CHAPTER IX

R E S U M E

The miliolite rocks of Kutch which are somewhat different from their counterparts in Saurashtra, comprise aeolian accumulations of biogenic sand grains of marine origin. These deposits reveal an interesting depositional history wherein fluctuating sea levels and strong wind action have combined to generate these deposits.

Miliolite rocks as such have been a subject matter of interesting debate whether these deposits are marine or aeolian. Most of the previous workers, though having contributed significantly to the knowledge on miliolites have somehow carried out generalised studies. The present author being considerably benefited by the contribution of all the previous workers, has in this thesis made an attempt to describe in extenso, intrinsic sedimentological and diagenetic aspects of the Kutch miliolites.

Detailed mapping by the present author of almost all miliolite occurrences, has very clearly established that sheets of miliolites occur at different altitudes, and it would be most unrealistic to invoke several high strandlines to explain marine deposition at various levels. Invoking tectonism too is not possible because there are few evidences to support tectonic uplifts to explain the different heights of sheet miliolites, which could be taken as marine.

The present author has, on the basis of this study, come to conclusion that the miliolite deposits of Kutch show an aeolian origin and comprise accumulations of reworked marine particles by strong winds resting over the pre-miliolite topography as obstacle and sheet deposits at different altitudes.

In Kutch, the miliolite occurrences are restricted to the rocky Mainland, forming a well-defined SW-NE zone overlooking the sandy beaches of South Kutch coast and extend from the upper fringes of the coastal plains to the foot of the Northern Hill Ranges. The topography and drainage of this part of the Mainland has been responsible for the deposition of miliolite rocks by providing appropriate obstacles and sheltered sites for the wind-borne material that were lifted from the southern coast and dumped inlandward. The miliolite rocks thus occur on Kutch Mainland in its eastern and central inland areas in the form of isolated and scattered outcrops. These rocks occupy (i) low ground at the base of the hills, (ii) topographic depressions in hilly areas like valleys and plains surrounded by ridges and (iii) hollows on the slopes of the big hills and ridges, and show considerable diversity in their nature and occurrence.

Based on the modes of occurrence in different exposures, they have been categorised as (i) obstacle deposits (Category A) and (2) sheet deposits (Category B). Obstacle deposits (A) are seen resting against hill slopes in hollows and depressions. The shape, thickness and extent of these deposits depend on the depth and shape of the hill slope hollows that they have occupied. These deposits usually show cross-stratification that consists dominantly of tabular and wedge planar sets. The obstacle deposits have been observed to comprise two distinct types as (i) windward face deposits (A_1) and (ii) leeward (slip-face) face deposits (A_2). Sheet deposits (B) occur in flat areas like older river valleys, rocky amphitheatres, flat-topped hills and pedeplains, and occur at various elevations. This category has been divided into four types, viz. (i) valley-fill deposits (B_1), (ii) sheets at the base of obstacle deposits (B_2), (iii) sheets as thin veneers within the hilly terrain (B_3) and (iv) sheets resting on the flat-topped hills (B_4).

Taking a total view of the petrographic data provided by the thin sections, the author has been able to study the three components, viz. allochems, detrital particles and cement in considerable detail. The term allochems has been used to include (a) the various bioclastic particles (b) peloids and (c) vadoids and cortoids. The biogenic constituents comprising microfossils, fragments of molluscan megashells, bryozoa, echinoderm spines, ostracodes, algae, etc. show varying degree of abrasion and micritisation and in many cases the original internal structures have been totally obliterated, to give rise to peloids, Transformation of bioclasts to peloids is due to a process of micritisation which is seen to have been brought about by the action of bacteria, fungi and algae. Looking somewhat similar to peloids, are the vadoids and 'coated grains' or 'cortoids'. These are derivatives of bioclasts and peloids modified by certain diagenetic processes. Cortoids comprise abraded to unabraded bioclasts, peloids and other particles with relatively thin micritic envelopes. Vadoids are also a variety of coated grains which have originated in a vadose environment; their nucleii are coated with very fine alternate dark and clear concentric laminae. The detrital particles consist predominantly of quartz, with smaller proportions of fragments of basalts, laterite, different types of sandstones etc and a few minerals like felspar, augite, hornblende, magnetite and haematite.

The conversion of the loose carbonate sands (miliolitic sands) into consolidated rock (limestone) included following three main diagenetic processes during which the calcitization of metastable minerals to low-Mg calcite took place;

(a) conversion of high magnesian calcite to low magnesian calcite, during which the original texture of the shell was preserved with a thin micritic envelope.

(b) The aragonite allochem's dissolution is partial or complete, resulting in the total loss of allochem.

(c) Precipitation or calcitisation of low-Mg calcite derived from the dissolution of aragonite and high-Mg calcite allochems to occur as cement between particles or as 'mould filling' cement within intraparticles spaces.

The cementing material in miliolite is a sparite filling up the inter and intraparticle spaces and binding them together. In practically all thin sections of miliolite, two generations of cement A and B have been recognised. The cement 'A' is the first generation cement, commonly fibrous in habit and is seen to grow normal to the particle surface, which corresponds to the early diagenetic processes, while the cement 'B' is of second generation, is usually coarser than the former and is characterised by isometric drusy or blocky mosaics that occur as pore-filling crystals. In most of the thin sections cements of both the generations are encountered.

In Kutch miliolite diagenesis, meteoric water appears to have played a dominant role, although the role of ground-water also might have been significant at times. These processes appear to have operated over a protracted period covering almost the entire Late Quaternary. The process of compaction and cementation have been brought about in a vadose environment under the influence of fresh water. The constituents are seen bound and cemented together by a medium to coarse calcitic (sparite) cement, which has also filled the primary (interstitial) and secondary vugs and openings in the rock. The source of the sparite cement in miliolite has been mostly endogenic, i.e. the $CaCO_3$ has been derived from within the rock formation itself, on account of the dissolution of aragonite and high-Mg calcite constituents and precipitation as low-Mg calcite mainly by meteoric waters.

The precipitation and growth of cement in miliolite were controlled by various factors as (i) climate, (ii) mineralogy of allochems, (iii) availability of fresh water (iv) rate of supersaturation of solution (fresh-water), (v) nearby geological formations and (vi) mode of distribution of miliolitic sands. Depending upon these factors, the miliolite rocks show varying degree of cementation e.g. the sheet miliolites are more consolidated and less friable than obstacle deposits which are loosely consolidated and more friable in nature.

Following 7 types of cements have been grouped generationwise as (i) Drusy rim cement -'A', (ii) Gravitational cement-'A', (iii) Dog-tooth cement -'A',(iv) Meniscus cement -'A', (v) Syntaxial rim cement - 'B', (vi) Pore filling cement-'B' and (vii) Vadose crystal silt (post-dates 'A' and pre-dates 'B').

The occurrence of vadoids in the Kutch miliolite, has provided a conclusive evidence in support of their fresh water diagenesis.

The original unconsolidated miliolitic sands consisted of (a) organic particles with aragonitic skeleton (the molluscs, corals and Halimeda algae), and (b) organic particles with high magnesian calcite skeleton (most of the foraminifers, coralline algae and echinoderms).

On an average, majority of biogenic grains are of sand size, and show a size variation from silt to medium sand (0.062-0.5 mm). Most of the bioclasts in miliolite are rounded to well rounded. In some thin sections, alternate laminations made up of fine and medium size carbonate grains are distinctly observed. Individual laminae are comparatively well sorted. The grain size variation as observed in thin sections from different locations, points to the following characteristic features of considerable genetic significance:

(i) Though there is an overall decrease in the grain size from SW to NE, the pattern of size variation is not very smooth. This reflects sediment transport in instalments and against successive obstacles, under winds of variable energy, local reworking and sorting of earlier deposited material.

(ii) There is a progressive increase in sorting from SW to NE.

(iii) Individual samples, especially from obstacle dune, reveal alternate laminae of grains of different sizes pointing to an aeolian layering.

Under arid and desertic conditions, wind plays an effective role in transporting sediments. An essential requirement for the effectiveness of aeolian action is that the sediments have to be dry. The present author has visualised a transport mechanism for the Kutch miliolites, which could be comprising diverse combinations of all the three processes, viz. surface creep, saltation and suspension. The gentle to moderate topographic rise was an important factor to have enabled the aeolian sands to travel long distances inlandward from the coast. Moreover, the gaps provided by the valleys of the rivers Kankawati, Chok, Sai, Vengdi, Kharod, Rukmavati must have offered more conducive conditions. The surface creep mechanism according to the author, was also quite effective. The surface did not act alone. It might have shifted the sediments at a reasonable distance from the source from where it could be subsequently transported further inlandward by other two processes. The vice versa could also be true. Sand particles, transported to long distances by action of whirlwind, could also be affected by further surface creep or saltation.

Although, the author has invoked a dominant role of wind-borne transport and deposition for most of the sheet miliolite deposit occupying low-lying areas, he is of opinion that quite a few sheet occurrences especially those which contain cobbly and pebbly layers and calcrete crusts are typically indicative of fluvio-aeolian deposition. In such cases erosion of dunal material during sudden spells of heavy downpour and its subsequent transport, deposition and consolidation in nearby valley sites, appear to be the main processes.

From the faunal point of view, the miliolite rocks are identical to those of present day beach sands and consist of broken molluscan shell fragments, ostracodes, abraded tests of gasteropods, pelecypods, foraminifera, echinoderm spines and bryozoa, with a fair proportion of peloids. On account of high degree of abrasion, it was rather difficult to identify the foraminifera separated from the miliolite upto the species level. Thus, the identification upto generic level, has shown the occurrence of Ammonia sp., Elphidium sp., Quinqueloculina sp., Pararotalia sp., Elphidium crispum (Linnaus), Spiroloculina sp., Triloculina sp., Nonion sp., Cibicides sp., Globigerina sp., Bulimina sp., Eponides rependus (Fitchell and Moll).

The abundance of biogenic carbonate sand particles in miliolite indicates a carbonate generating shallow high energy Quaternary sea. The subsequent regression of the sea synchronized with a glacial stage marked by a dry climatic phase.

The author has thus postulated a palaeo-strandline about + 25 m above the present sea level and the miliolitic sand is supposed to have been generated during this high sea stand. The sea subsequently regressed to as much as -20 m below the present level. Of course, it is not unlikely that the entire phenomenon of increasing regression was punctuated by periodic rise and fall of sea level depending on the global climatic changes. The present author has however refrained from pinpointing the absolute heights and depths of the transgression and regression along the Kutch coast in term of glacio-eustasy alone. The height of the transgressive stmandline therefore has been taken in a relative sense only. The author has thus visualised two factors primarily responsible for the generation of adequate quantities of carbonate sands and their subsequent transportation to their present sites, viz. (1) A high energy carbonate sand generating shallow marine environment and (2) An intermittent but progressive regression of strandline exposing beach and littoral sands to wind action. The main observations and conclusions arrived at by the present author in this thesis can be summarised as under:

(1) The constituents of the Kutch miliolites, especially the allochems, comprise sand-size carbonate beach material of marine origin.

(2) The present day miliolites represent aeolianites having been deposited by the strong action of wind.

(3) Southwesterly winds lifted and transported sands inlandward and deposited them at appropriate sites.

(4) Subsequent fresh water diagenetic processes cemented these bioclastic sands into consolidated miliolites.

The above sequence of events essentially involved a combination of marine, aeolian and vadose environments in that order, which appear to have been responsible for the origin of Kutch miliolites. Shallow high energy coastal marine environment was responsible for the generation of beach sands with a dominance of biogenic carbonate sand particles. Strong aeolian action has to be invoked for lifting up the sands and dumping them at their present sites. Their subsequent consolidation and diagenesis in a vadose environment typically points to an effective role played by meteoric water. In this evolutionary model the factors of climatic variations and eustatic sea level changes during the Quaternary period have played an indirect but effective roles in the operation of the various processes responsible for the miliolite rock formation.