Chapter - VIII

R E S U M E

The Saurashtra Peninsula is dotted with three types of Quaternary organoclastic carbonate deposits viz. ancient beach rocks, miliolite limestones and stabilised sand dunes. The ancient beach rocks were formed in the littoral and spray-zone areas of Middle Pleistocene (120 - 130 kyr B.P.) high sea and underlie the miliolites. The miliolites seem to have been formed by the aeolian actions during the regressive phase of Middle to late Upper Pleistocene sea. The stabilised sand dunes represent the coastal aeolian accumulations pertaining to the Holocene sea. This account dwells with an integrated study of all the Quaternary carbonate deposits of Saurashtra in general and the miliolite rocks in particular which throws considerable light towards an understanding of various depositional events and climatic

fluctuations that took place during the Quaternary period. Among these, the miliolites have posed an interesting debate regarding their origin, whether they have been deposited in marine environment or by the terrestrial (aeolian) processes; their present disposition being related to glacio/tectono eustatic changes.

The shelly fragmental coast fringing rocks were described by various workers as littoral concrete, dead coral reefs & oyster beds, Chaya Formation etc. assigning their age mostly younger than miliolites while Patel (1991 a) has designated these rocks as ancient beach rocks considering them older than miliolites. The detailed field studies clearly reveal that these ancient beach rocks in Saurashtra, occuring all along the South Saurashtra coast from Dwarka in the NW to Veraval and beyond in SE, lie below the miliolites and represent the littoral & beach accumulations along the foreshore of ancient sea. At most of the places they show facies variation in grain size both, vertical and lateral. The presence of alternate coarse beach material and fine miliolitic material typically suggests a complex beach-dune environment. They show low angled planar cross stratifications together with graded beddings & lenses of megashells and occur as coastal sheets gently dipping towards the sea. At places they also form coast parallel low mounds.

The miliolites are, *per se*, aeolian accumulations of reworked ancient beach material. In coastal areas they overlie either beach rocks or older rocks forming almost continuous exposures from Dwarka to Gopnath where they occur as submerged

dunes, coastal cliffs & shore platforms, coastal ridges, valley fill sheets and few obstacle deposits. In inland areas their occurrences are controlled by pre-miliolite topography, as a result they are encountered only in the sheltered sites all over Saurashtra Peninsula forming patchy exposures of varying dimensions. Very near to the present coast in the inland areas, the miliolites form scattered outcrops representing fossilised barchans, parabolic dunes, transverse & longitudinal dunes, and sheet deposits in interdunal areas, river valleys and coastal plains. In far inland areas they occur as obstacle deposits forming echo dunes & climbing dunes on windward side and falling dunes & shadow dunes on leeward side. They also form thin sheets in the intramontane depressions, in river valleys and at the base of the obstacle deposits merging with one or other type of sheet deposits. The miliolites show typical low to high angled dunal cross stratifications. The windward obstacle deposits exhibit wedge type cross beddings with dips of foresets varying from 5^{o} to as steep as 30^{o} with frequent change in the directions; the confining true bedding planes being absent. The leeward deposits are characterised by mostly tabular cross stratifications with occasional presence of slump features. The coastal miliolites, also show trough type cross stratifications developed due to the migrating mega-ripples, dunes and sand waves. Curved beddings, ripple marks, mud cracks, convolute laminations etc. are also observed. The sheet miliolites too, exhibit low angled planar cross laminations, rhythmic layering, ripple drift laminations and at places typical 'wadi' type of deposition characterised by alternate aeolian & fluvial cycles.

Occurring as coast parallel transverse ridges and longitudinal mounds, the stabilised sand dunes are restricted to the coastal areas of Saurashtra Peninsula where they rest on either miliolites, ancient beach rocks or even Tertiaries. Though these dunes are stabilised, they have not undergone much diagenetic modifications and hence are very much friable and do not show internal sedimentary structures similar to those of miliolites.

The beach rocks comprise the mega & micro shells of gasteropoda & pelecypoda, and tests of foraminifera together with the fragments of bryozoan, echinoids, corals, algae, sea weeds, sponges etc. The intraclasts, beach shingles and lithoclasts of older rocks are also encountered within them. Petrographically they are mostly biopelmicrites and biomicrites, and occasionally biosparites as per Folk (1959, 1962). As these comprise majority of grains larger than sand, they can be designated as calcirudites after Grabau (1904). The constituents of beach rocks are bounded by aragonite and calcite cements.

The miliolites comprise more than 70% allochems (similar to those encountered in beach rocks) alongwith the detritals, all cemented by low Mg nonferroan sparite cement, and are grouped into biopelsparites and occasionally pelsparites after Folk (1959, 1962) and calcarenites as per Grabau (1904). The average grain size in miliolites, in general, decreases from SW (coastal areas) to NE (inland areas) - the prominent wind direction. The calcite cements in miliolites exhibit various ultra-structures viz.

meniscus cement, dripstone - drapstone cement, dog-tooth spar cement, circumgranular rim cement, syntaxial rim cement, blocky void filling cement etc., suggestive of their formation under mostly vadose and occasionally phreatic freshwater conditions.

The constituents of stabilised sand dunes are mostly fine to very fine grained and are relatively rich in detritals as compared to miliolites. However, on Dwarka - Veraval coastal segment they are rather coarser. The granulometric analyses of these sands substantiate their affinity to the present-day beach sands.

The insoluble residues of the Quaternary carbonate deposits of Saurashtra comprise mainly quartz and rock fragments together with small amounts of feldspar and heavy minerals. Other residues include limonitic lumps, foraminiferal & bryozoan casts, plant tissues etc. The relative proportion of various residues in general do not show any trend within each type of deposit, however, they are much higher in the stabilised sand dunes. The quartz forms the major insoluble residue in all the three types of deposits and shows bimodal nature. The subrounded, greasy and polished ones characterise their long transportation while the angular to subangular and transparent ones suggest their derivation mostly from the nearby fluvial regime. The scarcity of silt & clay in the residues of miliolite rocks and dunal sands further supports their aeolian origin.

The XRD data suggest the presence of calcite, aragonite, quartz and feldspars in all the three types of deposits; the major being calcite & quartz. In beach rocks and stabilised sand dunes

the aragonite peaks are frequently encountered while in miliolites they are scarce. The Mg% reflected by the deflection of 100 peak of calcite, is also higher in beach rocks and stabilised sand dunes as compared to miliolites. The aragonite and high magnesian calcite are metastable carbonate minerals and their presence in the deposit indicates its mineralogical immturity. The beach rocks being littoral to spary zone deposits containing large size bioclasts, their meteoric diagenesis is relatively inhibited on account of marine waters as compared to the miliolites so typically formed under meteoric environment. Further the sheet deposits including the coastal dunes, are nearer to the freshwaters than the obstacle deposits like climbing & falling dunes of inland areas. It is because of these reasons the relative survival of unstable aragonite is seen in these deposits.

The thermoluminescence (TL) studies reveal the presence of prominent NTL and NTL + ATL glow peaks due to the laterally precipitated $CaCO_3$ cement in beach rocks and miliolites. Their better resolution in beach rocks perhaps indicates the presence of high Mg calcite and/or protodolomitisation. The absence of NTL glow peaks in the dunal sands could suggest the solar bleaching of TL during the period of successive transportation and accumulation of the sediments. The presence of magnesian impurities in the crystal lattices deflects the TL glow peaks of calcite in the glow curves of carbonate deposits of Saurashtra, which is in consonance with the XRD results.

The SEM studies of beach rocks showing the presence of micritic and fibrous aragonite cements suggest their formation in active intertidal/beach environment. The presence of secondary blocky calcite cement in pore spaces in these rocks indicates the influence of meteoric waters in later stage. The precipitation of fine meniscus and drusy rim cements between the constituents in miliolites has commenced from the calcareous substrates with the development of almost equant tabular calcite crystals that suggest their low magnesian nature. Such calcite cement often showing single step growth, also substantiate their precipitation from mild solutions in meteoric environment. The SEM photomicrographs of some of the coated grains (vadoids) in miliolites exhibit alternate low Mg calcitic micrite & microsparite cortices with downward thickening, having high frequency of enfacial triple junctions between calcite crystals. These features suggest their formation by precipitation from $CaCO_3$ solution and not due to the neomorphism of originally aragonitic marine ooids. This also substantiates the formation of vadoids in typical alternating vadose & phreatic freshwater conditions under meteoric environment. The scanning of quartz grains from beach rocks reveal randomly oriented 'V' shaped indentations with straight or slightly curved grooves suggesting their formation in high energy coastal regime under turbulent aqueous conditions. The chemical etching on some of the quartz grains further suggests the action of chemically active fluids during the diagenesis. The quartz grains from miliolites show curved faces and well rounded, polished nature which on closer view exhibit graded arcs, upturned cleavage plates and meandering ridges, and are accompanied by

angular to subangular quartz grains with conchoidal fractured faces. The former indicates their aeolian transport while the latter, though in subordinate amounts, suggests their derivation from fluvial regime. The stabilised dunal sands reveal the scattered precipitation of fine calcite at their grain contacts indicating the initiation of early cementation in shallow-vadose meteoric environment.

The beach rocks and miliolite limestones of the study area are well cemented, indurated rocks as compared to the sand dunes which are merely stabilised. Obviously the former two have undergone a long period of diagenesis. The diagenesis of the miliolites was brought about in meteoric environment while that of beach rocks was initiated in nearshore environment, under the control of some intrinsic (mineralogy, grain size, porosity & permiability) as well as extrinsic factors (climate, vegetation, time etc.). The various Quaternary carbonate deposits of Saurashtra have passed through one or other of the five sequential stages of diagenesis proposed by Land et al. (1967) and Gavish & Friedman (1969) as :

1. Generation of carbonate sediments and their stabilisation
2. Early cementation and compaction after their stabilisation in a perticular environment
3. Mineralogical stabilisation after loss of Mg^{2+}
4. Dissolution of aragonite and precipitation of calcite and
5. Recrystallisation or neomorphism

The influx of freshwater in the Quaternary carbonate sediments of study area has greatly facilitated their

lithification/cementation. Their mineralogy and degree & duration of sediment exposure to the freshwater conditions are the factors of paramount importance in controlling the diagenetic maturity. The beach rocks of Saurashtra clearly show the presence of primary cement as aragonite in fibrous & micrite forms together with secondary void filling low Mg sparry calcite cements, both pointing towards their formation in nearshore areas of an ancient sea under the influence of freshwaters (meteoric & groundwater). The presence of large amount of aragonite dissolution, high Mg clacite alteration and low Mg calcite precipitation in beach rocks and miliolites suggest their overall diagenetic maturity and mineralogical stabilisation. The presence of various cement morphology togehter with the development of secondary porosity and low Mg nonferroan calcite mineralogy in miliolites, suggest their diagenesis in meteoric environment. The early cementation & compaction remain relatively intensive in fine grained deposits. In miliolites this is seen as well developed primary cements and relatively better compaction causing oriented & imbricated grain arrangement, plastic bending & breakage of grains, tangential & truncated grain contacts etc. However, the compaction in both the types of deposits viz. beach rocks & miliolites is not that much significant due to the coarse grained nature of former one and lack of overburden pressure in latter one. The overall diagenetic maturity of beach rocks over miliolites is evident by thin section, XRD and TL studies, although, their immaturity reflected by the presence of considerable amount of aragonite and Mg^{2+} in calcite, especially in those of Dwarka area, could be due to poor

rainfall & arid climate in this part of coastal segment of Saurashtra.

The younger stabilised sand dunes which are relatively rich in detritals as compared to miliolites, have suffered lesser degree of freshwater influx. As a result, they have remained diagenetically immatured as indicated by the presence of aragonite and high Mg calcite in their XRD curves. Although, the presence of low Mg clacite peaks in these deposits collectively represent the originally low Mg calcitic allochems as well as newly formed low Mg calcite cements. The beach rocks and miliolites thus belong to the III, IV and V stage of diagenetic scheme of Land et al. (1967), whereas the stabilised sand dunes have hardly reached upto II or III stage.

The deposition of bioclastic carbonates in Saurahtra has much relevance to the sealevel changes and climatic fluctuations during Quaternary Period. The oscillatory regression of Middle Pleistocene high sea which gave rise to the beach rocks on its shore, progressively exposed enormous amount of beach and littoral sands to glacially strengthened southwesterly onshore winds. The winds lifted these coastal sands in instalments by combined processes of traction, saltation and suspension and deposited them inlandward as various types of dunes and sheets over pre-miliolite topography. These aeolian accumulations, marked by arid phases, were stabilised and their diagenesis have been brought about under vadose and/or phreatic meteoric water environment during the subsequent humid climatic phases. Although in general, the

process of transportation and deposition of the bioclastic carbonate sands remained active for an arid phase of such a long span from Middle Pleistocene till late Upper Pleistocene, that was punctuated by interveening sub-humid to humid climatic phases related to the alternating glacial-interglacial stages of small durations. This is ideally seen in quite a few miliolite sections intercalated with red kankary pedogenised layers, fluvial sediments, terrestrial debris, karstified surfaces, abrupt termination of primary sedimentary structures etc. The subsequent oscillation in Holocene sealevel similarly gave rise to the stabilised sand dunes in coastal areas of Saurashtra Peninsula.