Chapter - VII

DEPOSITIONAL ENVIRONMENT

GENERAL

The ancient beach rocks, miliolite limestones and stabilised sand dunes - all together form an interesting Quaternary record in Saurashtra. These bioclastic carbonate deposits, as mentioned earlier, have preserved imprints of fluctuating sealevels and consequent palaeoclimatic changes, which in many ways resemble to those of Kutch and other parts of the world. So far as their origin is concerened, these deposits, especially the miliolites, have posed an interesting debate since hundred years or so. The marine allochems being chief constituents in miliolites, have prompted some workers (Fedden, 1884; Foote, 1898; Shrivastava, 1968 a & b; Lele, 1973; Verma & Mathur, 1978; Baskaran et al., 1986 & 1989 etc.) to invoke shallow, warm, open marine conditions for their deposition. On the other hand, the occurrence of foraminiferal sands in far inland areas of Rajasthan as well as typical aeolian structures of miliolite deposits questioned against such a simple inference to be of marine origin. Goudie & Sperling (1977) explained the long distance wind transport of the foraminiferal tests in Thar desert and supported the aeolian origin of miliolites as envisaged earlier by Carter (1849), Chapman (1900), Glennie (1970), Biswas (1971), Sperling & Goudie (1975) etc. This was further supported by SEM studies of quartz grains from miliolites (Agrawal & Roy, 1977; Agrawal et al., 1978) and detailed field & thin section studies of Kutch miliolites (Patel & Allahabadi, 1988 and Patel, 1991 b). There are few others (Evans, 1900; Adye, 1914; Rajaguru & Marather, 1977; Marathe et al., 1977; Merh, 1980; Chakrabarti & Baskaran, 1989 etc.) who believe the miliolites of Saurashtra partly to be of marine and partly to be of aeolian origin. Recently, Patel & Bhatt (1992 a) have defined the miliolites *sensu stricto* and furnished several evidences in support of aeolian origin for Kutch and Saurashtra miliolites. The integrated studies of these carbonate deposits all together on a regional scale clearly reveal the major role played by sealevel changes and coeval Quaternary desertification in Western India (Patel & Bhatt, 1991, b). It will be therefore worth reviewing the world-wide Quaternary eustatic changes as a whole in brief and along Gujarat coast in particular.

QUATERNARY SEALEVEL CHANGES

Global

The Quaternary period, the Great Ice Age, is characterised by an interplay of glacial and interglacial stages, each respectively causing cold-arid climate with lowering, and warm-humid climate with rising of sealevels. The studies in Central North America and Alpine region have shown the signatures of such sealevel fluctuations related to the different climatic stages (Zeuner, 1959; Fairbridge, 1961; Russel, 1964; Charlesworth, 1966; De Lumly, 1976; Kukla, 1977; Holmes, 1978 etc.), which are given in the following table (Table VII.1).

Table VII.1 : Climatic stages during Quaternary glacio-eustatic changes in Central North America and Alpine region.

Stage	Climatic Stages		Transgressive Cycle	
	Central North America	Alpine Region		
Post-glacial	--	--	Flandrian	Holocene
Glacial	WISCONSIN	WURM (W)	--	Late Pleistocene
Interglacial	Sangamen	R/W	Monasterian	
Glacial	ILLINOIAN	RISS (R)	--	
Interglacial	Yarmouth	M/R	Tyrrhenian	Middle Pleistocene
Glacial	KANSAN	MINDEL (M)	--	
Interglacial	Aftonian	G/M	Milazzian	
Glacial	NEBRASKAN	GUNZ (G)	--	Early Pleistocene
Interglacial	--	D/G	Sicilian	
Glacial	PRENEBRASKAN	DONAU (D)	--	
Pre-glacial	--	--	Calabrian	Pre Pleistocene

(Source : Merh, 1987 and Patel, 1991 a)

However, there is no unanimity about the actual values of high or low stands and also about the number of oscillations. It has been also pointed out that besides glacio-eustasy, the role of tectono-eustasy should also be identified and understood in such studies. It is further dangerous to apply the concept of global sealevels to the local areas placed far apart in different parts of the world as visualised by Morner (1983). Although, recently Shackleton & Opdyke (1973), Moore (1982) and Chappell & Shackleton (1986) have presented rather reliable and widely accepted global sealevel curves based on isotope studies. Shackleton and Opdyke (1973) gave a glacio-eustatic curve based on the oxygen isotope (O^{18}/O^{16}) studies of deep sea foraminiferal tests, revealing sealevel maxima at 120, 100 and 80 kyr B.P.; the maximum being of about +15 m around 120 kyr B.P. (Fig. VII.1). Moore (1982) used U-series isotope dates of fossil corals and postulated high sea stands at 120, 105, 80, 60 and 40 kyr B.P. suggesting the maximum (~ +3 to 7m) around 120 to 140 kyr B.P. and lowering of sealevel upto −120m before 20 kyr (Fig.VII.2). More recently Chappell & Schackleton (1986) have prepared a more accepted global curve from the oxygen isotope studies of foraminifera from deep sea (Fig. VII.3). Accordingly the sealevel was highest (~ +5 to 6 m) about 125 kyr B.P. and fall upto −140 m with a series of minor oscillations about 19 kyr B.P. The rising of the present sea from its lowest was comparatively very fast and as per Fairbridge (1960), the Flandrian (Holocene) transgression was greatest and fastest, reaching its crest about 6000 years ago. Merh (1987) while reviewing the present status of Quaternary sealevel changes

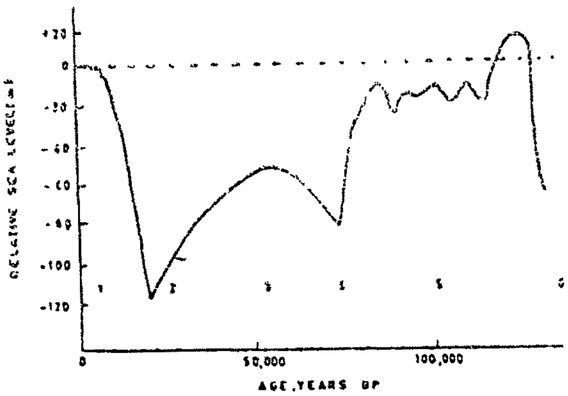

Fig VIII 1: Glacio-eustatic sea level curve by Shackleton & Opdyke (1972).

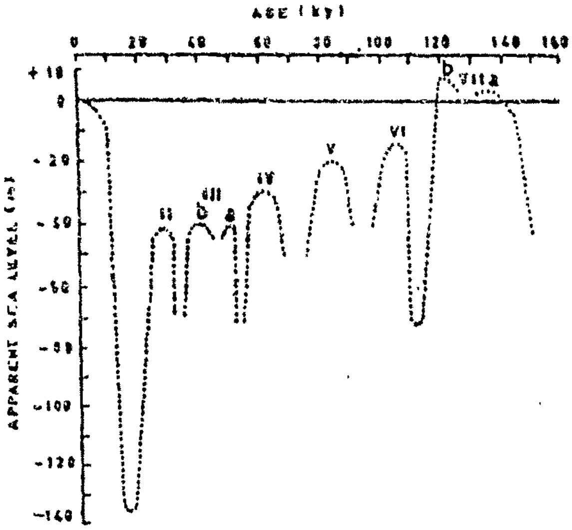

Fig. VIII 2: Late Quaternary sea levels according to Moore (1982).

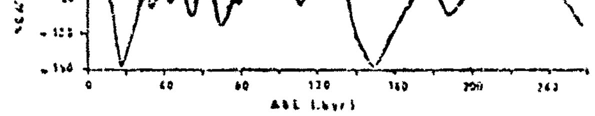

Fig VIII 3: Sea level curve by Chappel & Shackleton (1986).

commented that, "...there appears to be a general acceptance for 18,000 yrs B.P. when the sea that was at the lowest, started rising. It is also generally agreed that the rising stopped at about 6000 yrs B.P. since then there has been a slight regression of 2 to 3 m".

Indian coastline

The record of Quaternary sealevel changes along Indian coastline, in the form of erosional as well as depositional geomorphic features have been incorporated by several workers like Chatterjee (1962), Pascoe (1964), Niyogi (1968 & 1971), Ahmad (1972), Vaidyanadhan (1981), Sambasiva Rao (1982), Kale & Rajaguru (1985), Patel et al. (1985), Patel (1991 a) etc. The glacial lowering of sealevel along western coast of India is also evident by Nair (1971, 1974 & 1975), Nair et al. (1979), Nair & Hashimi (1980), Rao (1990), Nigam et al. (1991) etc. from the NIO. Although, the existing information is sporadic, its relation with neotectonic activities or any other local geological event is not yet understood. Besides, the reliable absolute dates for transgressive or regressive events are also not fixed.

The Quaternary carbonate deposits of Saurashtra and Kutch together with various geomorphic evidences have been used by many workers from M.S.U., G.S.I., O.N.G.C., P.R.L., and Deccan college for the study of Quaternary sealevel changes. Recently Patel (1991 a) has presented an utmost attempt on Quaternary strandlines in Gujarat, incorporating the various landforms on the Mainland Gujarat coast, miliolites of Saurashtra & Kutch and fossil sand dunes of North Gujarat. He correlated the coastal plains, alluvial cliffs & plains, meandering of the river channels, ancient beach rocks & miliolites, relict alluvial patches in mudflats, river terraces, raised mudflats, coast parallel sandy ridges, aeolianites and Harappan port towns with the higher sealevels upto ~ +20m (Mid. Pleistocene) and ~ +6 to 10m (Holocene) in Quaternary period. The occurrence of buried river valleys & channels, cliffy river mouths, submerged miliolites & sandy ridges together with marked gradient difference around −20 m below the present shoreline etc. have prompted him to invoke an intervening lower strandline around −20 m which perhaps can be compared with one of the still stand of the Late Pleistocene glaciation (10,000 to 12,000 yrs B.P.) when the strandline was much below than the present sealevel. Based on this study Patel (1991 b) envisaged the deposition of miliolites from the exposed beaches of glacial sea by strong southwesterly winds which during successive interglacial wet phases underwent a process of freshwater diagenesis to give rise to the indurated miliolite rocks. The present study is in agreement with model suggested by him for the deposition of inland miliolite occurrences in Kutch and Saurashtra.

RADIOMETRIC DATES

Attempts have been made by a few geoscientists to determine the age of the Quaternary carbonate deposits of Saurashtra, especially of the miliolites by radiometric dating (C^{14}, Th^{230}/U^{234}, U^{234}/U^{238} etc.) techniques. Although these rocks, belonging to open interactive diagenetic system, raised several reservations on the reliability of these dates obtained in most cases using bulk samples (Merh, 1980; Bruckner et al., 1987; Gupta, 1991). The following table (Table VII.2) summarises the available dates for these deposits.

Table VII.2 : Broad summary of dated Quaternary carbonate deposits of Saurashtra

Reference	Location	Material dated	Age	Method used
1. Agrawal (1970)	Porabandar & Baradia	Shells & Coral	36070 yrs	C^{14}
2. Gupta (1972)	Salaya to Dwarka	Corals Shells	4575 ±105 yrs 35070 +5586 yrs −3300	" "
3. Gupta & Amin (1974)	Salaya & Okhamadhi	Corals	5.2 ±0.1 upto >45 kyr	"
			6.0 ±0.2 upto 123 ±9 kyr	Th^{230}/U^{234}
			Recent to 118 ±46 kyr	U^{234}/U^{238}
4. Govindan et al. (1975)	Badalpur	Oyster shell	21430 yrs	C^{14}
5. Lele et al. (1977)	Barda Hill	Miliolite	31163 yrs	Ca/Mg
	Somnath	Oyster	21128 yrs	
6. Hussain et al. (1980)	Adityana	Miliolite	177 +20 kyr −15	Th^{234}/U^{238}
	Dungarpur	Miliolite	95 ±12 kyr	
7. Bruckner et al. (1987)	Una to Porbandar	Miliolites	38 to 292 kyr	Io/U
	Mangrol	Ostrea shell	86 kyr	
	Porbandar	Shell	94.9 ±10% kyr	ESR
	Chorwad	Shell	115 +10% kyr	
8. Baskaran et al. (1989)	Various parts of Saurashtra	Miliolites	56 − 70 kyr 75 − 115 kyr 140 − 210 kyr	Th^{230}/U^{234}
9. Chakrabarti & Baskaran (1989)	NR.Jamnagar	Miliolite	54.2 kyr	Th^{230}/U^{234}

The dates thus obtained are not in harmony with any type of the Quaternary deposit, especially the beach rocks and miliolites. The deposition of these rocks were to be placed in a long span of time from Middle Pleistocene to Early Holocene which could be the prime factor for their wide range. The corals, shells and oysters occur in the beach deposits of Middle Pleistocene high sea as well as that of Holocene sea. The lack of stratigraphic positions of these mateirals may give the ambiguity in the dates. Moreover, the Quaternary carbonate rocks of Saurashtra have passed through various geological events viz. sediment generation, their accumulation, stabilisation, cementation and upto some extent recrysatllisation. It is doubtful whether the dates thus obtained represent any such specific geological event. Therefore the author has not touched this part of the studies. However, the scatter of dates may throw some light on their deposition in instalments and also on the relative stratigraphic positions.

DEPOSITIONAL HISTORY

The generation of carbonate sands is a very complex phenomenon that involves various physical, biological and chemical processes in the inter-dependant environments. The various workers (Schmidth, 1956; Hiltermann, 1966; Jordan, 1971; Milliman, 1974; Wilson, 1975; Davis, 1983 etc.) have investigated the carbonate generation in modern environments in different parts of the world. They have suggested in general, the following important parameters which favour the carbonate sand generation.

1.	Climate	–	Tropical and subtropical i.e. Between $30^{\circ}N$ and $30^{\circ}S$ latitudes
2.	Salinity	–	Normal to hyposaline
3.	Depth & light	–	Shallow, Photic zone (10 to 200 m)
4.	Energy cond.	–	High energy with strong waves & surf
5.	Substrate	–	Hard and uneven
6.	Other	–	Adequate supply of O_2 and food, little influx of terrigeneous sediments, partial pressure of CO_2 (PCO_2) etc.

The variation in these parameters is responsible in bringing about the changes in the ecological conditions and thus, control the amount as well as the type of carbonate sand generation. Based on the detailed field observations and laboratory investigations, the depositional history of the Quaternary carbonate deposits of Saurashtra can be ascertained in the following sequence of events.

(a) As postulated by Bruckner (1989) and Patel (1991 a), the Saurashtra Peninsula has experienced the interglacial transgression of maximum upto ~ +15 to 20m in Middle Pleistocene (? 120 – 130 kyr B.P.). This shallow, open and warm tropical high sea has generated huge amount of bioclastic carbonate beach sands all along the high energy coasts of Saurashtra between Okha-Dwarka in NW and Veraval-Kodinar and beyond in SE. The low energy northern and eastern coastal segments of Saurashtra characterised by muddy waters with high terrigenous influx even in past, have inhibited the much generation of carbonate sands in these areas. On the contrary, the high energy western and southwestern coasts of Saurashtra has remained a carbonate generating coast under the positive influence of the above mentioned factors even today. This open high energy coastal segment of Saurashtra, facing the clear normal to hyposaline waters of Arabian sea and having in it sluggish almost seasonal (ephimeral) rivers like Vartu, Bhadar, Ozat, Sorti etc. that does not influx much detritals, provide favourable environment for the growth of various invertebrate fauna in offshore region. The study of topography and bathymetric charts of these segments suggest that, since the Middle Pleistocene when the sea was rather high, the carbonate sand generating conditions have not much changed. Besides this, the absence of influence of Indus borne sediments from north on this coast can be due to the dynamic barrier caused by high velocity tidal currents of Gulf of Kutch (Nair et al., 1982). Thus, following the famous maxim 'present is key to the past', it can be inferred that the similar conditions on shorelines of ancient progressively regressing high sea might have generated the bioclastic carbonate sediments which have given rise to the beach rocks on their shore and miliolites beyond their shore as well, and also the dunal sands in Holocene time.

(b) The progressively oscillatory regression (upto about -20m or more) of this high sea that synchronised with onset of glacial stage and marked by the prolonged arid-desertic conditions during late Middle Pleistocene till early Holocene exposed enormous amount of beach and littoral organogenic sands to the glacially strengthened southwesterly onshore winds. Almost similar climatic conditions (dry-arid) were prevailing in western India including

Kutch, Saurashtra and South Rajasthan (Patel & Bhatt, 1992 b) and also on western continental shelf (Nair & Hashimi, 1980; Rao, 1990). According to Patel & Bhatt (op. cit.), in SW Rajasthan i.e. in the area north of the Great Rann of Kutch and deltaic region of palaeo-perennial Indus, Saraswati, Luni river systems, the regression of this Middle Pleistocene high sea exposed huge amount of littoral as well as fluvial sands and their northeastward transport brought about the desertification of once a fertile 150-200 km wide low tract of Indus-Saraswati-Luni plains. However, the neotectonic activities in Himalaya in the same span of time that shifted the perennial rivers like Indus & Sutlej in west and Yamuna in east (Allchin et al., 1978; Yash Pal et al., 1980; Hegde, 1982 etc.) and resultant loss of Ghaggar-Hakra-Saraswati system was also equally responsible in the Thar desertification.

The lithification of the beach rocks in Saurashtra also commneced during this period under the mixed (marine & meteoric) water conditions on the shores of that sea as evident by the presence of fibrous and micritic aragonite cements and higher percentage of Mg^{2+} in their calcites.

(c) The southwesterly strong onshore winds that lifted these carbonate sands, carried them inlandward areas by combined process of traction, saltation and suspension. During their passage to the site of deposition, these stormy winds also carried some detrital material from the various river valleys/channels and alluvial plains, and deposited them in instalments on the pre-miliolite topography as various type of dunes and sheets to give rise to the present disposition of coastal as well as inland miliolites.

(d) The subsequent interglacial rise of sealevel till Holocene, marked by the humid phase was responsible for the stabilisation and lithification of these aeolian sediments, undrowned by the rising sea, under the influence of freshwater (meteoric) diagenetic processes which have cemented these bioclastic sands into consolidated miliolite rocks. The dissolution of aragonitic allochems with development of intragranular porosity, diagenetically formed coated grains, various cement morphology and their low magnesian nonferroan sparry calcite mineralogy - all provide evidences for mostly vadose and occasionally phreatic, freshwater diagenetic environment for the miliolites of Saurashtra (Bhatt, 1992). In beach rocks too, the process of diagenesis was continued now under freshwater condition as revealed by the presence of second generation of low Mg, nonferroan sparite cement infilling their porosity.

(e) The process of transportation, deposition and consolidation of miliolitic sands did not took place at a stretch but was interrupted several times by oscillations in sealevel and resultant micro-fluctuations in palaeoclimate (Patel & Bhatt, 1992 c). The presence of intercalated red kankary pedogenised layers, fluvial sediments, terrestrial debris, karstified surfaces, abruptly truncated sedimentary structures etc. suggest brief periods of wet phases in a prolonged arid phase indicating micro-fluctuations in palaeoclimate. In thin sections of miliolites the occurrence of vadose silt, diagenetically formed coated grains and more than one generations of cements, further substantiate the minor breaks in the diagenetic environment. These breaks may be of few hundred or tens of hundred years and not 'micro' in sense suggested by Bruckner (personal communication).

(f) The regression of the Holocene sea (upto present level) marked by the next glacial arid climatic phase has facilitated the deposition of the stabilised coastal carbonate sand dunes which at places underlie the present-day coastal dunal sands, facing the high energy sand generating Holocene coastal segments. This high sea has left its imprints as raised mudflats on the low energy coasts. The Th^{230}/U^{234} and U^{234}/U^{238} dates (4500 to 6700 yrs B.P.) obtained for the corals and shells from the dead coral reefs and raised beaches of western and northern Saurashtra coasts by Gupta & Amin (1974) and Gupta (1977) perhaps relate to this Holocene transgression.

The presence of aragonite and high magnesian calcite as revealed by XRD studies of the stabilised dunal sands substantiate the just onset of meteoric diagenesis in these deposits.

MECHANISM OF WIND TRANSPORTATION

The transportation of the carbonate sediments from coast towards inland areas has involved main three types of mechanisms viz. traction, saltation and suspension as suggested by Bagnold (1941), and has resulted in selective wind sorting. As per Twidale (1976), about 25% of the sand travels by rolling & sliding (traction) and 75% by saltation and suspension together (Fig. VII.4). According to him, the initial sand movement always occurs at the downwind end of an exposed sand surface and that the grains

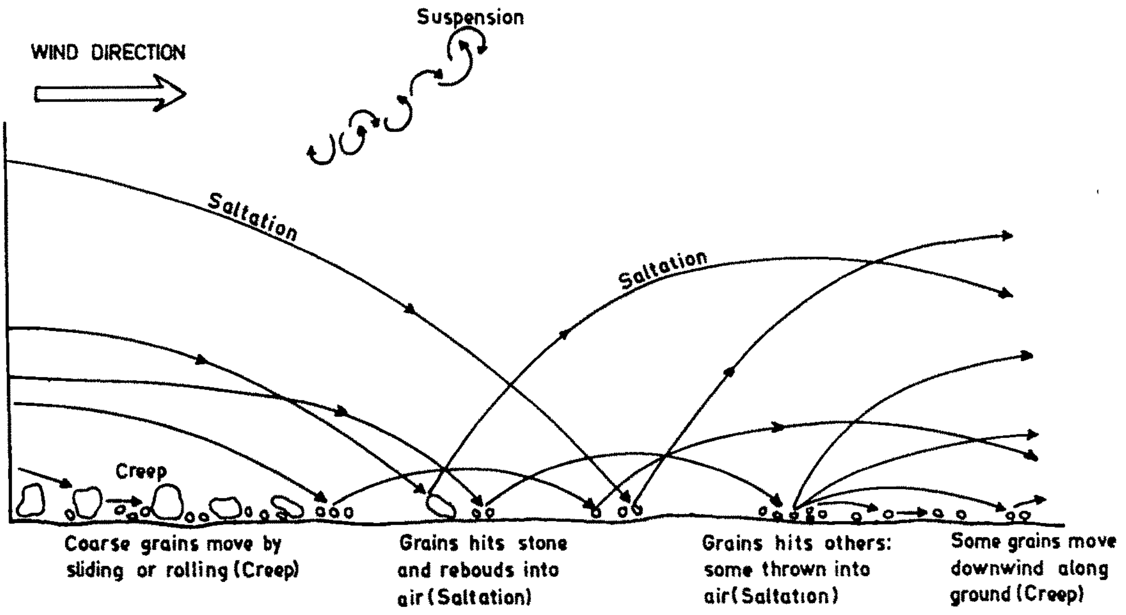

Fig.VII 4 Schematic diagram showing the transportation and the sorting action of sediments by wind.

are put in motion farther and farther upwind as the wind velocity increases. In general, however, it may be stated that a wind of 16 - 20 km/hr is needed to put sand grains into motion. Pethick (1984) has also observed that the wind with speed of 5 m/sec (18 km/hr) is required to initiate the sand movement. It is not always necessary that the sand grains should be transported by traction and saltation, it can be transported by suspension for considerable distances. This process (whirlwind) sometimes become so effective that it lifts even animals and other larger objects and carries them for considerable distances where on account of drop in velocity, dumps them from the sky. Twidale (1976) noted that "Each sand grain exposed at the land surface lies in a zone of low velocity caused by the frictional drag due to the sand grains themselves, pebbles, vegetation and other obstructions to the air-flow over near the ground. However, there is a rapid increase in velocity a short distance above the surface after which it remains essentially steady. The precise nature of the velocity gradient above the ground varies with the character of the surface. Turbulent eddies, which involve a dissipation of energy, are formed partly because of the roughness of the surface which induces pressure contrasts between the upwind and lee side of any obstacle, and partly because of the large temperature differences commonly developed between the air and the sand surface in hot desert region. ...yet this near-surface turbulence which poses the main problem to transport is also the means whereby clay and sand particles are put in motion. Sand grains are lifted out of this low near-ground velocity zone and follow short parabolic paths downwind. The initial lift is provided by numerous turbulent updrafts of air, which provides an upward suction. The height to which the grains are lifted varies according to their mass and to the force of the updraft. The larger vortices are capable of lifting not only dust, but also leaves, twings and other debris high into the air. They are capably responsible for lifting the small animals which are occasionally reported as falling from the sky in the tropical deserts". So, as commented by Allahabadi (1986) it is not necessary to invoke a wind speed of 500 km/hr to lift a sphere of 300 micron diameter to a height of 1 km above the ground as envisaged by Baskaran (1985). Moreover, the Stoke's law can not be made applicable in the miliolites as their grains are in most cases not spherical.

The wind deposits the sediments it has carried into the low velocity or dead zones created by topographic roughness and other obstructions. Twidale (1976) has noted that the sand and clay accumulations take place mostly over and around the obstructions such as shrubs, rock outcrops and ridges which disturb the air flow, due to which the secondary eddies and currents set up and zones of low velocity or dead areas get developed.

In Saurashtra, such processes have given rise to various kind of modes of occurrences of miliolites, such as transverse ridges, parabolic dunes, barchans, longitudianal dunes, climbing dunes & echo dunes (windward), falling dunes & shadow dunes (leeward) etc. alongwith the different types of sheet deposits. Their internal sedimentary structures like large scale planar and occasionally trough type cross beddings, convolute laminations, alternate fine & coarse sand laminations, relative grain size variation from SW to NE etc. further suggest their deposition by the winds of varying velocity and the effect of selective wind sorting. However, quite a few miliolite occurrences, especially the valley fill sheet deposits which contain layers of pebbles &

gravels along their bedding planes, suggest their deposition by fluvio-aeolian processes. In such cases the erosion of dunal material during sudden spells of heavy downpour and its subsequent transport, deposition and consolidation in nearby valley sites could be the prime factor in giving rise to these deposits which in turn are identical to the 'wadi' deposits of Glennie (1970).