CHAPTER - V

TEXTURAL AND COMPOSITIONAL CHARACTERISTICS

SCOPE OF STUDIES

Textural and compositional studies are important tools towards a proper understanding of the depositional aspects of any sedimentary rock. In case of carbonates, these provide much more details, especially the precise mode of origin as well. These studies have enabled the author, to throw considerable light on many aspects related to the problem of miliolite.

In this chapter, the author has analysed representative samples from all types locations for the purpose of following studies:

1. Petrographic studies: Routine studies of thin sections to determine the nature of various allochems, detrital clastics and the cement. To identify and distinguish calcite from dolomite and also ferroan from non-ferroan calcite, the author studied stained miliolite thin sections under polarising microscope, following the procedure given by Dickson (1965).

2. Textural studies: Thin section studies to obtain data on the shapes and sizes of the various allochem constituents and detrital clastics and their modes of arrangement.

3. Frequency studies: Thin section studies for determination of the proportions of the cement vs. total allochems and varying percentage of allochems (and allied carbonate particles) and detrital grains. To obtain the percentage by volume (vol %) of the individual constituents, the 'Dual measurements' technique of Dunham (1962) was followed.

4. Insoluble residue studies: Determination of the 'relative' or the 'absolute' amount of non-carbonate acid insoluble residues (sand, silt and clay) and the $CaCO_3$ content.

5. Micropalaeontological studies: Studies of disaggregated samples and thin sections for understanding the microfaunal characteristics.

The author has observed that the detailed and systematic field and laboratory studies of the miliolite occurrences of Kutch throw significant light on many such aspects of Saurashtra miliolite which have not yet been fully understood. It is not the intention of the author to suggest that petrographically these calcarenites of the two regions are identical, but many of the findings and observations when applied to Saurashtra will enable the future workers to distinguish between the marine and the aeolian miliolites of Saurashtra. Also, the methodology and technique followed by the author in petrographic analysis of his own samples from Kutch could be appropriately applied to miliolites of other areas including Saurashtra.

PETROGRAPHIC STUDIES

In hand specimen, the miliolite rock is seen to be white to dirty white in color, somewhat friable, made up of sand size calcareous and terrigenous grains, supported with a spar cement. Petrographic details of the miliolite of different categories have been obtained on the basis of the routine thin section studies. According to the author who has broadly followed the nomenclature and classification of limestone suggested by Folk (1959, 1962), the rock can be best termed as 'biopelsparite'; the term 'biopelsparite' has however been used exclusively as a descriptive term without invoking any genetic significance.

The present author has attempted to evaluate and analyse the petrographic characters to properly understand (i) the origin and nature of the source material and

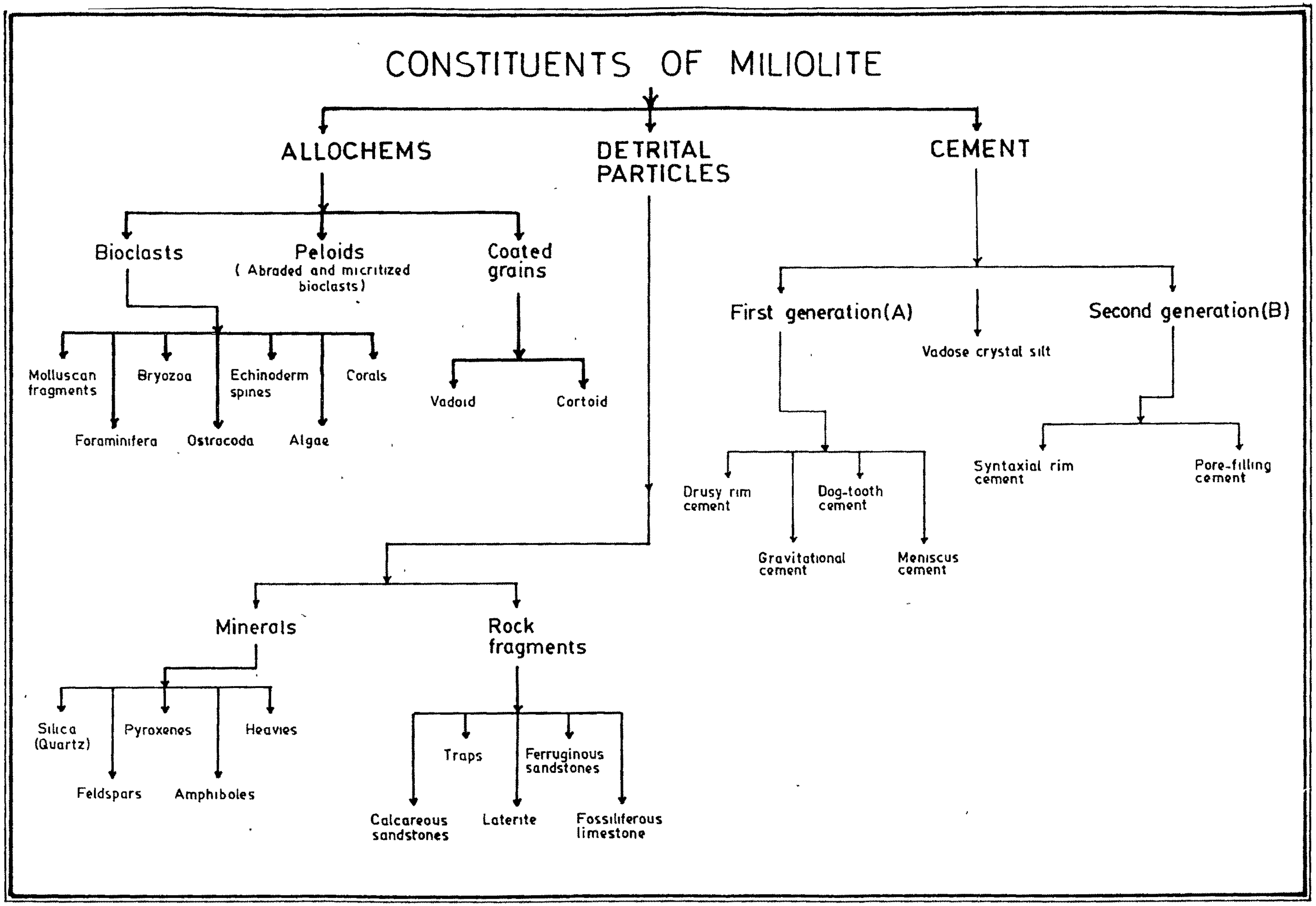
(ii) the diagenetic processes (solution, cementation, lithification and alteration of sediments after deposition).

Taking a total view of the petrographic data provided by thin sections from different locations, the author has been able to distinguish three components, viz. allochems, detrital particles and cement. The salient features of these constituents are given in (Table V.1), and their details have been discussed in the subsequent text.

(A) Allochems

The term allochem originally proposed by Folk (1959, 1962) has been used by the present author in a slightly broader sense to include (a) the variety of bioclastic particles comprising microfossils (foraminiferal and tiny molluscan tests), fragments of molluscan megashells, bryozoa, echinoderm spines, ostracodes, algae, corals, etc.
(b) peloids and (c) vadoids and cortoids (Plate V.1 & 2).

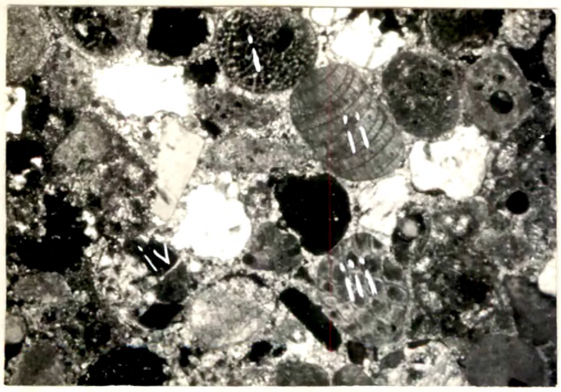
In fact 'peloids' (which have been mistaken by many as oolites) are quite dominant and are derived from the bioclasts by processes of abrasion and micritisation. Also, looking very much similar to oolites, occur in many thin sections, rounded or elliptical grains of vadoids (Peryt,1983). These also could be confused with oolites or pseudo-oolites, which they are not. For the purpose of this study and



Table·V·I CONSTITUENTS OF KUTCH MILIOLITES.

Plate V. 1

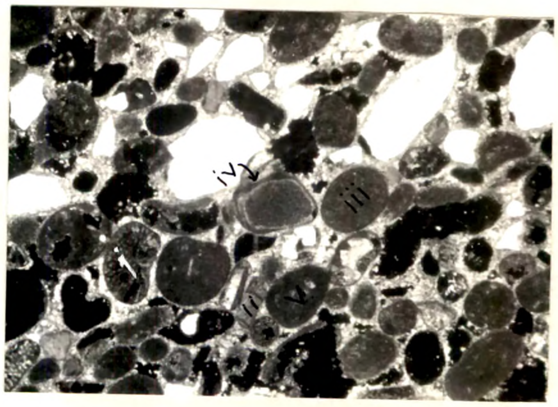
Photomicrographs of miliolite allochems (Kutch)



(a)

(i) Echinoderm spines
(ii) Coralline algae
(iii) Bryozoa
(iv) Foraminifera (Rotaliidae)

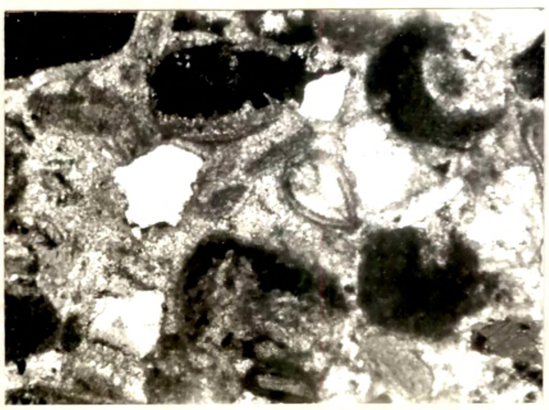
(X 40, PPL)



(b)

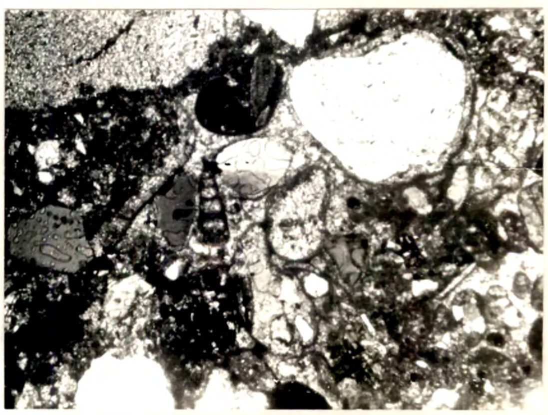
(i) Echinoderm spines
(ii) Coralline algae
(iii) Peloids
(iv) Cortoid
(v) Foraminifera (Milioliidae)

(X 40, PPL)



(c)

Intact lamellibranch test
(X 70, PPL)

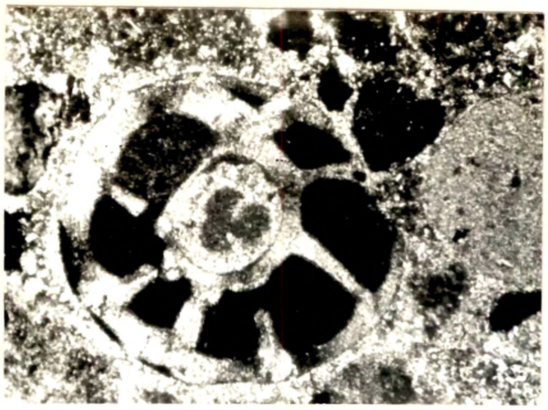


(d)

Longitudinal section of gasteropoda
(X 40, PPL)

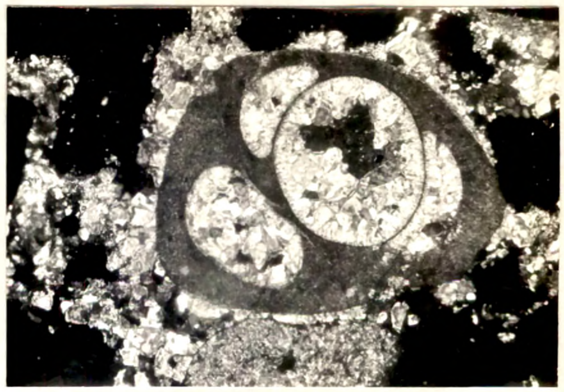
Plate V. 2

Photomicrograph of miliolite allochems (Kutch)



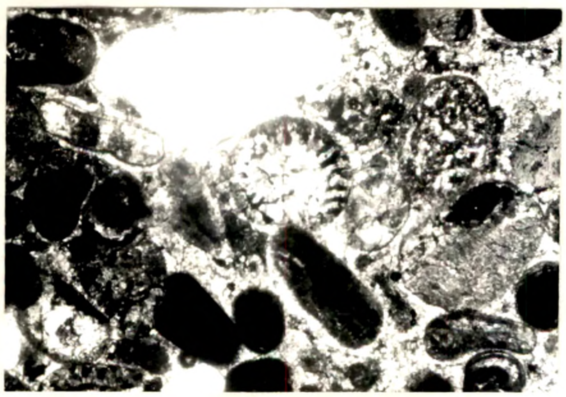
(a)

Foraminifera (Rotaliidae) chambers completely filled with micrite
(X 140, PPL)



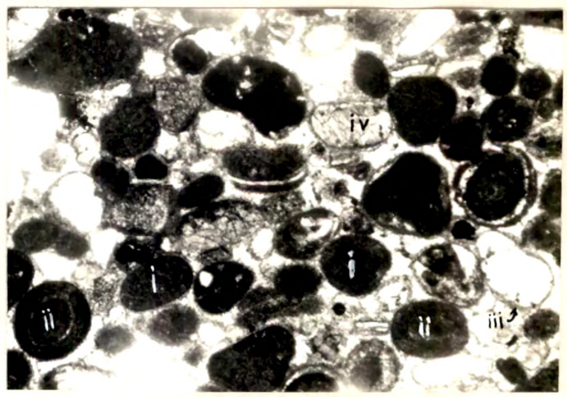
(b)

Foraminifera (Milioliidae) chambers filled with coarse sparite
(X 140, PPL)



(c)

Coral fragments (at the centre) surrounded by peloids and molluscan shell fragments
(X 40, PPL)



(d)

i) Peloids
ii) Vadoids
iii) Cortoid
iv) Molluscan shell fragments

(X 40, PPL)

convenience of description the author has included these coated grains (vadoid and cortoids) with other allochems in view of the fact that they are a diagenetic product with bioclastic or peloid nucleii. Oolites and/or psuedo-oolites are significantly absent.

(a) Bioclasts

The bioclasts comprise mainly sand-size grains of (i) broken and abraded molluscan fragments (ii) foraminifera (iii) bryozoa, (iv) ostracoda, (v) echinoderm spines, (vi) algae, (vii) corals, etc., all showing marked but varying degree of abrasion and rounding. Total absence of complete megashells is of significance.

(i) Molluscan fragments

Molluscan bioclasts are the most dominant and comprise gasteropoda and lamellibranchia. Mostly they consist of sand-size fragments of megashells, but tiny intact tests are not uncommon. They are rounded to well rounded and commonly exhibit grey or yellow color in thin sections, and occur as circular, elliptical, crescentic or elongated grains. It is observed that many of them have been preserved as 'moulds' with infillings of sparitic cement. Lamellibranch fragments are more important and generally show a distinct 'foliated' internal structure. Majority of the molluscan particles indicate a size upto 1 mm and form 2-25 % of the total bulk of the rock.

Some thin sections have revealed the presence of tiny intact lamellibranch tests which are easily recognised by their elliptical shapes and radiating ribs from the umbones (Plate V.1c). Gasteropod is less common; it is seen forming as chambered grains, the shape depending on the original shape of the test (Plate V.1d). Quite often the chambers are filled with brownish yellow micrite and fine sparite.

(ii) Foraminifera

Foraminiferal tests show a variety of shapes and wall structures, and the different sections show different shapes and arrangements of chambers. The grains are of white, grey and brownish color in thin section and show a size variation from 0.12-1 mm. Rotaliidae, Elphidiidae and Milioliidae which include many groups are the dominant foraminifera. In many sections, the chambers are seen filled with a micrite and sometimes with sparite (Plate V.2 a,b).

(iii) Bryozoa

These are recognised by their characteristic arrangement of tubes and pores of different sizes within the skeleton (Plate V. 1 a). They are commonly red-brown in this section and show a size variation from 0.25 - 1 mm.

(iv) Ostracoda

These are not very common and are observed only sporadically. They occur as partly opened valves, which have been filled with fine sparite. They are recognised by their thin curved shells tapering at one end.

(v) Echinoderm spines

In thin sections, the spine fragments exhibit a wide variety of shapes; circular, elliptical or rod like. The former two shapes represent cross sections normal or oblique to the length of the spines, with maximum size, upto 1 mm. The cross-sections show typical radial structure and concentric lines (Plate V. 1 a,b). They are of grey or brownish yellow color in transmitted light and the various rings show optical continuity.

(vi) Algae

Algae is another important bioclast contributor. Two forms present are (a) Halimeda and (b) coralline algae. The Halimeda fragments are only sporadic and poorly preserved, but coralline algae is very common being well preserved (Plate V. 1 a). It is characterised by grains of grey color with reticulate structure. Most of the grains show size upto 1 mm, but a few grains are of the order of 1.5 mm which are restricted to samples from the South Kutch Mainland.

(vii) Corals

Fragments of corals occur as rounded to well rounded grains with maximum 1 mm size. The exact identification and evidence of their characteristics are difficult in thin sections because of their poor preservation. Since most corals have skeletons composed of aragonite which being unstable, dissolved rapidly in presence of fresh water to form calcium bicarbonate (Friedman & Sanders, 1978). However, they are identifiable by the microstructures like bundles of fibers or with dark lines down the middle (Plate V.2c). Their large central opening with radiating elements usually do not extend to the centre. Most of the coral grains have been recrystallised into sparite.

(b) Peloids

The use of the term 'pellet' has been avoided by the author since pellet is generally considered a synonym for 'fecal pellet' in the geological literature. McKee & Gutschick (1969), suggested the name 'peloid' for all particles of various origins which are oblong, cylindrical, spherical or rod shaped, usually without any internal structure. The term 'bahamite' is also used for micritised rounded bioclasts, devoid of any internal structure (Beales, 1958; Gygi, 1969; Bathurst, 1971). Milliman (1974), suggested the term 'pelletoid' to such carbonate grains. The author has, however, preferred the term 'peloid' which is more widely accepted for the micritic (cryptocrystalline) grains of bioclastic origins in which the internal structures are obliterated (Plate V.1b & V 2c,d).

In thin section the biogenic contituents show varying degree of abrasion and micritisation and in many the original internal structures have been totally obliterated. For the purpose of description and identification, the author has included all such grains as 'peloids'. On the other hand, even partly micritised biogenic fragments which can still be identified have been taken as bioclasts. In thin section, peloids appear opaque, greyish or brownish, and are usually elliptical, circular, crescentic and elongated, with diameters less than 1 mm, and dominate over the other individual allochem constituents. The shape of the peloid reflects the shape of the original grain from which it has been derived e.g. peloids derived from abrasion and micritisation of lamellibranch fragments represent elongated, elliptical and crescentic shape; those derived from gasteropods show elongated shape. Algal peloids which are sometimes quite abundant show different size and shape (circular and elliptical) with varying degree of abrasion.

The process of micritisation of bioclasts appears to have been brought about by the action of bacteria, fungi and algae (Bathurst, 1966; Friedman et al, 1971; Rooney & Perkins, 1972; Golubic et al, 1975). According to James (1972), the micritisation may also occur within caliche crust in the meteoric zone, resulting in transformation of carbonate particles into particles without microstructure. The complete process of micritisation consists in loosening the surface, abrading and rounding off the particles, later formation of micritic peloids (Flügel, 1982). The abrasion of the bioclasts have been primarily brought about by the action of wave and surf in marine environment and later by wind during transportation.

(c) Vadoids and Cortoids

Another category of allochem contituents is that of vadoids (Peryt, 1983) and 'coated grains' or 'cortoid'; (Flugel, 1982). These are derivatives of bioclasts and peloids modified by certain diagenetic processes (Plate V.2 d). Cortoids are the abraded to unabraded bioclasts, peloids and other particles with relatively thin micritic envelopes, Both, nevertheless happen to be products of diagenetic phenomena. The micrite envelope of cortoids appear black in transmitted light and grey in direct light. According to Folk (1974), the micrite envelope is a "result of very rapid precipitation either by organic influence or by evaporation or chemical reactions causing rapid degassing of CO_2, rapid supersaturation and multiple nucleation". In some thin sections, the fabric of biogenic fragments have been partly or completely dissolved, and the outline of the fragments is preserved by micritic envelope only.

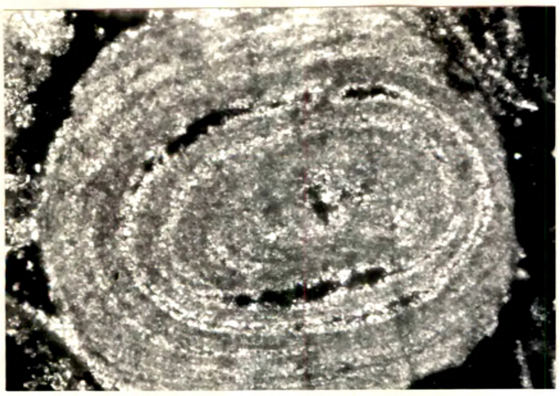
Vadoids (Peryt, 1983) are also a variety of coated grains which originate in a vadose environment. Their nucleii are coated with very fine alternate dark (micritic) and clear (Microspar) laminae and are characterised by skeletal nucleii of faraminifers, molluscan fragments, echinoderm spines, algae and peloids (Plate V.3). They are identical to what Esteban & Pray (1983) have called 'pisoids with skeletal nuclei', which were earlier termed as 'oversized marine ooliths' by Dunham (1969b). Their size depends on that of the nucleus; the maximum being 0.8 mm in miliolite rocks of the study area. These vadoids are mostly restricted to the sheet miliolites and the secondary hard crust (calcrete/caliche) in Kutch Mainland. These have been described in detail at a later stage.

(B) Detrital Particles

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. Complete absence of mica flakes is observed. The above

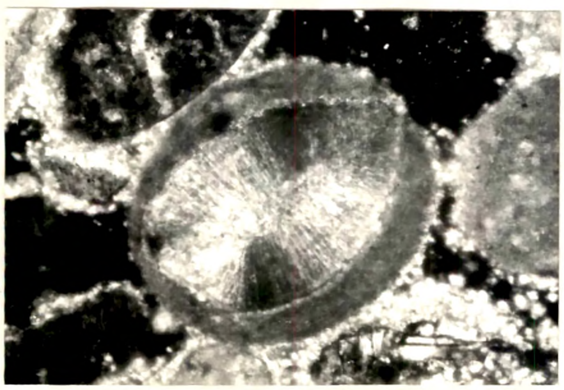
Plate V. 3

Photomicrograph of vadoids with bioclastic nucleii

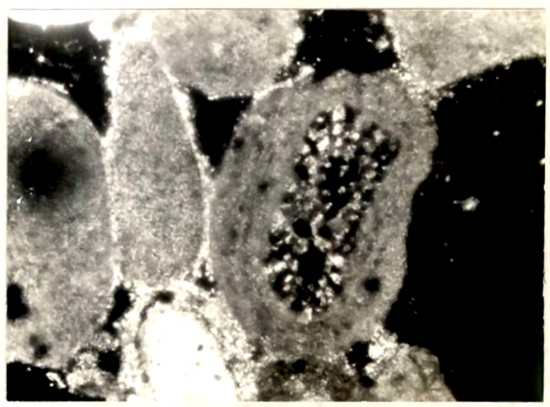


(a)
Peloid coated with alternate dark and light concentric laminae
(X 140, PPL)

(b)
Foraminifera as nucleus
(X 140, PPL)



(c)
Tiny lamellibranch test as nucleus
(X 70, PPL)



(d)
Echinoderm as nucleus
(X 140, PPL)

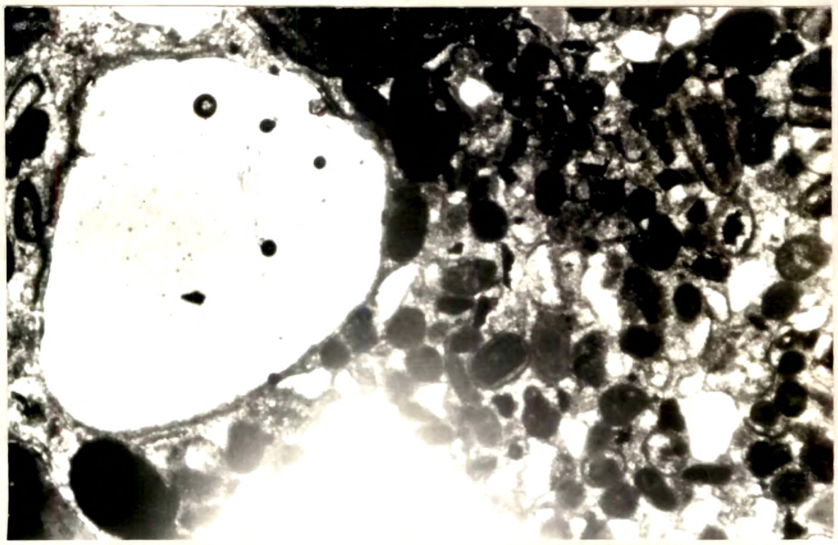
constituents are present in varying proportions forming 10-55 % of the total constituents. They mainly represent locally derived material that are transported from nearby areas, close to the site of deposition of miliolite rocks, and reflect the geology of the area. Most of the grains show a maximum size upto 1.5 mm; of course. Occasional presence of boulders and pebbles of locally derived rock fragments can also not be ignored, but these are observed in the field only.

It is interesting to observe that the finer quartz grains (upto 0.5 mm) are angular to sub-angular, while quite a few of the larger grains are sub-rounded to rounded (Plate V.4). Possibly some of the finer quartz grains are wind-borne, transported and deposited along with biogenic constituents whereas coarser grains have been derived locally either by the weathering of Bhuj sandstones or Tertiary sandstones.

(c) Cement

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 have been recognised. Workers all over the world who have studied carbonate

Plate V. 4



Photomicrograph showing two generations of quartz in Kutch miliolites
(X 50, PPL)

rocks of diverse environments have reported more than one generation of cement and have discussed their significance (Bathurst, 1958, 1971; Oldershaw & Scoffin, 1967; Milliman, 1974; Flugel, 1982; Gardner, 1983). The present author has followed the nomenclature of Flügel (1982) and has designated his two generations as cement 'A' and cement 'B' as under:

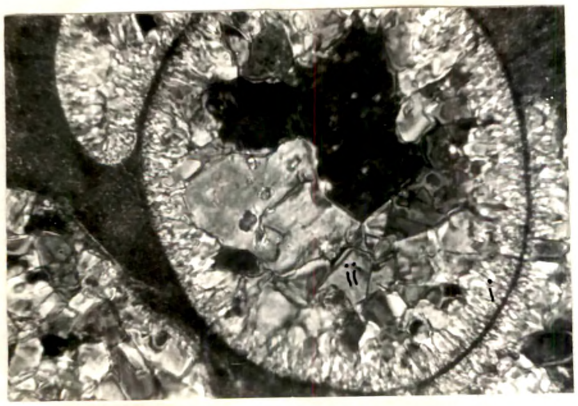
1. Cement 'A' is the first generation cement, commonly fibrous in habit and is seen to grow normal to the particle surface, which corresponds to the early diagenetic processes in limestone. This cement has a sharp contact with the surface of limestone constituents.

2. Cement 'B' is of the second generation cement and is usually coarser than cement 'A'. It is characterised by isometric drusy or blocky mosaics that occur as pore-filling crystals. It is often observed that the crystal size increases towards the centre of the voids or openings which it fills.

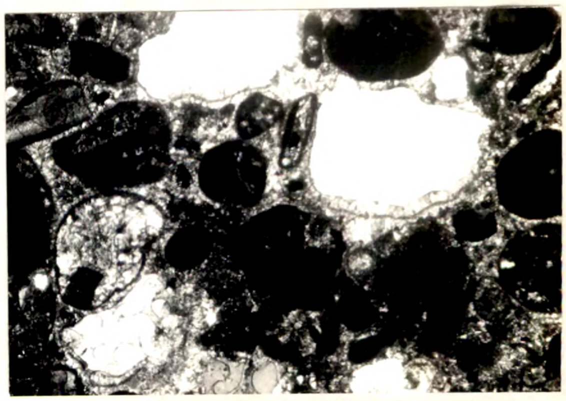
In most of the thin sections of the miliolite rocks of the study area, cement of both the generations ('A' & 'B') are encountered (Plate V. 5 & 6). Thin section stained with potassium ferricyanide and dye alizarin Red-S, reveal that these cements are mostly non-ferroan calcite. On the basis of a scrutiny of several thin sections, the present author has been able to identify atleast 7 types of cement

Plate V. 5

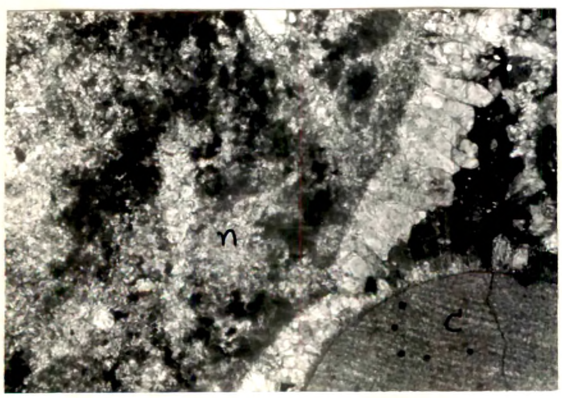
Photomicrograph of various types of cement in Kutch miliolites



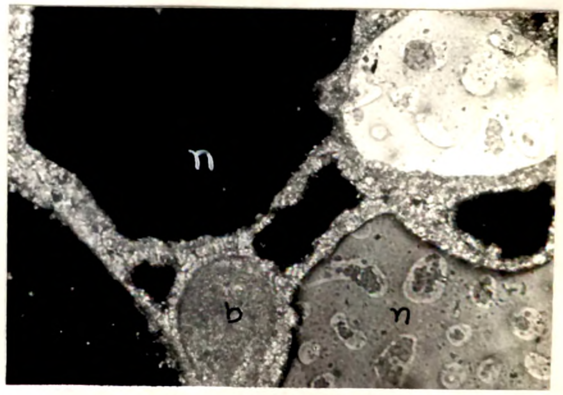
(a)
Two generation of cement
i) First generation (A)
ii) Second generation (B)
(X 340, PPL)



(b)
Gravitational cement
(X 40, PPL)



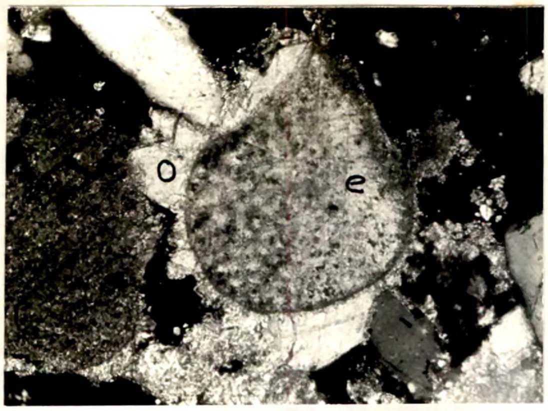
(c)
Dog-tooth cement growing on coralline algae bioclasts (c) and on non carbonate grains (n) in the interparticles pores
(X 140, PPL)



(d)
Meniscus cement between the bioclasts (b) and non-carbonatic lithoclasts (n)
(X 140, PPL)

Plate V. 6

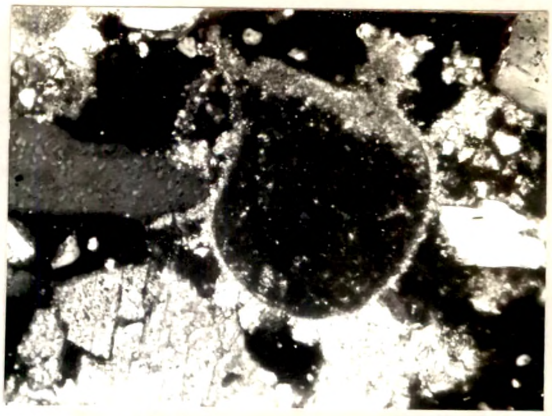
Photomicrograph of various types of cement in Kutch miliolites



(a)

Syntaxial overgrowth cement (o) on echinoderm fragment (e). The growth of cement has been prevented by adjacent grains

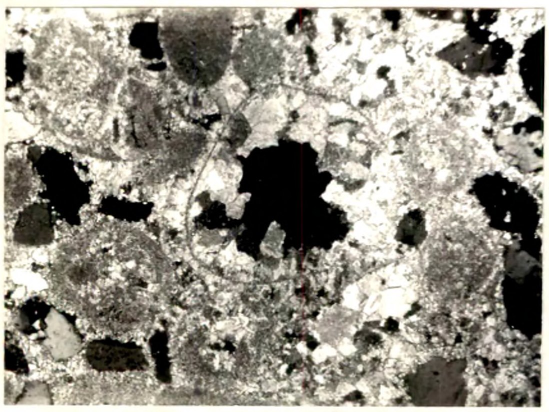
(X 140, PPL)



(b)

Syntaxial overgrowth cement (as 'a') in crossed nicols The white line on the surface of the grain is first generation cement (A)

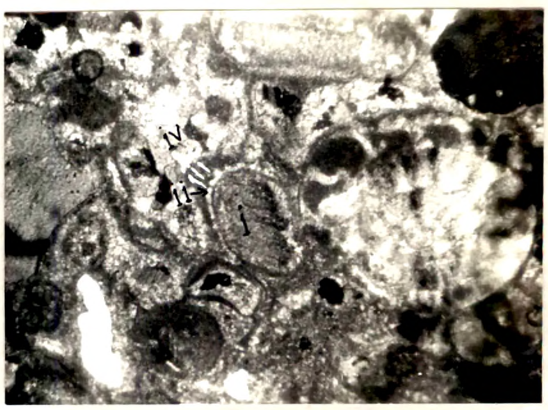
(X 140, PPL)



(c)

Pore-filling blocky cement. The outline of the pre-existing biogenic fragment is preserved by micritic envelopes (congruent dissolution)

(X 70, PPL)



(d)

Vadose silt in interstices openings (i) Allochem, (ii) Dog-tooth cement (A), (iii) Vadose silt, (iv) blocky cement (B).

(X 70, PPL)

belonging to 'A' or 'B' generation. He has categorised and described them as per below.

First Generation Cement (A)

(i) Drusy rim cement: usually forms a rim around the whole grain or lining the wall of the primary and secondary cavities in miliolite rocks (Plate V.5a).

(ii) Gravitational cement: occurs as incomplete rim which shows downward thickening like small-scale stalactite into the interstices at the base of the grain (Plate V.5b).

(iii) Dog - tooth cement: comprises small calcitype blocky cement lining the cavities and coating the surfaces of miliolite particles. This cement is commonly scalenohedral in habit with jagged dog-tooth corners (Plate V.5c). According to Flügel (1982), this cement is characteristic of aeolianites.

(iv) Meniscus cement: this cement shows a meniscus texture and occurs at the grain-contacts or in between the grains (Plate V.5d).

Second Generation Cement (B)

(v) Syntaxial rim cement: this has developed as overgrowth calcite cement on surfaces of allochem substrate (e.g. echinoderm, crinoid and miliolidae) and shares same crystallographic axes with the allochem. The author has included this cement as second generation cement, because in some thin sections the presence of the first generation cement has been observed to occur in the intervening spaces between this cement and the allochem substrate (Plate V.6 a,b).

(vi) Pore-filling cement: it is a granular cement which occludes the inter (primary) and intra (secondary) particle pore spaces and tends to fill the pores rather than rimming them (Plate V.5a & V.6c).

In some thin section 'Vadose crystal silt' is encountered. Mineralogically this cement is calcite, texturally it is silt (Dunham, 1969 a). It is observed that in thin section, this well sorted calcite silt fills up the voids and interstices in some miliolite rock. This cement usually post-dates the precipitation of first generation fibrous cement and pre-dates the precipitation of blocky calcite cement of second generation. (Plate V.6d).

The above categorisation is based on the accounts of cements reported from the carbonate rocks of different parts of world by the various workers (Pettijohn, 1949; Bathurst, 1958, 1971; Lucia, 1962; Orme & Brown, 1963; Friedman, 1964, 1968; Evamy & Shearman, 1965; Purser, 1969; Taylor & Illing 1969; Dunham, 1969 a, 1971; Land, 1970; Muller, 1971; Jacka, 1974; Folk, 1974; Schneider, 1977; Badiozamani et al, 1977; Neugebauer & Ruhrmann, 1978; Burgess, 1979; Flügel; 1982, Gardner, 1983).

TEXTURAL STUDIES

The carbonate rocks, especially all types of miliolite, are unsuitable for crushing and/or dissolving. As a result it was rather very difficult to carry out textural analyses by the usual sieving method. Alternatively, therefore the author investigated and measured the largest apparent diameter of miliolite particles in polished thin sections, following the procedure adopted by Krumbein (1935), Rosenfeld et al. (1953), Friedman (1958) and Hotzl (1966).

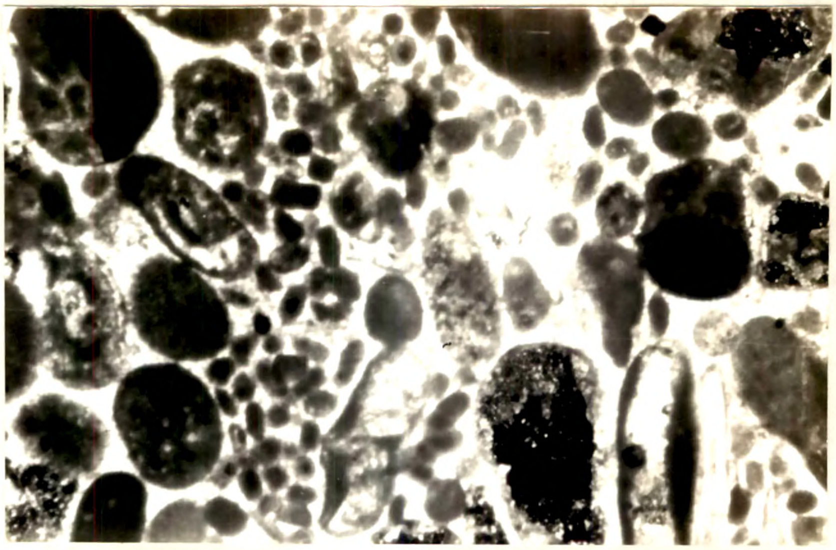
It was observed that on an average, majority of biogenic grains are of sand size, and show a size variation from silt to medium sand (0.062-0.5 mm), the largest biogenic grain size being 1.6 mm which is restricted to the southern parts of the Central Highland. Thus, the rock can be grouped as 'calcarenites'.

Most of the bioclasts in miliolite are rounded to well-rounded. On the other hand, the terrigenous (detrital) particles show heterogeneity in shape and size. The terrigenous particles which occur in subordinate proportions, depending on their genesis, show different textural characters, and are bimodal. The finer grains (upto 0.5 mm) of quartz which in all probability comprise transported particles along with bioclasts, are commonly sub-angular to sub-rounded. The larger quartz grains ($>$ 0.5 mm) are more interesting, some of them are angular, while others are well rounded. Obviously, these represent locally generated quartz derived from the weathering of the pre-existing Mesozoic and Tertiary rocks. The angular to sub-angular quartz grains seem to have been derived from Bhuj sandstone, while the larger rounded quartz grains have come from the Tertiary sandstones.

In some thin sections, alternate laminations made up of fine and medium size carbonate grains are distictly observed (Plate V.7). Individual laminae are comparatively well sorted; especially the ones which are made up of finer grains are better sorted and show a sharp difference in grain size with that of the coarser laminae. Glennie (1970), has considered this feature to be one of the most important criteria for the identification of wind-deposited sand. It is interesting to note that the elongated grains in obstacle deposits (mainly slip-face type) are arranged/ oriented almost parallel to each other and to the laminae (Plate V.8). This is obviously due to the selective deposition based on shapes of these grains along the slope of the obstacles provided by hills. The above phenomena have not been observed in sheet miliolites.

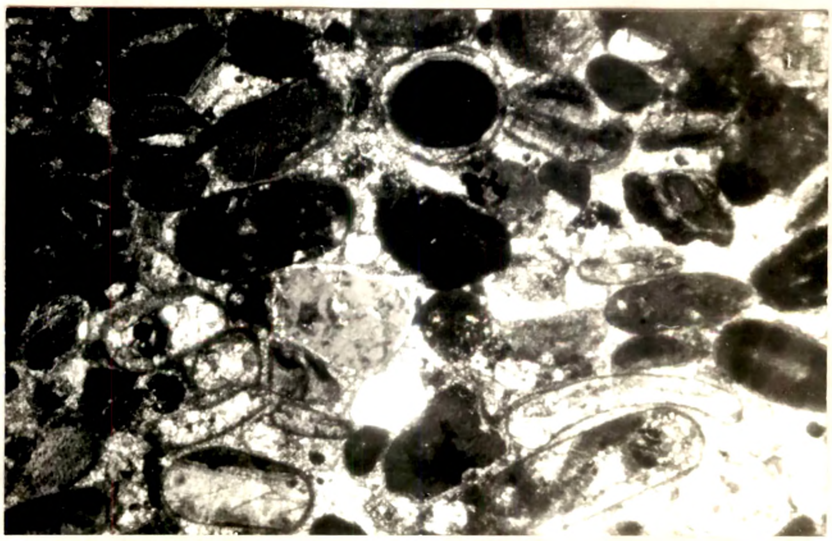
To obtain the trend of grain-size variation of the allochems from coast to inland, the author selected samples

Plate V. 7



Photomicrograph showing the alternate coarse and fine laminae in miliolites.
(X 50, PPL)

Plate V. 8



Photomicrograph showing the orientation of elongated allochems.
(X 50, PPL)

along two traverses AA' and BB', which extend from SW (present day coast) to NE upto Banni and the Great Rann, and stretching across the Kutch Mainland, starting from the southern coastal plains, and passing through Central Highlands towards Northern Hill Range (Ref.Fig.III.1). The maximum and average size of the various biogenic material like peloids, shell fragments, algae, echinoderm spines, bryozoa etc. from various localities along these traverses are measured and the grain size distribution curve of these biogenic constituents, were plotted against the distance from South Kutch coast along the traverses AA' and BB' (Tables V.2 to 5; Fig.V.1 to 4). The size variation along these two sections, clearly shows that, there is an overall decrease in the grain-size from SW to NE - the then prevailing wind direction. A close relationship between the grain-size and the topography along these sections has also been observed. The grain size values along these sections on a cursory look, may not look meaningful, but when their relationship to surface topography is taken into account, they show a definite pattern. From this frequency graph, it has become clear that the pre-miliolitic topography has not only controlled the miliolite deposition but has also controlled the grain-size variation. The size of the various biogenic constituents of the miliolite is coarse wherever the

Table V.2

Variation in maximum size of various allochems in Kutch miliolite along section AA' (Ref.Fig.III.1)

Loca-lity *	Dist. from coast in km	Allochem size in mm						
		Peloids	Shell frag-ments	Echin-oderm spines	Bryoz-oan	Algae	Miliol-iidae	Rotalii-dae
9	22	0.58	0.83	0.53	1.24	0.83	0.53	0.37
10	23	0.74	0.99	0.91	0.83	1.03	0.74	0.74
31	24	0.74	0.74	0.74	0.91	0.74	0.66	0.66
16	30	0.66	0.91	0.78	0.70	0.83	0.78	0.58
7	33	0.58	0.87	0.58	0.58	1.00	0.74	0.34
30	35	0.66	0.91	0.66	0.70	1.07	0.53	0.74
52	40	0.66	0.41	0.58	0.41	1.12	0.26	0.37
51	41	0.91	1.03	1.03	0.91	1.24	0.99	0.91
71	45	0.49	0.45	0.33	0.37	0.49	0.29	0.24
36	50	0.74	0.66	0.66	0.83	0.83	0.58	0.74
34	53	0.66	0.58	0.70	0.49	0.58	0.66	0.83
56	54	0.41	0.37	0.53	0.37	0.37	0.29	0.49
64	59	0.66	0.49	0.47	0.41	0.87	0.47	0.41
60	70	0.74	0.66	0.66	0.58	0.74	0.58	0.49
24	82	0.75	0.91	0.70	0.91	0.91	0.66	0.66

* Locality as per Fig.IV.1

Fig.V.1 MAXIMUM SIZE VARIATION OF VARIOUS ALLOCHEMS OF KUTCH MILIOLITE IN RELATION TO DISTANCE AND TOPOGRAPHY ALONG TRAVERSE AA'.

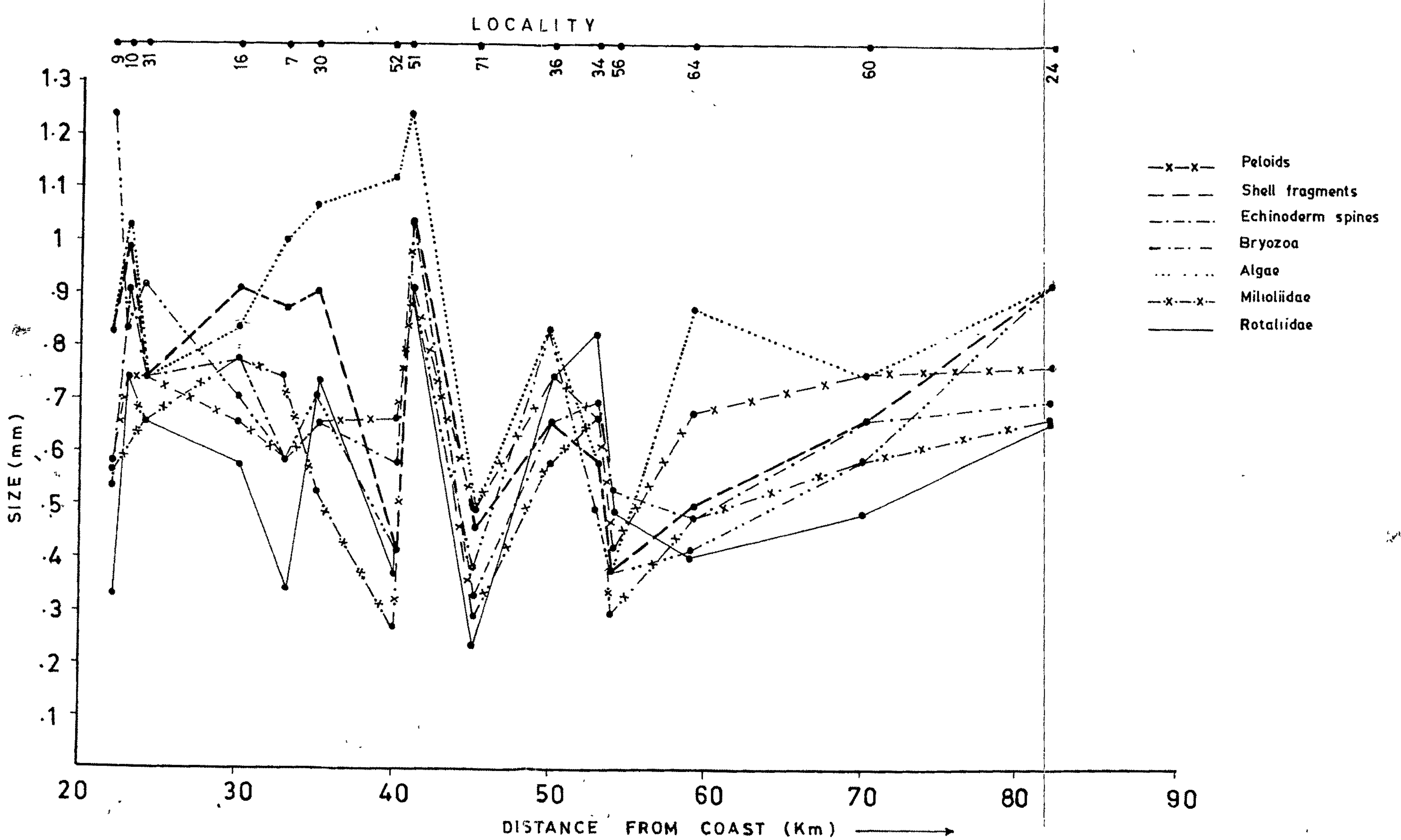


Table V.3

Variation in average size of various allochems in Kutch miliolite along section AA' (Ref.Fig.III.1)

Locality *	Dist. from coast in km	Allochem size in mm						
		Peloid	Shell fragments	Echinoderm spines	Bryozoan	Algae	Miliolidae	Rotaliidae
9	22	0.25	0.38	0.39	0.58	0.42	0.38	0.28
10	23	0.42	0.57	0.52	0.48	0.64	0.52	0.52
31	24	0.41	0.39	0.43	0.67	0.51	0.41	0.47
16	30	0.29	0.33	0.36	0.41	0.37	0.37	0.38
7	33	0.24	0.31	0.33	0.41	0.73	0.42	0.21
30	35	0.20	0.34	0.32	0.46	0.45	0.39	0.39
52	40	0.18	0.25	0.30	0.30	0.48	0.22	0.26
51	41	0.36	0.39	0.49	0.53	0.58	0.41	0.54
71	45	0.18	0.21	0.33	0.37	0.34	0.24	0.17
36	50	0.31	0.40	0.44	0.52	0.48	0.34	0.45
34	53	0.24	0.31	0.42	0.38	0.34	0.38	0.46
56	54	0.17	0.20	0.27	0.27	0.26	0.25	0.35
64	59	0.28	0.26	0.35	0.34	0.57	0.33	0.33
60	70	0.23	0.39	0.47	0.43	0.51	0.32	0.43
24	82	0.31	0.48	0.41	0.53	0.33	0.38	0.36

* Locality as per Fig.IV.1

Fig.V.2 AVERAGE SIZE VARIATION OF VARIOUS ALLOCHEMS OF KUTCH MILIOLITE IN RELATION TO DISTANCE AND TOPOGRAPHY ALONG TRAVERSE AÁ.

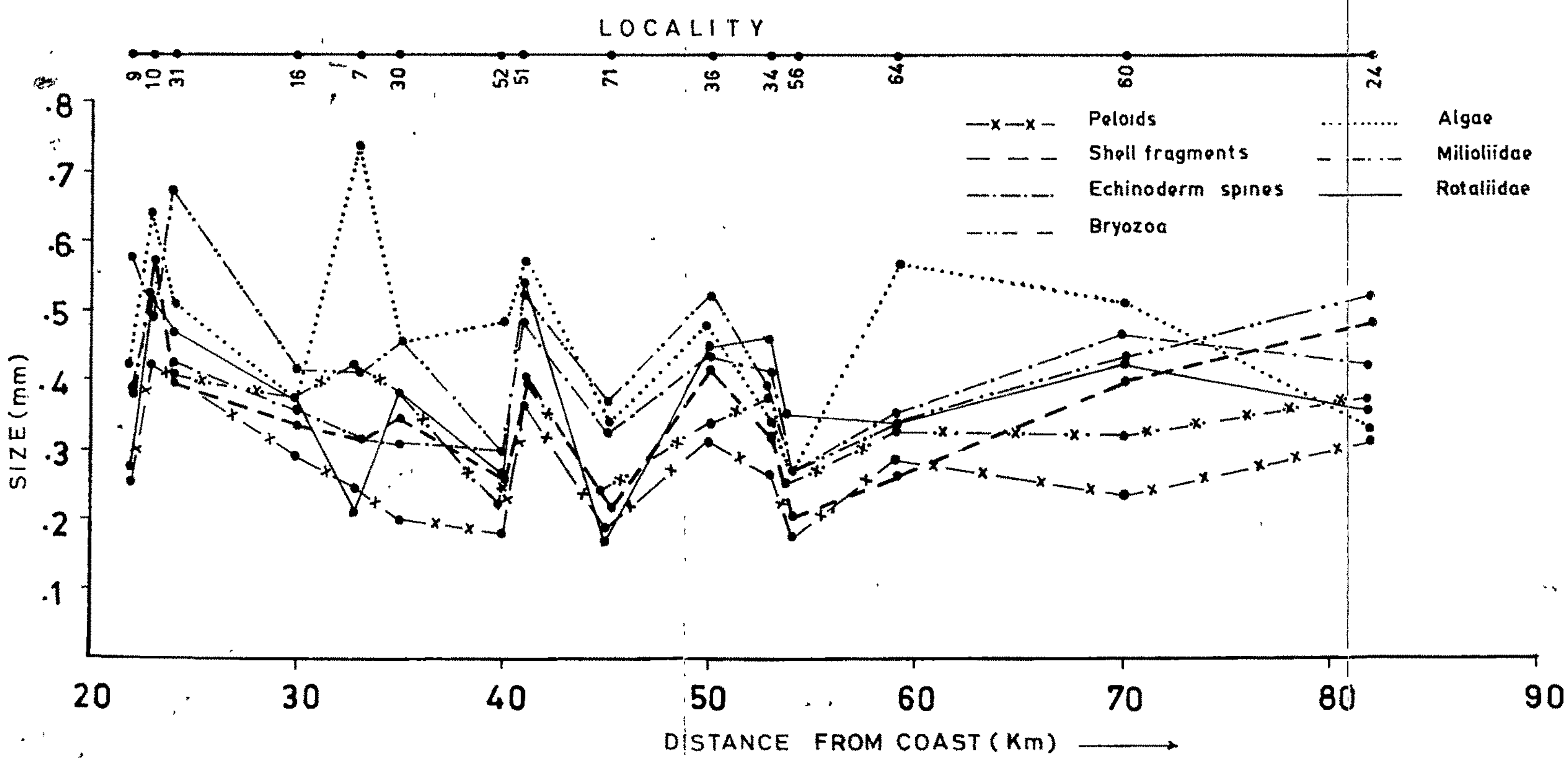


Table V.4

Variation in maximum size of various allochems in Kutch miliolite along section BB' (Ref.Fig.III.1)

Locality *	Dist. from coast in km	Allochem size in mm						
		Peloid	Shell fragments	Echinoderm spines	Bryozoan	Algae	Miliolidae	Rotaliidae
48	22	1.61	1.32	0.87	1.16	1.57	0.91	0.66
43	23	0.66	0.66	0.66	0.49	0.49	0.58	0.49
21	26	0.74	0.68	0.66	0.58	1.16	0.83	0.62
47	42	0.53	1.07	0.49	0.74	0.99	0.37	0.49
66	44	0.66	0.95	0.74	0.41	1.00	0.41	0.33
26	50	0.66	0.58	0.41	0.58	0.91	0.53	0.49
20	54	0.49	0.62	0.70	0.49	0.91	0.37	0.49
29	55	0.33	0.41	0.37	0.37	0.53	0.41	0.33
11	56	0.41	0.49	0.58	0.78	0.70	0.41	0.49
67	58	0.66	0.74	0.66	0.83	0.74	0.58	0.49
54	60	0.58	0.78	0.58	0.66	0.83	0.53	0.83
39	61	0.41	0.83	0.37	0.33	0.53	0.33	0.41
50	63	0.53	0.49	0.76	0.76	0.58	0.53	0.83
8	71	0.58	0.66	0.58	0.83	1.03	0.58	0.58
58	72	0.66	0.87	0.70	0.78	0.83	0.66	0.66
33	80	0.33	0.74	0.74	0.33	0.66	0.41	0.33
22	92	0.50	0.58	0.38	0.49	0.53	0.37	0.45
13	103	0.58	0.63	0.45	0.70	0.70	0.41	0.50

* Locality as per Fig.IV.1

Fig.V.3 MAXIMUM SIZE VARIATION OF VARIOUS ALLOCHEMS OF KUTCH MILIOLITE IN RELATION TO DISTANCE AND TOPOGRAPHY ALONG TRAVERSE BB'

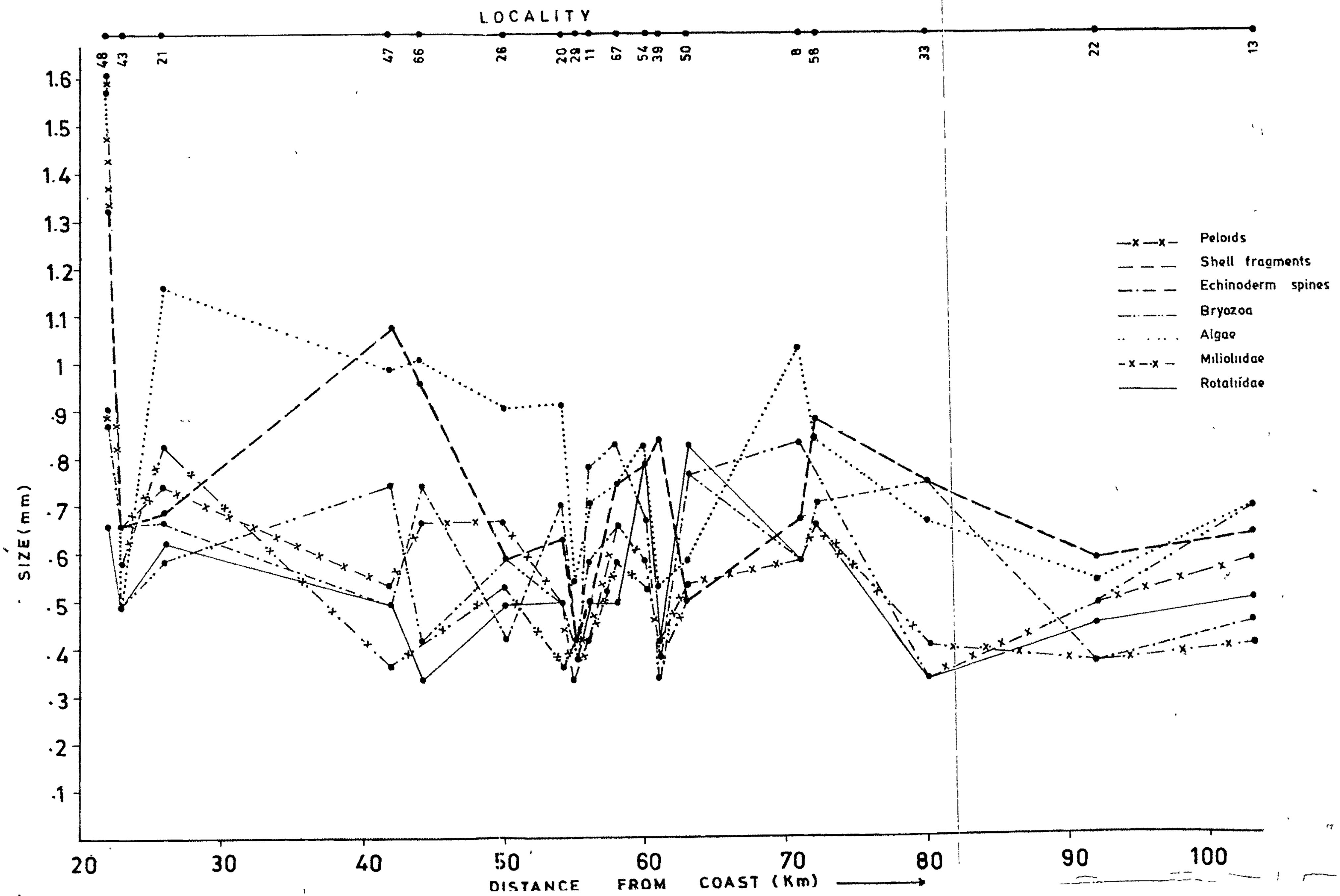


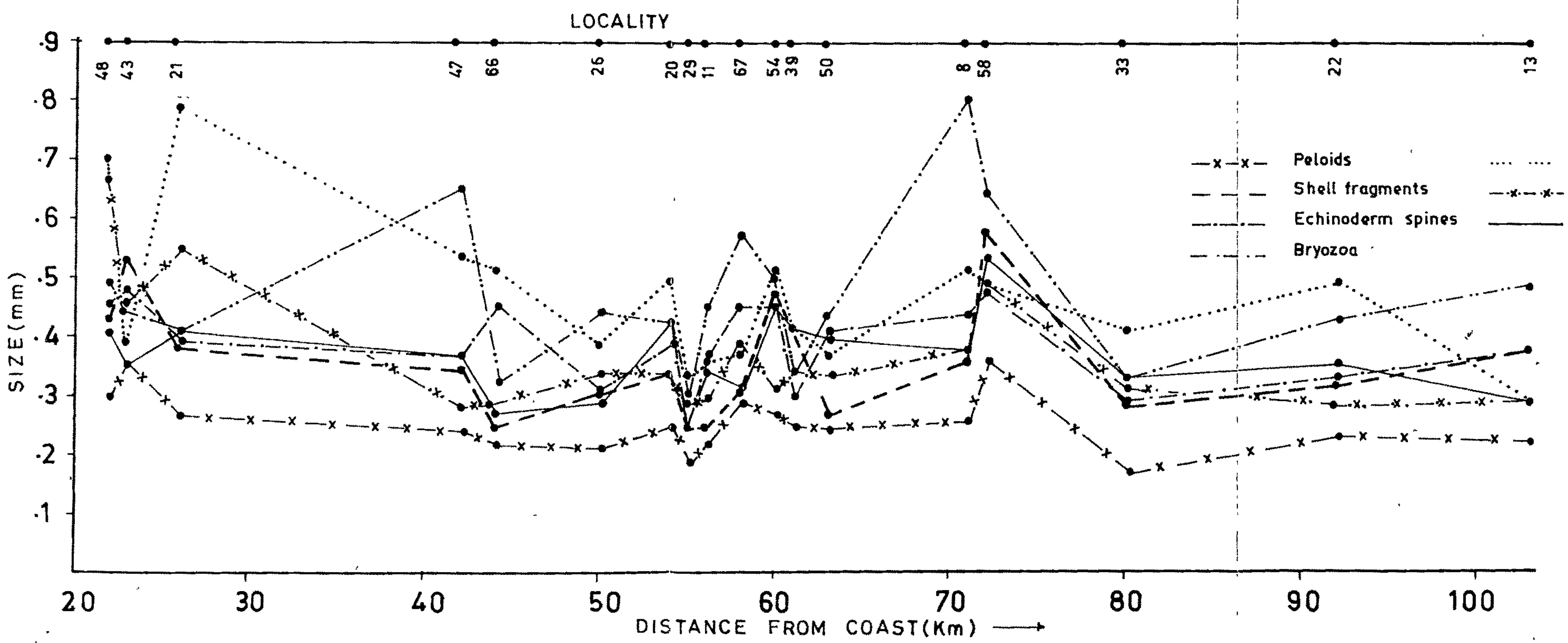
Table V.5

Variation in average size of various allochems in Kutch miliolite along section BB' (Ref.Fig.III.1)

Loca-lity *	Dist from coast in km	Allochem size in mm						
		Peloid	Shell frag-ments	Echino-derm spines	Bryoz-oan	Algae	Miliol iidae	Rotalii dae
48	22	0.30	0.43	0.45	0.49	0.70	0.66	0.41
43	23	0.36	0.53	0.48	0.44	0.39	0.45	0.35
21	26	0.27	0.37	0.39	0.41	0.79	0.56	0.41
47	42	0.24	0.34	0.37	0.65	0.53	0.29	0.36
66	44	0.22	0.24	0.45	0.32	0.51	0.27	0.27
26	50	0.21	0.30	0.31	0.44	0.39	0.34	0.29
20	54	0.25	0.33	0.39	0.42	0.49	0.33	0.43
29	55	0.19	0.24	0.25	0.30	0.33	0.28	0.23
11	56	0.21	0.24	0.37	0.45	0.35	0.29	0.34
67	58	0.29	0.30	0.45	0.57	0.37	0.38	0.32
54	60	0.27	0.47	0.45	0.49	0.51	0.31	0.45
39	61	0.25	0.41	0.30	0.33	0.41	0.33	0.41
50	63	0.24	0.27	0.41	0.43	0.37	0.33	0.40
8	71	0.26	0.35	0.44	0.80	0.51	0.37	0.37
58	72	0.36	0.58	0.48	0.63	0.49	0.47	0.53
33	80	0.17	0.28	0.29	0.33	0.41	0.31	0.33
22	92	0.23	0.31	0.33	0.41	0.49	0.27	0.35
13	103	0.21	0.36	0.38	0.49	0.29	0.30	0.29

* Locality as per Fig.IV.1

Fig.V.4 AVERAGE SIZE VARIATION OF VARIOUS ALLOCHEMS OF KUTCH MILIOLITE IN RELATION TO DISTANCE AND TOPOGRAPHY ALONG TRAVERSE BB'.



topographical highs (hills and ridges) are present along the sections. This has led the author to conclude that the transportation of miliolitic sands from the palaeo-coast has taken place by such action of wind that the topographic highs acted as obstructions for the winds transporting miliolitic sands north-eastward.

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 dunes, reveal alternate laminae of grains of different sizes pointing to an aeolian layering.

FREQUENCY STUDIES

The miliolite limestones are seen to comprise allochems and detrital material cemented together by sparry calcite. To classify these rocks and also to determine the relative abundance of the various constituents (allochems, detrital material, cement etc), the author volumetrically analysed the rocks of different categories in thin section by following the 'Dual measurement' technique of Dunham (1962) and obtained the volume percentages of the individual constituents (Table V.6&7). From this chart it is seen that in almost all samples studied, the vol % of bioclasts exceed those of peloids. Hence, on the basis of this frequency studies, following the Folks classification (Folk , 1959, 1962),the miliolite rocks of study area have been broadly classified as 'biopelsparite'. Also, most of the miliolite rocks comprise a large proportion of allochems as compared to detrital material. Unlike the size variation studies that show a definite pattern from SW to NE which is controlled by topography and mode of transport, the frequency data as expected does not show any trend.

INSOLUBLE RESIDUES STUDIES

In order to study the insoluble residues, the 'absolute' and 'relative' amount of terrigenous component (non-carbonate residues) and carbonate content from the different types of miliolite were obtained. This was done by dissolving 25 gm of miliolite rock in dilute Hcl for 24 hours. The non-carbonate acid insoluble residues (terrigenous material) are mainly quartz, pyroxenes,

Table V.6

Thin section analysis of various constituents (% by volume) of Kutch miliolites along section AA' (Ref.Fig.III.1)

Loca-lity *	Dist. from coast in km	Constituents (Vol. %)							
		Terrigenous material	Cement ($CaCO_3$)	Peloid	Bioclasts				
					Shell fragments	Foraminifera	Bryozoan	Echinoderm spines	Algae
9	22	5.66	38.17	8.83	21.52	5.37	0.07	0.22	1.37
10	23	22.25	35.96	4.68	21.04	12.11	-	0.38	3.52
31	24	13.63	25.12	24.44	11.81	14.43	5.46	0.80	4.21
16	30	16.03	31.11	15.10	25.77	4.26	1.64	2.02	3.98
7	33	17.21	18.62	31.64	25.65	1 .28	0.6	3.85	1.05
30	35	9.57	33.26	18.86	20.15	6.35	-	0.56	11.17
52	40	34.86	36.69	9.76	7.28	1.47	-	3.13	6.73
51	41	21.20	29.89	21.56	7.87	13.57	0.84	1.37	3.60
71	45	27.49	39.10	24.46	4.27	3.19	-	-	1.43
36	50	17.23	28.38	23.73	14.81	2.35	3.44	5.34	4.63
34	53	10.83	40.23	20.46	13.43	7.97	-	1.76	5.31
56	54	20.84	27.89	25.62	12.92	3.40	-	0.90	7.88
64	59	23.55	47.50	20.17	2.38	2.71	-	2.49	1.13
60	70	44.08	34.01	11.79	2.71	4.87	-	2.15	0.34
24	82	52.34	29.15	7.87	3.30	1.36	-	1.79	4.14

* Locality as per Fig.IV.1

Table V.7

Thin section analysis of various constituents (% by volume) of Kutch miliolite along section BB' (Ref.Fig.III.1)

Locality *	Dist. from coast in km	Constituents (Vol %)							
		Terrigenous material	Cement ($CaCO_3$)	Peloid	Bioclasts				
					Shell fragments	Foraminifera	Bryozoan	Echinoderm spines	Algae
48	22	22.17	34.44	14.51	12.45	4.19	0.22	2.80	9.13
43	23	21.77	44.31	10.22	7.83	9.07	2.34	2.49	1.88
21	26	27.95	41.71	4.47	4.17	13.20	-	-	8.44
47	42	21.92	28.87	17.55	16.68	4.81	-	2.38	7.72
66	44	33.04	30.27	14.46	12.75	3.58	-	-	5.33
26	50	34.93	37.87	9.55	9.04	4.08	1.37	-	3.09
20	54	23.13	36.90	8.20	11.01	8.05	2.83	4.33	5.46
29	55	32.51	34.92	16.89	7.02	6.22	-	-	2.37
11	56	27.52	37.97	19.95	6.11	1.91	-	1.58	5.21
67	58	30.06	28.85	19.55	12.62	5.26	0.30	1.77	2.57
54	60	17.79	42.21	18.43	13.52	1.24	1.63	-	5.09
39	61	79.01	10.77	3.05	4.87	2.26	-	-	-
50	63	24.75	27.74	20.42	10.64	6.60	-	1.52	8.25
8	71	25.00	37.03	13.60	10.12	3.32	2.04	2.20	6.63
58	72	32.19	26.43	16.34	13.76	0.56	-	0.34	10.30
33	80	25.16	54.41	7.47	6.68	1.92	-	0.22	4.07
22	92	27.64	40.47	22.78	2.94	0.90	-	0.68	4.52
13	103	27.74	33.90	25.13	6.93	0.56	-	0.79	4.88

* Locality as per Fig.IV.1

amphiboles, some heavies (accessory minerals), and rock fragments of trap, ferruginous sandstone, laterite, silt and clay.

The rock contain 35 to 89 % $CaCO_3$ by weight and 8 to 62 % terrigenous material (Table V. 8 & 9). This variation of the terrigenous content, is on account of the type of the source rock available near the site of deposition of miliolite. It is observed that variation in insoluble residue content of miliolite rocks also does not show any particular trend from SW to NE.

To determine the size variation of the terrigenous components of miliolite, the material was sieved through 35, 120 and 230 ASTM mesh, and it was observed that majority of these grains show range upto 0.5 mm. Obviously the bigger fragments are locally derived and represent material added from the nearby sources.

The 'absolute' and 'relative' amounts of the composition of terrigenous component (non-carbonate residues) provide important clues in understanding the process of accumulation and deposition of carbonate sands of Kutch. The amount of silt and clay (upto 5 %) present in miliolite is very small. This fact provides an additional criteria supporting wind-borne origin (Glennie, 1970; Davis, 1983).

Table V.8

Insoluble residues and $CaCO_3$ content (% by weight) of Kutch miliolites along section AA' (REf. Fig.III.1)

Loca lity *	Dist. from coast in km	Insol uble residues (x)	$CaCO_3$ (y)	Insoluble residues (x) (% by weight)			
				Size in mm			
		x+y=100		Coarse 0.5	Medium 0.5 - 0.125	Fine 0.125-0.062	Silt+clay 0.062
9	22	49.40	50.60	3.20	40.24	3.36	2.60
10	23	37.96	62.04	2.16	27.08	6.32	2.40
31	24	39.36	60.64	5.68	27.52	2.40	3.76
16	30	29.32	70.68	4.88	21.56	1.28	1.60
7	33	43.08	56.92	7.20	22.20	9.92	3.76
30	35	11.36	88.64	0.76	7.40	1.72	1.48
52	40	39.32	60.68	20.72	8.96	5.36	4.28
51	41	27.84	72.16	1.48	17.32	4.80	4.24
71	45	43.12	56.86	14.24	22.32	4.40	2.16
36	50	40.12	59.88	9.52	24.76	3.20	2.64
34	53	26.12	73.88	.08	23.64	1.68	0.72
56	54	21.32	78.68	-	19.36	0.96	1.00
64	59	57.52	42.48	20.32	29.72	4.60	2.88
60	70	52.20	47.80	2.60	39.72	6.28	3.60
24	82	24.76	75.24	1.6	20.16	1.16	1.84

* Locaity as per Fig.IV.1

Table V.9

Insoluble residues and $CaCO_3$ content (% by weight) of Kutch miliolites along section BB' (Ref.Fig.III.1)

Locality *	Dist from coast in km	Insoluble residues (x)	$CaCO_3$ (y)	Insoluble residues (x) (% by weight) size in mm			
				coarse 0.5	Medium 0.5-0.125	Fine 0.125-0.062	Silt+Clay 0.062
48	22	34.52	65.48	16.28	12.92	3.04	2.28
43	23	40.84	59.16	16.40	22.00	1.60	0.84
21	26	58.20	41.80	9.52	42.88	1.16	4.64
47	42	37.84	62.16	8.76	21.08	5.16	2.84
66	44	21.80	78.20	0.04	16.68	3.44	1.64
26	50	44.12	55.88	17.92	15.72	6.72	3.76
20	54	48.84	51.16	2.00	34.96	6.92	4.96
29	55	33.84	66.16	0.08	25.04	7.56	1.16
11	56	38.40	61.60	0.20	32.36	3.64	2.20
67	58	32.28	67.72	-	21.72	7.00	3.56
54	60	52	48	16.76	20.68	11.08	3.48
39	61	49.56	50.44	0.92	33.88	11.40	3.36
50	63	32.28	67.72	0.48	25.20	4.56	2.04
8	71	54.80	45.20	4.24	45.16	2.76	2.64
58	72	39.20	60.80	16.68	15.52	5.04	1.96
33	80	64.36	35.64	30.16	21.84	9.12	3.24
22	92	43.52	56.48	0.68	32.28	8.40	2.16
13	103	47.12	52.88	14.16	16.20	11.76	5.00

* Locality as per Fig.IV.1

MICROPALAEONTOLOGICAL STUDIES

Micropalaeontological aspects of the Kutch miliolites were investigated by comparing the microfauna of the present day beach material of the South Kutch coast. The samples of Recent beach and coastal dune sands were collected from Jakhau, Suthri and Mandvi beaches, and those of miliolites were taken from different inland occurrences. The present author considerably benefitted by the guidance provided by Dr. Kanan Pandya who has worked extensively on the microfaunal aspects of Saurashtra biogenic sands.

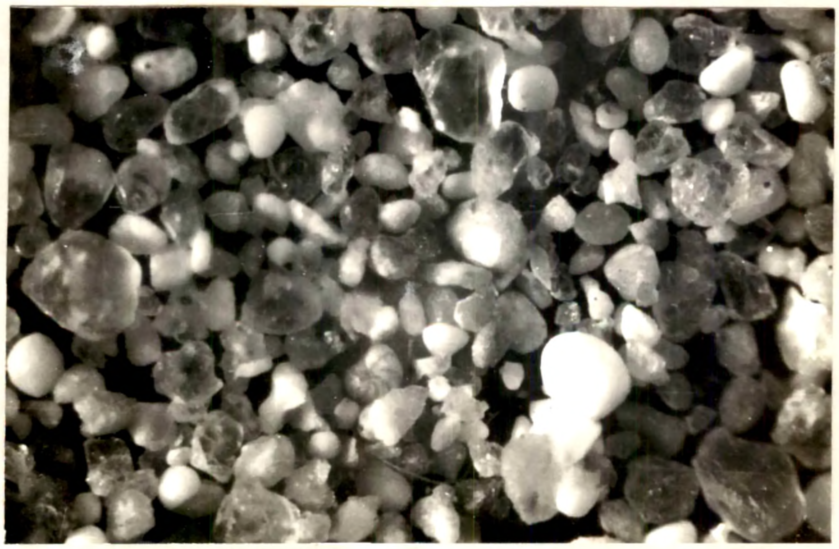
The study was carried out with the presumption that the miliolites are the ancient analogues of the present day bioclastic sands. The bioclastic components of inland miliolites and Recent beach sand reveal almost similar and identical faunal population (Plate V.9).

In Kutch, the beach and coastal dune sands consist of quartz, broken molluscan shell fragments, tests of pelecypods and gasteropods, foraminifera, bryozoa, echinoid spines, sporadic fragments of corals, ostracodes, heavies and rocks fragments. Tests of foraminifera are both abraded and unabraded, and at places, in beach sands, the tests and shell fragments comprise abraded to unabraded forms, the

Plate V. 9

Photomicrograph of unconsolidated beach sands and disaggregated miliolite constituents.

(a)
Beach sand (south Kutch coast)
(X 34)



(b)
Disaggregated miliolites
(X 34)

abraded ones could be representing organisms that grew further offshore and were subsequently transported to the beach, the unabraded ones have originated not very far from the low-water line. Alternatively, the abraded test could be representing earlier formed organisms subjected to a longer period of wave and surf action as compared to the unabraded tests.

The microfauna of the beach sand has been observed to comprise few planktonic and dominantly benthonic forms (Plate V.10) such as Ammonia dentatum (Parker & Jones), Ammonia annectens (Parker & Jones), Ammonia beccarii (Linne'), Pararotalia baltovskoy, Elphidium crispum (Linnaus), Quinqueloculina seminulum (Linnaus), Quinqueloculina spp., Elphidium sp., Eponides repandus (Fitchel & Moll), Poroeponides lateralis (Terquem), Triloculina sp., Cibicides sp., Amphistegina sp., Bulimina sp., Spiroloculina sp., Globigerina sp., Gasteropods, Ostracodes, Bryozoa, Echinoid spines, and Alcyonarian spicules.

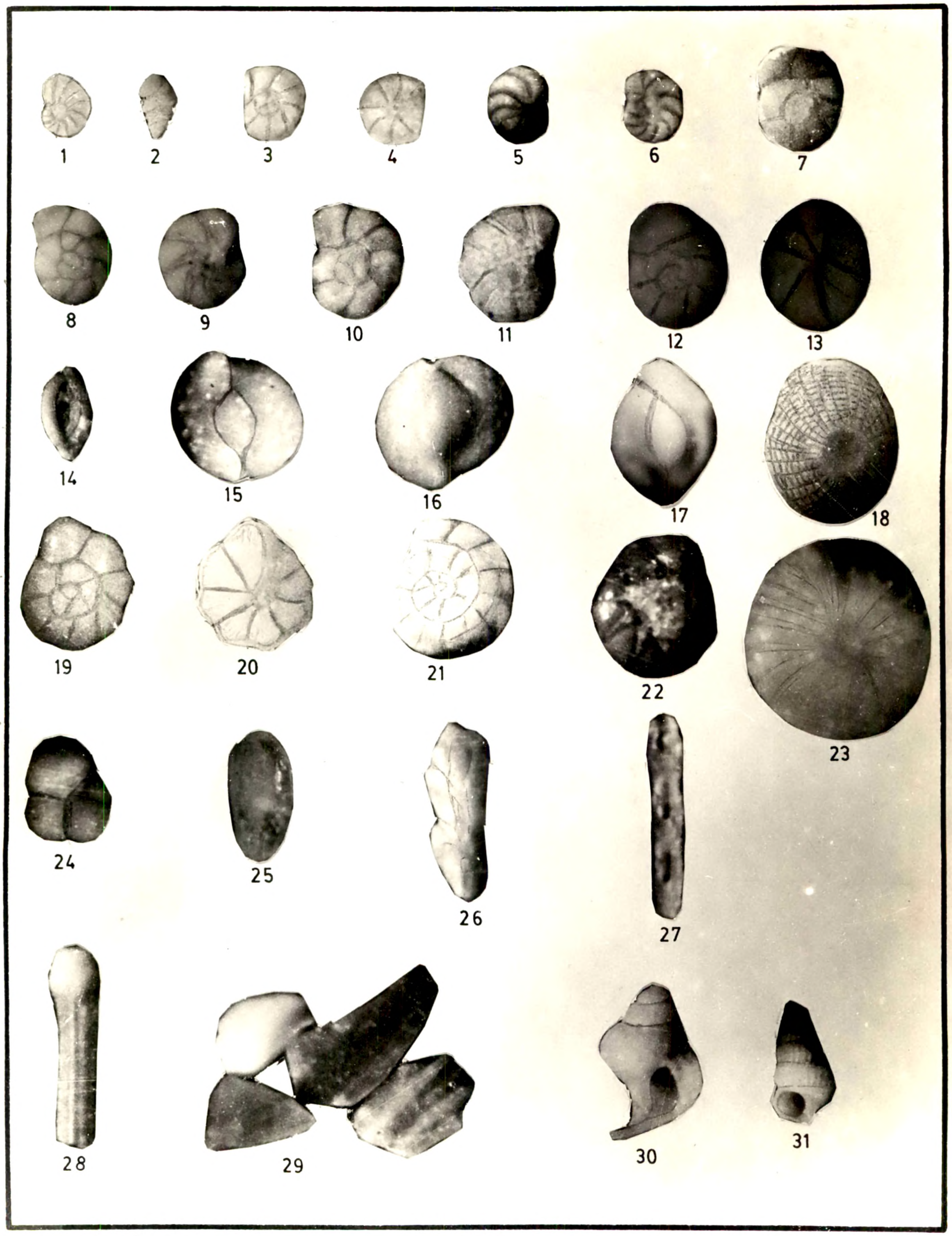
In the beach and coastal dunes sands Ammonia dentatum (Parker & Jones) and Ammonia annectens (Parker & Jones) dominate in medium grained sands (0.5 - 0.25 mm) and Pararotalia baltovskoy in fine grained sands (0.062-0.25 mm).

Plate V. 10

Various Bioclasts in Beach Sands (South Kutch Coast)

1. *Nonion* sp. (X 52)
2. *Bulimina* sp. (X 46)
3-4. *Eponides repandus* (Fitchel & Moll) (X 42)
5-7. *Cibicides* sp. (X 33 and X 70)
8-9. *Ammonia annectens* (Parker & Jones) (X 44)
10-11. *Ammonia dendatum* (Parker & Jones) (X 23)
12-13. *Poroeponides lateralis* (Terquem) (X 33)
14. *Spiroloculina* sp. (X 31)
15-16. *Triloculina* s. (X 45)
17. *Quinqueloculina* sp. (X 72)
18. *Elphidium crispum* (Linnaus) (X 50)
19-20. *Pararotalia baltnyskoy* (X 54)
21-22. *Ammonia beccarii* (Linne') (X 50)
23. *Amphistegina* sp. (X 45)
24. *Globigerina* sp. (X 84)
25. Ostracodes (X 34)
26-27. Bryozoa. (X 31 & X 32)
28. Echinoid spine (X 47)
29. Pelecypods shell fragments (X 28)
30-31. Gasteropod (X 39 & X 35)

PLATE V. 10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From the faunal point of view the miliolite rocks are identical to those of beach sands and consist of broken molllsucan shell fragments, ostracodes, abraded tests of gasteropods, pelecypods, foraminifera, echinoderm spines and bryozoa of course with a fair proportion of peloids. The amount of shell fragments is comparatively less than those of the beach sands. The peloids appear to be more in number and have been derived from abrasion and micritization of bioclasts (Plate V.11). The foraminiferal content is mostly of benthonic type, but the tests do not reveal clear morphological features on account of abrasion. In general, the families of Rotaliidae and Elphiididae dominate over others. The Milioliidae is scarcely present. A few planktonic forms (Globigerina) were also encountered.

A distinct variation in sizes of foraminiferal test is also encountered on going away from the coast towards north. In the beach sand the genus Ammonia shows size range variation of 0.50 mm to 0.75 mm and Elphidium shows variation from 0.40 mm to 0.65 mm. Similarly, the tests separated from the miliolite rocks of Kotada, situated at the southern Mainland Kutch, show a size range variation for Ammonia and Elphidium as 0.45 mm to 0.60 mm and 0.30 mm to 0.37 mm respectively.

Plate V. 11

Photomicrograph of peloids of beach sands and disaggregated miliolite

(a)

Beach sand peloids (south Kutch coast)
(x 34)

(b)

Miliolite peloids
(x 34)

The northernmost deposits (Jhura) of miliolite in Kutch. Mainland, show the variation in size from 0.25 mm to 0.47 mm and 0.30 mm to 0.35 mm for Ammonia and Elphidium respectively. It is evident from the size range variation that there is a reduction in the size of foraminiferal tests inlandward.

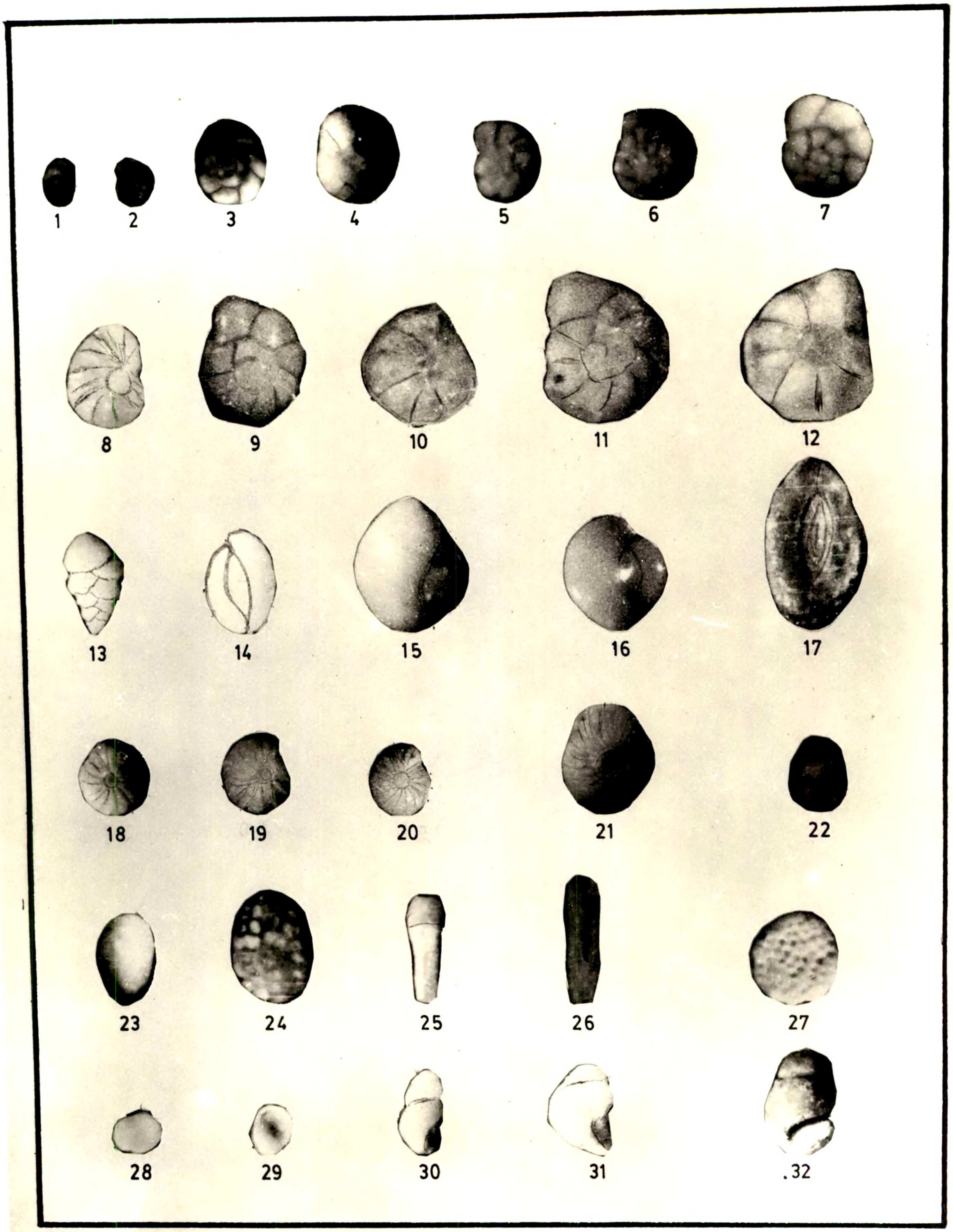
On account of high degree of abrasion of the tests it was rather difficult to identify the foraminifera separated from the miliolite upto the species level. Thus barring a few forms, the author has given the generic list of the most of the foraminifera and other bioclasts (Plate V.12) as under:

Ammonia sp.
Elphidium sp.
Quinqueloculina sp.
Pararotalia sp.
Elphidium crispum (Linnaus)
Spiroloculina sp.
Triloculina sp.
Nonion sp.
Cibicides sp.
Globigerina sp.
Bulimina sp.
Eponides repandus (Fitchell and Moll)

Plate V. 12

Various Bioclasts in Disaggregated Kutch Miliolite

PLATE V.12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Gasteropoda

Bryozoa

Echinoid spines

Pelecypods

Ostracodes

Coral fragments

The benthonic foraminifera indicate warm, shallow, agitating and nearshore environment. In general, they inhabit a wide variety of environments like estuary, tidal flats and beach, and can survive considerable variation of salinity, temperature and pH. Though, indicating marine origin, their abraded tests support a combination of various processes like wind, wave and surf actions.