CHAPTER-VIII

PALEOCLIMATIC ASPECTS

GENERAL

The detailed characteristics of the continental sequences reveal an interesting late Quaternary paleoclimatic history. The successive events of deposition, both fluvial and aeolian, punctuated by periods of non-deposition and pedogenetic changes, throw considerable light on the climatic changes that played their due roles in depositional processes and pedogenesis. Climates ranging from humid through semi-arid to arid have left their imprints in the sediments at various stratigraphic levels. Although it has been found somewhat difficult to precisely fix the dates of the climatic variations vis-a-vis depositional history and subsequent changes, a broad chronology of events has been worked out which quite clearly highlights the control exercised by various types of climate.

The factor of climatic control has been studied and analysed with three assumptions viz. (i) High (strong) fluvial action was related to semi-arid phases (ii) breaks in the deposition and subsequent exposure of the sediments to subaerial processes (development of pedogenesis, calcretisation etc.) have been considered as indicative of humid to sub-humid climate (iii) the aeolian silt deposits typically represent period of aridity. It is however not very clear how exactly the global sea-level curves and related climatic variations in terms of warm-humid and cold-arid are reflected in comparable climate conditions in the sub-tropical areas. Perhaps periods of low sea-level synchronized with arid, semi-arid phases, whereas the progressive withdrawal of a transgressive sea marked increased fluvial activity. It is however not possible to precisely correlate sea-level changes with climatic variations, partly because of lack of knowledge in terms of prevailing climates in the sub-tropics and the role of neotectonism in depositional episodes of fluvial sediments.

PALEOCLIMATIC SEQUENCE

Taking into account the nature of the sediments, variation in the grain size upward, repetitive events of pedogenic changes comprising development of calcretes, rubification of silts and stabilisation of dunal sands, the author has reconstructed the following paleoclimatic sequence:

Semi-arid to arid	Present day unconsolidated sand, sheets and dunes	Sub-recent to Recent (Upper Holocene)
Sub-humid	Stabilisation and Pedogenisation of aeolian silts and sands. Paleosol formation, development of calcretes and some vegetal growth on the dune surfaces	Lower to Middle Holocene
Arid	Aeolian silt and fine sand accumulations as a more or less continuous cover showing typical dunal morphology.	Terminal Pleis-tocene extending to Lower Pleis-tocene.
Semi-arid	Deposition of sediments of third fluvial cycle	Upper Pleistocene
Humid to Sub-humid ?	Pedogenetic changes including rubification of the fluvial silts (upper most	Upper Pleistocene

	beds of the second fluvial cycle) and development of calcrete in the silt horizon.	
Semi-arid	Deposition of sediments of second fluvial cycle	Upper
Sub-humid	Pedogenesis of the upper part of the fluvial sequence including calcretisation (of fractured mud layers)	Middle
Semi-arid	Deposition of sediments of first fluvial cycle.	Pleistocene
Sub-humid	Pedogenetic changes of the basal mottled bluish green clays (including calcretisation).	Middle Middle Pleistocene
Humid	Deposition of marine clays during a period of transgression	Middle Pleistocene

The above climate sequence is very well defined in the successive formations taken to comprise Quaternary deposits of Middle Pleistocene upward. The climatic changes ranging from humid through semi-arid to arid are well documented and the above sequence of climate variation has been worked out on the basis of following assumptions.

1. Strong fluvial action synchronized with semi-arid phase.
2. Pedogenetic changes are indicative of a sub-humid to humid climate, on account of the action of sub-aerial processes during non-deposition.
3. Arid phase was responsible for the widespread deposition of wind blown sands and silts. It is presumed that the aeolian silts and sands essentially comprised fluvial sediments reworked by wind action during the arid phase.
4. Amelioration of aridity and some increase in humidity was primarily responsible for the phenomenon of stabilisation of the aeolian sediments all over the study area (and also to its south upto central Gujarat and in the north upto south Rajasthan).
5. The present day climate though by and large, semi-arid to arid is characterised by fluctuating dry and wet spells. N.Gujarat and S.Rajasthan today experiences long spells of dry climate broken periodically by reasonably heavy rainfalls at intervals of a few years.

SEDIMENT CHARACTERISTICS VIS-A-VIS CLIMATIC FACTOR

Before the onset of the first fluvial cycle that gave rise to Valasana member. the basal clay horizon was exposed to sub-aerial processes bringing about some pedogenetic changes mainly calcretisation. This pre-~~pedogenetic~~ supposes withdrawal of the Middle Pleistocene high sea, (prior to the onset of fluvial sedimentation) thereby exposing the tidal muds and silts to the action of atmospheric agencies. Calcretisation of the mud is ideally seen in the form of tubes, veins and strings of calcrete criss-crossing the horizon. The phenomenon of mottling (ferric to ferrous) can also be indicative of the effect of sub-aerial processes. The entire phenomenon of pedogenetic changes is an indication of time interval before the fluvial material started being deposited and this could be taken as an evidence of climatic change from semi-arid to humid.

The main bulk of the fluvial sedimentation comprised two cycles of deposition,the material having been brought and deposited in two instalments. Each starting with a gravel and fining upward. An intervening period of non-deposition and some pedogenetic changes separates the two cycles, the fractured mud of the earliest cycle (Valasana member) has been weakly pedogenised and has given rise to development of calcrete tubes and strings interspersed within the mud horizon. The second cycle overlying the Valasana member (Sindari member) indicates a rejuvenation of the fluvial regime which has been taken as an indication of return of semi-aridity.

The rubified silts of Hirpura formation is strikingly different from the underlying laminated mud of Sindari member. The junction is quite well defined and the entire thickness is more or less silty and conspicuously reddened. The rubification is typically a phenomenon related to the period of non-deposition with pedogenic changes brought about by sub-aerial processes of sub-humid to humid climatic conditions. Obviously the silty horizon (Hirpura formation) represents the uppermost part of the second fluvial cycle and the process of reddening marks the termination of the second fluvial activity.

The rubified horizon is followed upward by another major fluvial cycle of deposition (Saroli formation), which in turn indicates onset of a wet phase. Interestingly this fluvial sequence shows an upward coarsening, from a muddy bottom horizon through sand to the gravelly upper part. Such a sequence points to a progressive increase in the depositional energy and is in contrast with the earlier two fluvial cycles which show coarsening upward, gravel to mud/silt. This third fluvial cycle with the topmost portion being gravelly, appears to have been terminated abruptly;sudden onset of aridity brought to an end the fluvial deposition. It is interesting however to note that there was no appreciable gap between the deposition related to the two climatic events, semi-arid followed by arid because the fluvial deposits do not show any evidences of action of sub-aerial processes (pedogenesis, calcretisation etc).

The succeeding phase of high aridity which was responsible for the accumulation of extensive aeolian deposits, referred to also as loessic silts marks a major global paleoclimatic event and has been recognised in most parts of the world. This arid phase synchronized with a very low sea-level, the fall having been of the order of 120 m and represents the last major arid phase of the late Quaternary. The aeolian sediments deposited during this phase form a more or less continuous horizon, the upper part of which is characterised by very conspicuous stabilisation. The hummocky and undulating topography of the study area, a feature reflecting this aeolian horizon and its subsequent stabilisation points to the onset of the last paleoclimatic event viz. some increase in humidity. The phenomena of stabilisation and extensive calcretisation of the aeolian material is attributed to the onset of a sub-humid phase which marked the end of aridity and synchronized with the rise of the Holocene sea-level. Since the advent of the increased humidity, till present day, the climate has been fluctuating between arid and sub-humid, thereby giving rise to the existing pattern consisting of a combination of shifting sands and partial stabilisation from time to time depending upon the periodicity of the rainfall.

CHRONOLOGY OF PALEOCLIMATIC EVENTS

The chronology of paleoclimatic changes, a phenomenon related to successive glacial and interglacial events of the Quaternary is not fully established, especially for the Lower and Middle Pleistocene. Some information for the Upper Pleistocene is available and on the basis of indirect evidences like the nature of variation in the sediments (fluvial/aeolian), climatic sequences inferred from the foraminifera of deep sea cores and a number of sea-level curves (the rise and fall of sea-level indicative of warm and cold climate respectively), a tentative chronology and broad dates and durations of humid, semi-arid and arid climatic phases can be obtained. The sequence of climatic fluctuations of the Holocene beginning with the Terminal Pleistocene aridity is better documented. In the Indian context too, this is true and the available data from North Gujarat and southwest Rajasthan (study area) and southern Rajasthan (to the north of the study area) provides a reasonably clearer picture of the Holocene climatic fluctuations.

PLEISTOCENE

Meagre dependable information on the paleoclimates for the major part of the Pleistocene is available and not yet fully understood. The classical concepts of the Pleistocene glacial and interglacial stages based on studies in the Alpine region divided the Pleistocene epoch into five glacials (Donau (D) - Glacial I, Gunz (G) - Glacial II, Mindel (M) - Glacial III, Riss (R) - Glacial IV and Wurm (W) - Glacial V) and the intervening warmer interglacials (D/G, G/M, M/R and R/W). It has been postulated that M/R was a period of great intergalcial, while the R/W was a period of last interglacial (Table 8.1). The last glacial synchronized with the 2000 years B.P. aridity and the Holocene warming forms the post glacial stage.

Zeuner (1959) attempted to correlate the interglacial stages with various high sea-levels of the Quaternary. The successive younging sea-levels have been designated in the geological literature as Calabrian (Pre-Pleistocene), Scillian (D/G), Milazzian (G/M), Tyrrhenian (M/R), Monastirian (R/W) and Flandrian (Post W). Zeuner (1959), as well as Fairbridge (1961) postulated a progressive falling of transgressive sea-levels during the periods of interglacial sea-levels rise. The sea-level curve based on the most important premise of the close relationship existing between climatic fluctuations and transgressive - regressive sea-levels given by Fairbridge (1960) however is now not generally accepted and it is not found possible to visualise very high sea-levels in the early part of the Pleistocene (a period of around 200 K.Y. B.P.) is almost negligible and the details of climatic fluctuations till the advent of Middle Pleistocene are not available. In this connection the works of Chappel and Shackleton (1986), Emiliani (1955),

	WARM		POST GLACIAL
GL-V	COLD WARM COLD	WURM (W)	LAST GLACIAL
	WARM COLD WARM	R/W	LAST INTERGLACIAL
GL-IV	COLD WARM COLD	RISS (R)	GLACIAL
	WARM	M/R	GREAT INTERGLACIAL
GL-III	COLD WARM COLD	MINDEL (M)	GLACIAL
	WARM	G/M	INTERGLACIAL
GL-II	COLD WARM COLD WARM COLD	GUNZ (G)	GLACIAL
	WARM	D/G	INTERGLACIAL
GL-I	COLD WARM COLD - WARM - COLD - WARM COLD WARM COLD	DONAU (D)	GLACIAL
	WARM	PREDONAU	PREGLACIAL

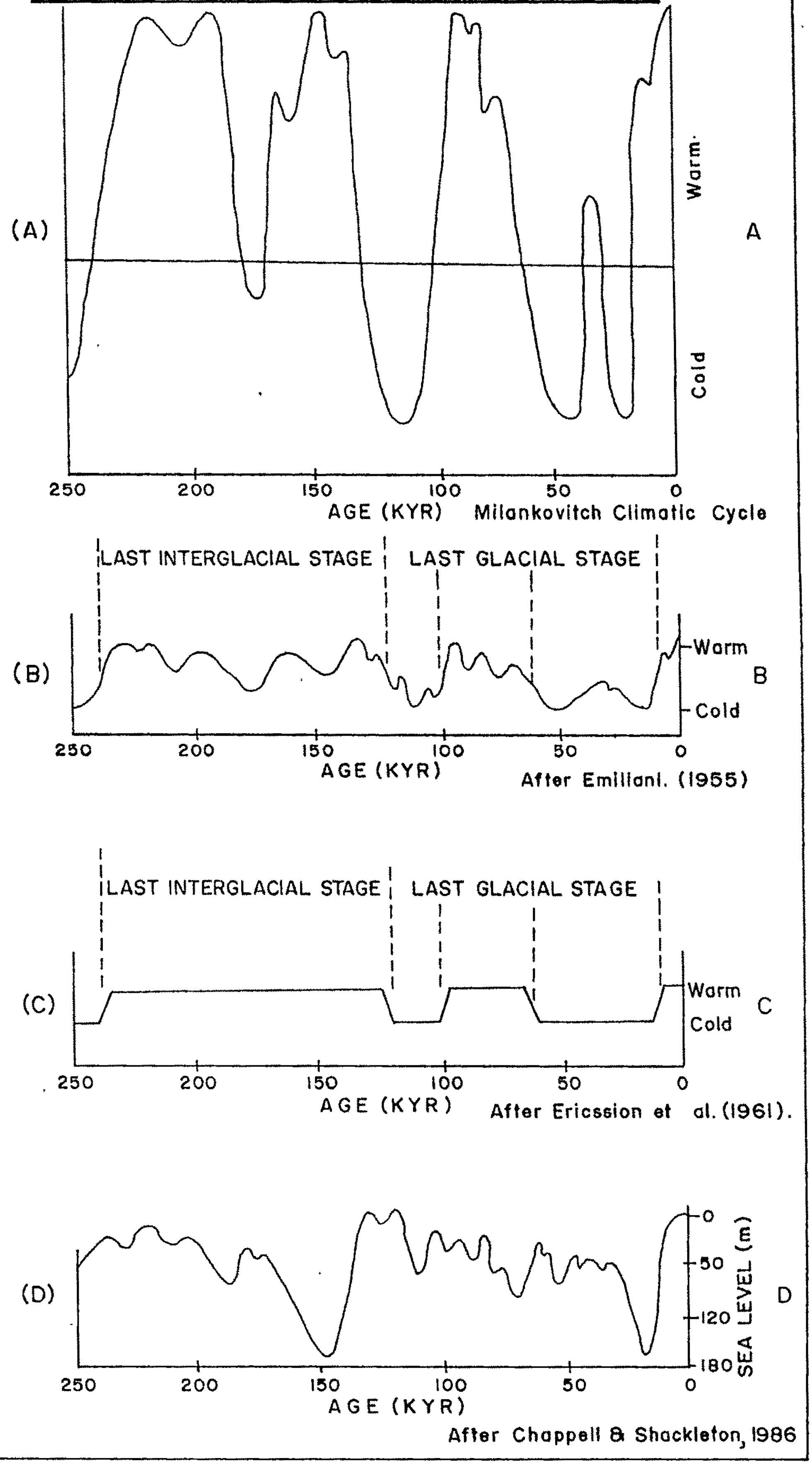
Table 8.1 : Glacial and Interglacial epochs of the Pleistocene

Ericsson (1961) and Milankovitch (1941), do provide a reasonably clear though broad picture of the climatic stages since the advent of Middle Pleistocene (Fig. 8.1).

The main bulk of the fluvial sequence of the study area which broadly belongs to Middle and Upper Pleistocene, falls within the last interglacial stage and the successive fluvial cycles perhaps indicate climatic fluctuations within the main interglacial stage. The entire fluvial cycle sequence which is resting over the bluish marine clays, which according to Merh (1992) represents the high sea-level of the Middle Pleistocene, appears to have been deposited over a period of about 200 K.Y.

The sea-level curve of Chappel and Shackleton (1986), (Fig. 8.1) shows almost 150 m fall of sea-level around periods of extreme aridity (glaciation in Polar areas) might have contributed towards the fluvial activity and its course in the intervening periods. The high sea-level of the Middle Pleistocene dated around 240 K.Y. (Chappel and Shackleton, 1986) must have progressively gone down, of course with minor fluctuations and it is quite reasonable to surmise that it was during this period of gradual regression and wet climate that the older Lakroda formation was deposited in two instalments viz. its two members (Valasana and Sindari). The climatic changes at the close of the deposition of Valasana member which brought about the pedogenesis of the upper mud horizon could be interpreted as a minor period of non-deposition and increasing humidity. At present there is no conclusive date to fix this event, but considering various sea-level curves and assuming the fall of sea level with increase in aridity, this event of

Fig. 8·1 CLIMATIC AND SEA LEVEL CURVES



non-deposition and pedogenetic changes could be anywhere around 180 K.Y. It is quite obvious that the main part of the fluvial sedimentation comprised two cycles of deposition, the material having been deposited in two instalments, each starting with a basal gravel and fining upward. The lower gravel of Valasana member shows considerable compaction and is almost rock like; it has been reported to contain Lower Paleolithic tools (Sankalia, 1946). Pant and Chamyal, 1990; Chamyal and Merh, 1992 have recorded this horizon of lower gravel from the Mahi and Narmada Valleys as well and obviously it shows a widespread development. Subbarao, (1952) recorded Lower Paleolithic tools from the comparable gravel of Mahi. According to Pant and Chamyal (1990), the Lower Paleolithic culture in Gujarat must have flourished around 200 kyr B.P., and they suggested that in the Mahi the lowermost gravel and the underlying clay deposits might be older than 200 K.Y. Baskaran *et al.* (1986) discovered Lower and Middle Paleolithic tools in the fluvial gravels underneath the miliolites of Hiran Valley in south Saurashtra; and they dated them around 190 K.Y. The gravels of Valasana member, which are more or less of the same age as those yielding Lower Paleolithic tools could also be assigned an identical age. Recently, Sareen *et al.* (1992) have dated this gravel horizon (using TL technique) to be less than 300 K.Y. Although it is not at all possible to precisely fix the age of this gravel, it is most likely that they could be belonging to an age ranging between 200 - 300 K.Y.

Taking into account the global climatic changes and sea level curve, the author has tentatively dated the second fluvial cycle. An approximate age for the cycle consisting of the Sindari member of Lakroda formation and the Hirpura formation could be assigned from 160 - 140 K.Y. The rubification of the Hirpura formation is attributed to the humid to sub-humid phase and was responsible for the sub-aerial exposure and reddening of the silty sediments and calcretisation. This event of non-deposition and sub-aerial weathering can broadly be dated to at its maximum at around 140 K.Y. The fluvial cycle resting over the rubified silts starting with mud and coarsening upward perhaps represents the period of last interglacial and its duration can tentatively be fixed from 130 K.Y.to 20 K.Y. i.e. the termination of the Pleistocene. An interesting feature of this formation is the coarsening upward of the grain size - mud to sand to gravel, indicating a progressively increasing depositional energy conditions towards the end of the cycle. An abrupt end of fluvial deposition and sudden change from wet to dry climatic conditions is envisaged at the boundary of the Saroli formation.

The aeolian silts rest over the fluvial sediments without any indication of break during which pedogenetic changes could be expected. This sudden change in climate marks the termination of Pleistocene period and the advent of the main arid phase. This event is very well documented and can be put anywhere around 20,000 - 18,000 B.P. This climatic change at the termination of Pleistocene marks the advent of Holocene and the striking arid phase which synchronizes well with the low sea-level (of the orderof -150 to -120 m).

HOLOCENE

The Holocene period comprising approximately the last 10,000 years of the geological record can in the study area be broadly divided into four main climatic phases.

i) The earliest part of the Holocene witnessed the continuation of the Terminal Pleistocene aridity. This dry climate marked by strong aeolian action gave rise to loess-like aeolian silt accumulations (sheets and dunes) all over North Gujarat and South Rajasthan.

ii) A wet phase followed during which the stabilisation of the accumulation took place. This wet period brought about conspicuous pedogenesis and development of calcrete horizons.

(iii) A brief arid phase of comparatively short duration and to this dry phase could be attributed the salinity of the Rajasthan lakes and development of playas.

(iv) The advent of the present day climate (sub-humid to semi-arid)

The precise durations of the various climatic phases and their chronological/absolute ages are still the subject matter of considerable debate and numerous workers (Singh *et al.*, 1972, 1974; Allchin *et al.*, 1978; Bryson and Swain, 1981; Singhvi, 1982; Swain *et al.*, 1983; Misra *et al.*, 1988; Sharma and Chauhan, 1991) who have investigated Holocenes of South Rajasthan have presented somewhat conflicting details though agreeing in the overall sequence of changes in the vents. Table 8.2 summarizes the conclusions made by these workers.

The author is not in a position to provide a detailed and precise picture, nor he is able to comment on the controversial aspects of the Holocene paleoclimates in the absence of dependable field evidences within the limits of his own study

AGE Years B.P. / WORKERS	Singh et al (1972)	Singh et al (1974)	Allchin et al (1978)	Bryson & Swain (1981)	Singhvi et al (1982)	Swain et al (1983)	Rajaguru (1983)	Wasson et al (1983)	Misra et al (1988)	Sharma & Chauhan (1991)	Dhir et al. (1994)	Singhvi et al (1994)
PRESENT - 1000	Salinity of lakes	Present day conditions		Wet phase (700 - 1100)				Present day		Marine inundations		
1000 - 3000		Increase in rain-fall (realtively dry) 1500 - 1800 BP)		Aridity at 2000 - 3000 BP) Lakes become saline and dry up at 3700 BP		Lakes start drying Salinity at 3700 BP		Very arid (3000 - 1700) Drying of lakes at 4000 BP		Aridity and salinity of lakes (3700 BP)	Aridity and srying of lakes	
3000 - 5000	Fresh water conditions	Aridity increases at 4000 BP Lakesdry up and salinity increases	Aridity	Wettest Phase of last 10000 years		Wet phase upto 3700 BP	Wet phase upto 4000 BP	Wettest phase	Marked Sub-humid wet climate (4000 - 10000 BP)		High water level	
5000 - 9500		Wet phase at 5000 BP Punctuated by minor changes at 8300						Lacustrine conditions		Wet phase	Moist Phase	
9500 - 10000	Sudden end to arid phase	Semi-arid sand dunes start to stab-ilise Fresh water cond-itions	Fresh water conditions	Wet phase cultivation seen Readvance of glaciers at 8300 yrs BP		Fresh water conditions. Lakes start filling up. Dunes stabilise.						
10000 - 18000	Aridity Aeolian activity widespread	Major aridity choking up of valleys, inland lakes formed	Major dry phase. Dunes extended over everywhere	Major aridity monsoons supressed.	Major aridity Dune activity starts from around 20000 BP	Extreme aridity Sand dunes formed Choking of valleys. Inland lakes formed	Aridity bet-ween (15000 - 25000 ka)	Major aridity Hypersaline conditions	Distinct dry climate during Terminal Pleistocene	Extreme aridity. Dune formations Lakes/Basins formed	Extreme aridity	Dune building activity (15 - 25 ka)

Table 8.2 : Sequence of climatic changes in South Rajasthan and North Gujarat

area and also on account of lack of geochronological dates. Broadly speaking, the alternating climatic sequence viz. arid - humid - arid - humid in the course of last 10,000 years are also revealed in the sediment record and can also be recognised in numerous features viz. aeolian deposits as sheets and dunes,peodgenisation and calcretisation causing stabilisation of the aeolian deposits, sporadic occurrence of second generation of dunal material and its subsequent partial pedogenisation and local development of fluvial deposits as flood plains.