correlatable with the humid phase (after 200 ka B.P.) of the arid and semi-arid region of southern Africa (Brooke *et al.*, 1990).

The overlying thick horizontally stratified sand lithounit is indicative of overbank sedimentation. The change in lithofacies from Gp to Sh suggests change in flow regime, channel planforms and change in bedload form coarse to fine. The thick pile of this planar stratified sand suggests longer time span and low rate of sedimentation. The occurrence of hardpan calcrete layer in the overbank as well as in the channel zone suggests shallow channel and wide floodplains, where sedimentation was taking place under episodic flood events. This characterizes the highly ephemeral stream nature that existed during the arid phase (Miall, 1986). The formation of calcrete layers and the evidences of lateral migration of channel (channel avulsion) suggests intervening more humid and dry phases. Not much pedogenesis has taken place in this unit which suggests frequent flood events and short time span to sub-aerial exposure. On the basis of the tentative age assigned to lower gravel (Gp) < 200 ka B.P., this event of overbank deposition must have taken place between 180 ka to 140 ka B.P. This matches well with the fluctuating sea-level curves of Chappell and Shackleton (1986) when the climate was sub-humid to semi-arid.

This is overlain by medium to coarse grained trough cross-stratified sand lithounit (St) of 1 m - 1.5 m thick. The shallow troughs of sand are indicative of initiation of slightly wetter phase at around 130 ka B.P. (based on the sea-level curves (and the tentative luminescence date of the overlying conglomerates). The occurrence of vertisol in the extra-channel areas points to bank stability and spells of wet and dry periods. The grain size data also suggests aeolian influx, confined to the floodplain area of the valley. Due to non-availability of an absolute date for this unit and the overlying gravel being around 108 ka old, it is presumed that the deposition of this unit and formation of vertisol might have taken place around 135 ka - 110 ka B.P. (?) (Last interglacial stage). However no evidences of any coarser deposits of this period were noticed.

The coarser trough cross-stratified conglomerate lithounit dated tentatively at ~ 108 ka B.P., overlies the vertisol and marks the top of the aggradation phase 1. The trough amplitudes and the coarser bed-load comparatively refer to more humid phase. From the various sea-level curves of Emiliani (1955); Chappell and Shackleton

(1986); Gillespie and Molnar (1995), it is noticed that there was a rise in sea-level at around 105 ka B.P. According to Nanson *et al.* (1992) the stage 5 was the pluvial phase that existed between 120 ka to 85 ka B.P. in Australia. The lithounit suggests a fluctuating climate with the intervening dry and wet spells and is evidenced by the ill-sorted nature of the calcrete clasts in conglomerate.

This conglomerate (Gt) is overlain by a (12-15m) thick sheetflood deposit. This is an oldest deposit of the aggradation phase 2 and is bracketed between ~ 86 ka to 50 ka B.P. (TL dates). This aggradational phase shows multiple soil horizons, a total number of three phases of soil development are recognized, pointing to three palaeo-surfaces. The pedogenesis of these horizons suggests intervening periods of non-deposition and sub-aerial weathering indicative of warm-humid climate. The three palaeosols show two weakly developed brown soils and one well developed red (rubified) soil which marks the top of the aggradation phase 2 (Plate 5.11). The brown soil-I that overlies the trough cross-stratified gravel has been dated at around ~ 86 ka B.P. This indicates that the sediments were deposited during slightly wetter phase between 86 ka to 80 ka B.P. This matches well with the sea-level curves (Fig. 7.1), with $\delta^{18}O$ substage 5a (Shackleton and Opdyke, 1973), and with stage 5 - pluvial phase in Australia (Nanson *et al.*, 1992). Juyal *et al.* (1995) have reported relative wetter phase at around 87 ka B.P. on the basis of the oyster shells from the Saurashtra coast, Gujarat. The pedogenic activity and calcrete formation points to a relatively dry phase. The overlying brown soil-II unit that dates back to ~ 60 ka B.P., suggests that the next wet phase was responsible for the deposition of this unit which later was subjected to subaerial weathering. The clay mineral assemblages of these two units is dominated by montmorillonite (smectite) alongwith subordinate amount of kaolinite and illite. The slightly high concentrations of kaolinite in this horizon is suggestive of high leaching and moderate drainage conditions (Singer, 1984; Weaver, 1989).

The overlying red silty sand lithounit (rubified soil) dates back tentatively to ~ 51 ka B.P. The sediments of this redsoil were laid after the pedogenesis of the brown soil-II. Laterally, the redsoil is replaced by sandy gravels indicating a more humid phase at ~51 ka which matches well with the sea-level curves (Fig 7.1). The intense pedogenesis and typical red colour suggests strong evidence of climatic fluctuations from wet to dry. From the clay mineral assemblages, dominated by smectite (montmorillonite) with subordinate amount of illite, kaolinite and hematite in trace amount suggests that the sediments were rich in ferromagnesian minerals which underwent diagenetic changes and led to the formation of ferric hydroxide during the process of hydrolysis (wet phase). Later the following dry phase resulted in the formation of more clay minerals like montmorillonite and transformation of the released ferric hydroxide to hematite during oxidizing conditions (dehydration) (Birkeland, 1984).

The homogenous red colour of the unit and high concentration of calcrete nodules in Bk horizon suggests that this lithounit has undergone strong pedogenesis during the sub-aerial processes under warm-humid or sub-humid to semi-arid climate. The redsoil horizons within the miliolites in Saurashtra have typically substantiated the intervening semi-arid to sub-humid phase in a prolonged glacial arid period developed during relatively moist oxidizing conditions in the presence of iron-rich minerals derived from nearby trappean rocks (Patel and Bhatt, 1995). Thermoluminescence dating of the comparable unit in the Sabarmati basin has been assigned an age of 58 ka B.P. (Tandon *et al.*, in press). Radiometric ages of carbonate nodules from the red-soil horizon assign an age of around 23 ka B.P. (Allchin *et al.* 1978). However, the ^{14}C dates of these nodules (i.e. 23 Ka) are considered to be the minimum ages and it is deduced that this pedogenetic event could have taken place any where before 23 Ka. Based on the TL-dates of the red-soil sediment in Sabarmati and Mahi valleys it has been possible to correlate them. Whereas considering the minimum age of the carbonate nodules (23 ka), the red-soil formation event could be bracketed between ~51 ka to 23 Ka B.P. This is correlatable with the stratigraphic record of Thar desert, where evidences of wetter conditions existed between the same period (Dhir *et al.* 1994).

Red soil formation in the Maghreb desert (North Africa) is interpreted to manifest climatic amelioration between 40 ka to 20 Ka B.P. (Rognon, 1987). Cooke and Verhagen (1977) studying the Kalahari desert assumed that a more humid climate as revealed by Speleothems for the period between 45 ka to 29 Ka B.P., and by Heine (1990), who also postulated a more humid climate from the lake sediments. The event of red soil formation correlates well with a regional wet phase in Australia identified by Nanson *et al.* (1992) as the stage 3 pluvial episode that occurred between 55 to 35 Ka.

The thick sediments that overlie the red soil marks the aeolian aggradation (phase 3, Sim-facies). These resting over the fluvial sediments indicate sudden change in the climate during terminal Pleistocene period and points towards advent of a major aridity. This event is well documented and can be bracketed between 22 ka to 18 ka B.P., which synchronizes well with the low sea-level of the order of 150 m to - 120 m (Fig. 7.1). In the Thar desert, this event is recorded at around 18 ka, and is revealed by the increase in sand mobility and increase in salinity in the major lakes of Rajasthan (Singh *et al.*, 1972; Allchin *et al.*, 1978; Swain *et al.*, 1983; Wasson *et al.*, 1983; Singhvi *et al.*, 1994; Dhir *et al.*, 1994). Sharma and Chauhan (1991) also reported extreme aridity, evidenced by dune formation at around 18 ka B.P. from Rajasthan. Gupta and Sharma (1993) invoked warm episode in Kashmir valley at about 20 ka to 18 ka B.P. The aeolian aggradation in Mahi valley thus coincides well with the available record of the surrounding areas and marks the onset of aridity taken consequently to be in tandem with the Last Glacial Maximum at around 18 ka B.P. The tentative TL dates obtained from the middle portion of the aeolian succession gave an age of around ~ 10 ka B.P. The initiation of the aeolian sedimentation in the absence of precise date cannot be fixed, and the major aridity in the area is likely to have started around 18 ka. The Holocene also witnessed the continuation of the Terminal Pleistocene aridity which was followed by a wet phase at around 9 ka to 6 ka B.P. that resulted in the stabilization of aeolian sediments accompanied by extensive calcretization and pedogenesis. Singh *et al.*, (1974) reported occurrence of relatively wetter phase at around 9 ka B.P.

The present day hummocky and undulating topography is the result of the stabilization process of the aggradation phase 3 and points to a minor change in the climate due to an increase in humidity. This phenomenon of stabilization, also accompanied by extensive calcretization is attributed to the change of a semi-arid to a sub-humid phase, marking the end of aridity.

The occurrence of microlithic tools over the dune surfaces suggest that the aridity had largely ceased by the time of the arrival of microlithic man in the area (Allchin and Goudie, 1971; Goudie, 1973). Presence of amorphous and aligned dunes to the north and south of Mahi river supports this fact (Allchin and Goudie, 1971). This suggests that amelioration of climatic conditions in western India, occurred around 10 ka to 5 Ka B.P. Evidences from the Thar Desert and lake records (Singh *et al.* 1974; Bryson and Swain, 1981; Wasson *et al.* 1983) implies that the regional change in climate was marked by a surplus of water around 6 ka to 8 ka B.P. This humid phase might have contributed to the stabilisation of the dunes in the Mahi basin also. An advent towards wetter conditions from 6 ka B.P. after an intervening drier period is also recorded from North Africa (Rognon, 1987).

After this aggradational phase, an event of incision predominated resulting in the development of a new channel along reactivated fractures, which exposed the older succession in the form of high vertical cliffs. This event evidently occurred after '6 ka B.P.

The aggradation phase 4 represents the development of a new drainage network which formed after phase 3. This is marked by another event of fluvial and marine sedimentation, indicative of changes in the climate from dry to humid. During this aggradation contemporaneous fluvial (in the alluvial plain) and rapid tidal/estuarine (in the coastal zone) sedimentation took place within the confined valley margins. The fluvio-marine sediments are suggestive of a transgressive phase of the sea characterized by inland migration in a wide funnel shaped estuary. This event of deposition must have taken place after 4 ka B.P.

The exposed sediment succession in the Mahi basin provides a complete palaeoclimatic record from Middle Pleistocene to Holocene. The detailed succession of palaeoclimatic events in the study area is given in Table 7.1. The succession starting with pedogenised mud unit marks the base of Quaternary sediment column in the study area. This pedogenised mud unit marks the high strandline of the Middle Pleistocene transgression (Merh, 1992) and were deposited under tidal and marginal marine environments (Merh, 1992; Raj and Chamyal, Comm.) during humid to semi-arid conditions. The first fluvial event (aggradation phase 1) is marked by the deposition of Gp facies under humid to sub-humid climate with intervening dry phase at around <200 ka B.P. The overlying thick pile of horizontally stratified sand (Sh_1 facies) suggests the change in channel planform and indicates fluctuating climate. The occurrence of hard pan calcrete within this unit suggests that the sedimentation took place due to episodic flooding during the arid phase between 180 ka to 140 ka B.P. The overlying medium to coarse grained trough cross-stratified sand lithounit (St) indicates slightly wetter phase at around 130 ka B.P. The occurrence of vertisol in the extrachannel area along this facies points to the spells of wet and dry phases. Based on

LITHOLOGY	DEPOSITIONAL / PEDOGENETIC EVENT	AGE	CLIMATE
Cross-stratified gravel, horizontally laminated silty-sand, planar cross-stratified sand (herringbone structure), tidal mud.	Contemporaneous deposition of fluvial and estuarine sediment, IV - aggradation	5 ka to 3 ka	Sub-humid to Humid
Stabilization of aeolian silts and sand (dunes), pedogenesis and formation of calcrete	End of aeolian activity, IIIrd - aggradation	10 ka * to 6 ka	Semi-arid to Sub-humid
Accumulation of aeolian silts and sands as a more or less continuos cover giving rise to typical dunal topography	IIIrd - aggradation	22 ka to 18 ka	Arid
(Formation of Red soil)	Rubification and pedogenetic changes in upper portion of IInd - aggradation.	51 ka to 23 ka[1]	Sub-humid to Semi-arid
Deposition of overbank fines, mainly silty sand under sheet floods, followed by pedogenesis and calcrete formation	IInd - aggradation (fluvial)	86 ka to 50 ka (51 ka* of red soil sediment) (60 ka* of Brown soil-II) (86 ka* of Brown soil - I) (108 ka* TL of Gt)	Sub-humid to Semi-arid
Deposition of planar and trough cross-stratified gravel, horizontally stratified sand alongwith calcrete layers, trough cross-stratified sand (and vertisol formation at around 125 ka).	Ist aggradation (fluvial)	< 200 ka to 100 ka (based lower Palaeolithic tools[2])	Humid to Sub-humid (with intervening dry phase)
Deposition of Tidal clays	Marine transgression Sub aerial weathering given rise to formation of vertisol	>240 ka	Humid to Semi-arid

([1] and [2] Allchin et al., 1978)
* TL-dates.

Table 7.1 : Palaeoclimate of the study area

the TL-date of overlying Gt lithounit at around ~108 ka B.P., it is presumed that the deposition of Sh_l facies and the deposition as well as the formation of vertisol can be tentatively bracketed between 135 ka - 110 ka B.P.

The overlying coarser trough cross stratified gravel lithounit marks the top of the aggradation phase 1 and indicates a slightly wetter phase alongwith an intervening dry spell around ~108 ka B.P. This gravel suggests deposition under highly ephemeral streams that existed in a semi-arid to arid region (Miall, 1986). This is overlain by a (12 m - 15m) thick sheet flood deposit comprising three distinct palaeosol horizons viz. two weakly pedogenised brown soils and a well developed rubified red soil unit that marks the top of the aggradation phase 2. The luminescence dates obtained assign an age of around ~86 ka B.P. to brown soil I, around ~60 ka B.P. to brown soil II and the rubified horizon has been dated to around 51 ka B.P. The aggradation phase 3 is bracketed between 86 ka to 50 ka B.P. The clay mineralogy and grain size data suggests that the deposition and sub-aerial weathering of these units took place under fluctuating sub-humid to semi-arid climate. The clay mineral assemblages of these soils suggests slightly wetter phase during the brown soil units. Radiocarbon dates of pedogenic calcrete nodules from the red soil give an age of around 23 ka B.P. (Allchin *et al.*,, 1978). This age of calcrete nodules is considered to be the minimum age for the pedogenic event of red soil. Hence the deposition of the red soil unit is bracketed between 51 ka to 23 ka B.P.

The thick pile of medium to fine silts and sands that overlies the sheet-flood deposits mark the aeolian aggradation phase 3. This is correlatable with the Last

Glacial Maximum at around 22 ka to 18 ka B.P. The TL date of around 10 ka B.P. from the middle portion of the aeolian succession indicates the continuation of Terminal Pleistocene aridity during early Holocene. The stabilization of the aeolian silts and sands resulted into the present day hummocky topography which is suggestive of a wet phase at around 9 ka to 6 ka B.P. The aggradation phase 4 marks the humid phase that occurred after 6 ka B.P. This aggradation comprises sediments of fluvial and fluvio-marine origin and suggests fluctuating sea level during the Middle and Upper Holocene time and marks sub-humid to humid climate.