Chapter – V

L A B O R A T O R Y   S T U D I E S

GENERAL

Though the Quaternary carbonate deposits of Saurashtra possess certain characters in common, they differ in many respects, especially with regards to the relative abundance of their constituents, grain size, degree of cementation, carbonate mineralogy etc. These have a direct bearing the depositional & diagenetic environment and inturn on palaeoclimatic conditions during the Quaternary period. This chapter incorporates mainly the laboratory studies that has helped the author in proper delineation of the depositional and diagenetic history of these deposits. As these carbonate rocks are genetically related to one another, they have been discussed in the text collectively. For the convenience the study is broadly described as per following:

(A) Compositional Studies

- (a) Constituents
- (b) Constituent frequency
- (c) Insoluble residues
- (d) XRD studies
- (e) TL studies

(B) Textural Studies

- (f) Size and shape of sediments
- (g) SEM studies

(A) COMPOSITIONAL STUDIES

(a) CONSTITUENTS

The detailed thin section studies of the ancient beach rocks and miliolite limestones as well as the examination of the stabilised dunal sands by binocular microscope clearly reveal that these carbonate deposits comprise three major components viz. allochems, detritals and cement. The allochems include a variety of bioclasts, peloids, intraclasts - aggregate grains and coated grains while mineral & rock fragments are chief amongst the detritals. The cement, present only in beach rocks and miliolites, is mostly sparry calcite and occasionally micrite & fibrous aragonite. Though, in general, the nature of these constituents remains almost same, their amount varies considerably especially in comparison to the stabilised dunal sands. Table V.1 gives the salient features of the various constituents present in these deposits which have been described subsequently as per below:

(1) Allochems

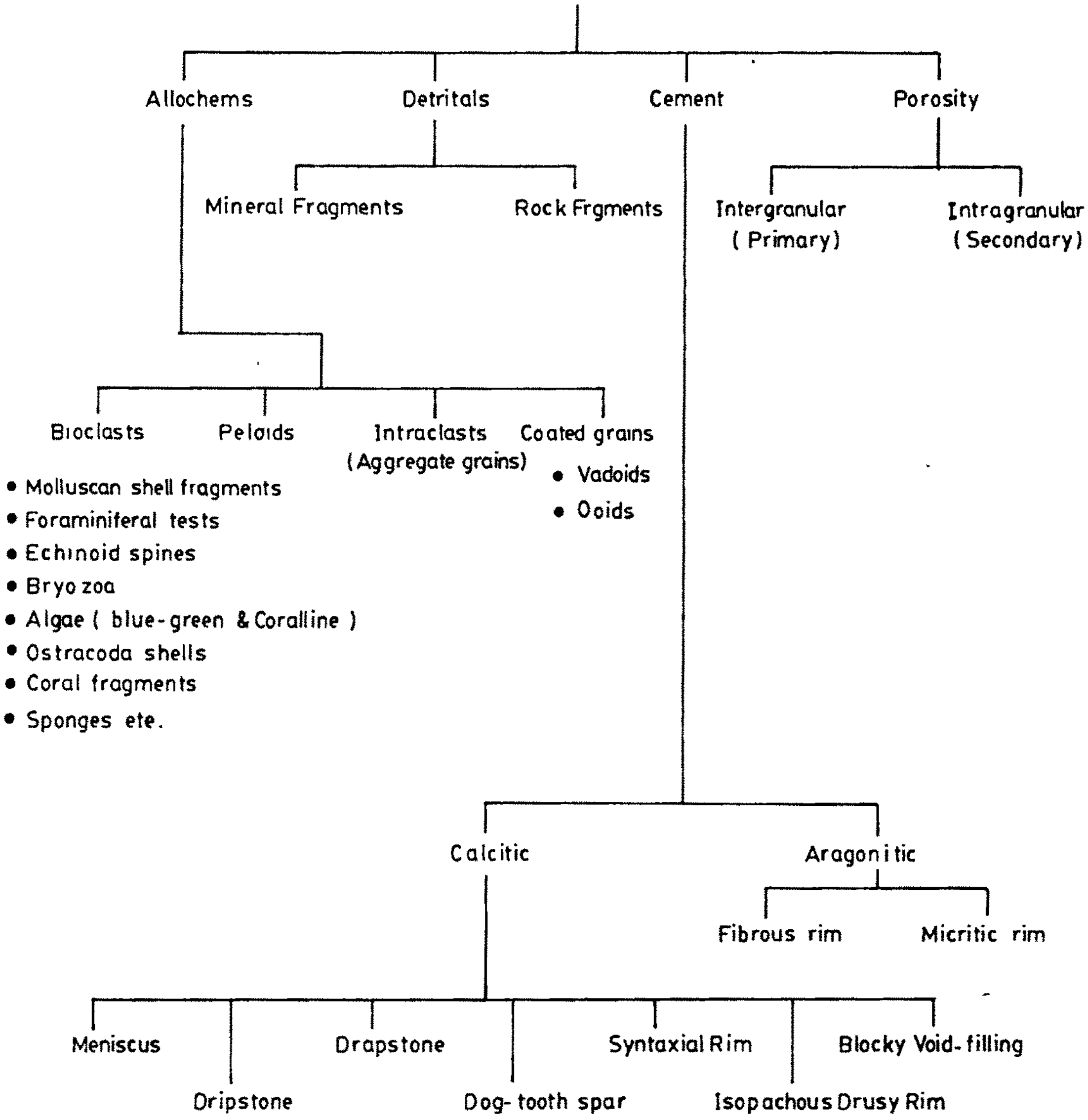
Folk (1959, 1962) proposed the petrographic classification for limestones and identified four major components in the allochthonous limestones and for the first time described them collectively as 'allochems', which include (i) skeletal elements, (ii) pellets, (iii) intraclasts and (iv) oolites. In the current literature, the term 'bioclast' is commonly used for his 'skeletal elements' while 'oolite' is applied to a rock consisting of 'ooids' (coated grains). The Quaternary carbonate deposits of Saurashtra also form the allochthonous type of deposits comprising almost all above mentioned allochems in varying proportions.

(i) Bioclasts

These comprise abraded to highly abraded skeletal fragments of different organisms constituting the bulk composition of the deposits. In the carbonate deposits of Saurashtra, atleast eight types of such bioclasts are recognised. These include molluscan shell fragments, foraminiferal tests, bryozoans, echinoid spines, algae - blue-green & coralline, ostracods, corals and sponges; the shell fragments of molluscans, namely lamellibranch & gasteropoda, being predominent over the other bioclasts. The various bioclasts vary in size and show distinct internal structures under microscope. In beach rocks, their size varies from medium to very coarse and even more, while in miliolites and dunal sands they show medium - fine to very fine sand size (0.3 to <0.12 mm).

Table. V.1

COMPOSITION OF VARIOUS QUATERNARY CARBONATE DEPOSITS OF SAURASHTRA



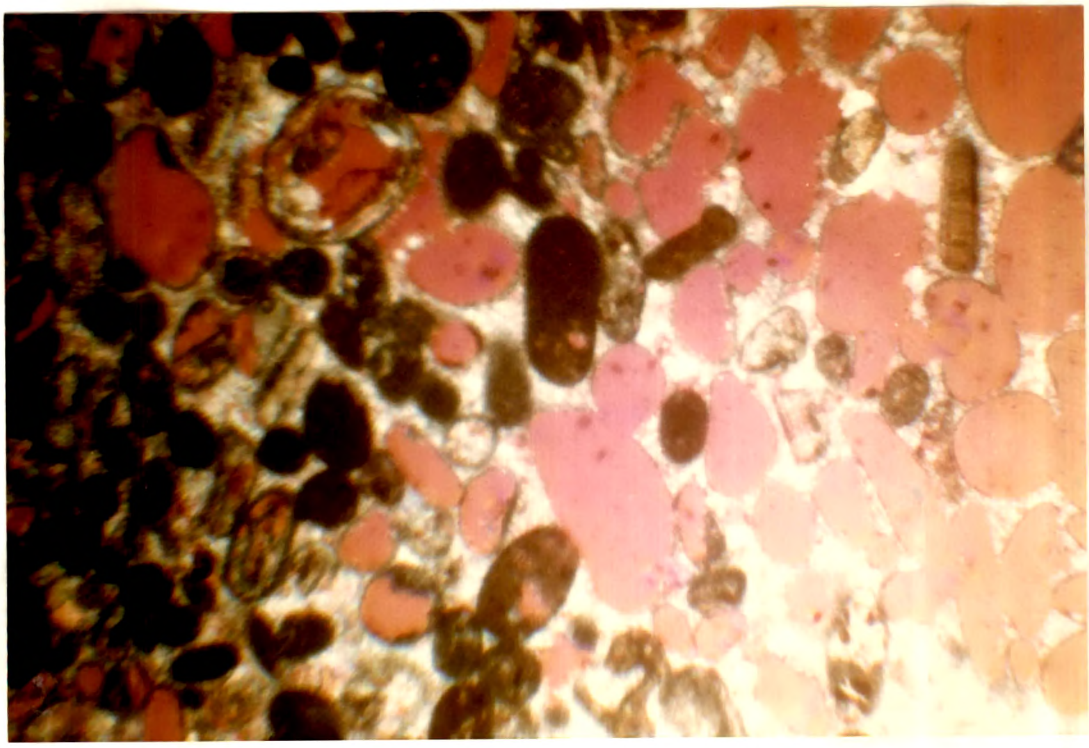
In beach rocks, the molluscans form intact as well as fragmental megashells mostly in chalkified and calcitised stage ranging in size from 0.5 mm upto 30-40 mm. Most of them are unidentifiable being abraded, and depending upon the original size & shape of the megashells they exhibit subrounded, elongated & crescentic shapes. However, some better preserved shells of *Cerithium, Telina, Cyprae, Arca* etc. are easily recognised. In miliolites and dunal sands, on the other hand, the abraded to highly abraded fragmental and sometimes intact molluscan tests show almost uniform fine to medium sand size (0.2 to 0.5 mm). These shell fragments, depending upon their diagenetic alteration, exhibit either original foliated, lamellar or wavy internal structure or moulds filled with sparite (Plate V.1). In certain miliolites, there is a development of secondary porosity on account of their dissolution during diagenetic processes, and only thin micritic boundaries of allochems are preserved (Plate V.2). The intact lamellibranch and gasteropod tests show their distinct elliptical shapes, the former is characterised by the radiating ribs from the umbones while the latter by chambered form in thin sections.

The <u>foraminiferal tests</u> are encountered in higher amounts in the miliolites and dunal sands than those in the beach rocks. Most of them are of benthonic nature belonging to the Rotaliidae, Elphidiidae and Milioliidae families. The major species encountered in these deposits are *Ammonia beccarii, Ammonia annectaus, Elphidium crispum, Elphidium indicum, Quinqueloculina sp., Quinqueloculina seminulum, Quinquiloculina venusta,*

Plate V.1

Photomicrograph showing internal structures of molluscan shell fragments (sf) in miliolite (PPL, 120X)

Plate V.2



Photomicrograph (with gypsum plate) showing intragranular porosity in miliolite (Crossed Nicols, 60X)

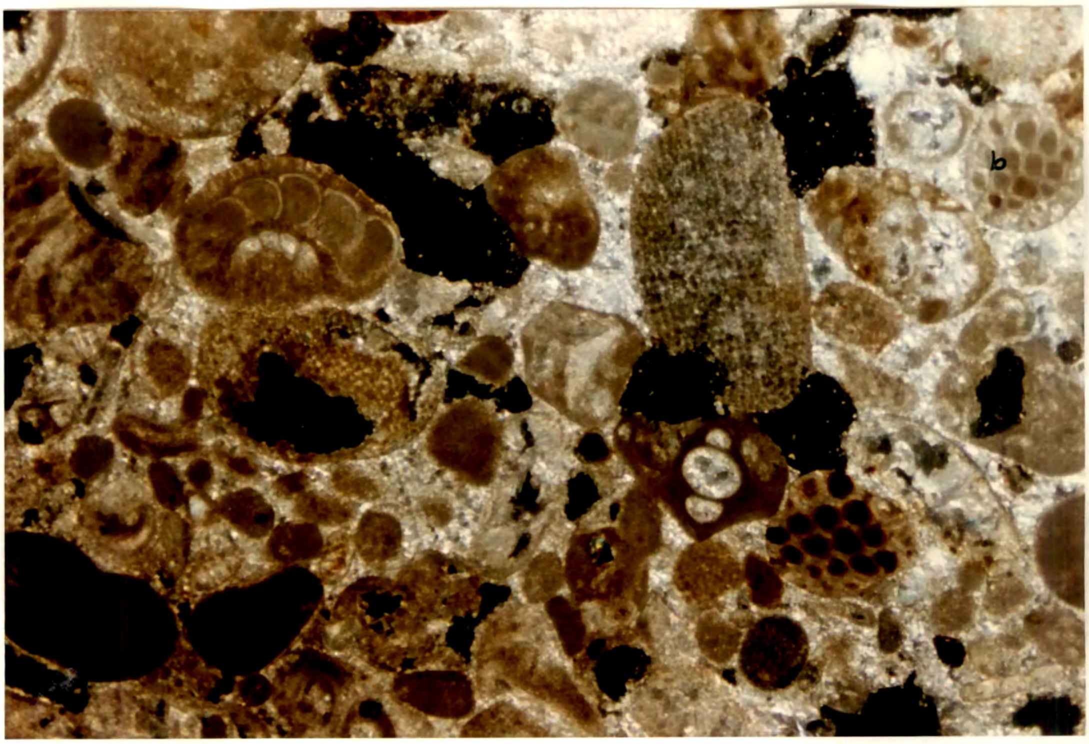
Triloculina sp., Spiroloculina indica, Discorbis sp., Cibicide sp. etc. Few planktonic species of *Globigerina* are also occasionally observed, especially in the dunal sands. In thin sections, the foraminifera occur as rounded and subrounded grains exhibiting variegated arrangements of the chambers and typical wall structures (Plate V.3 & 4). The bryozoans are recognised by their peculier shape with thick laminated walls and rounded zooecia within, often infilled with sparite or silt (Plate V.4). Though they appear red-brown in colour alike echinoid spines, the latter are characterised by either radial or parallel mesh-work in their transverse and longitudianal sections respectively. They further show circular, elliptical or rod like shapes having optical continuity with cement - known as syntaxial overgrowth (Plate V.5).

The calcareous algae present in these deposits belong to the two major types viz. coralline algae and blue-green algae. However, very occasionally that of *Halimeda* algae are also encountered. As the fragments of halimeda algae contain organic filaments in aragonite, they are preserved mostly in dunal sands and beach rocks, while they are scarce or almost absent in miliolites. The blue-grren algae occur as micro sheaths consisting poorly preserved aragonitic filaments and are encountered occasionally in these deposits. The coralline algae on the other hand is frequent and well preserved in all types of deposits and show oblong, subrounded to well rounded shape with reticulate and sheaf (grass-bundle) like structure (Plate V.6).

Plate V.3

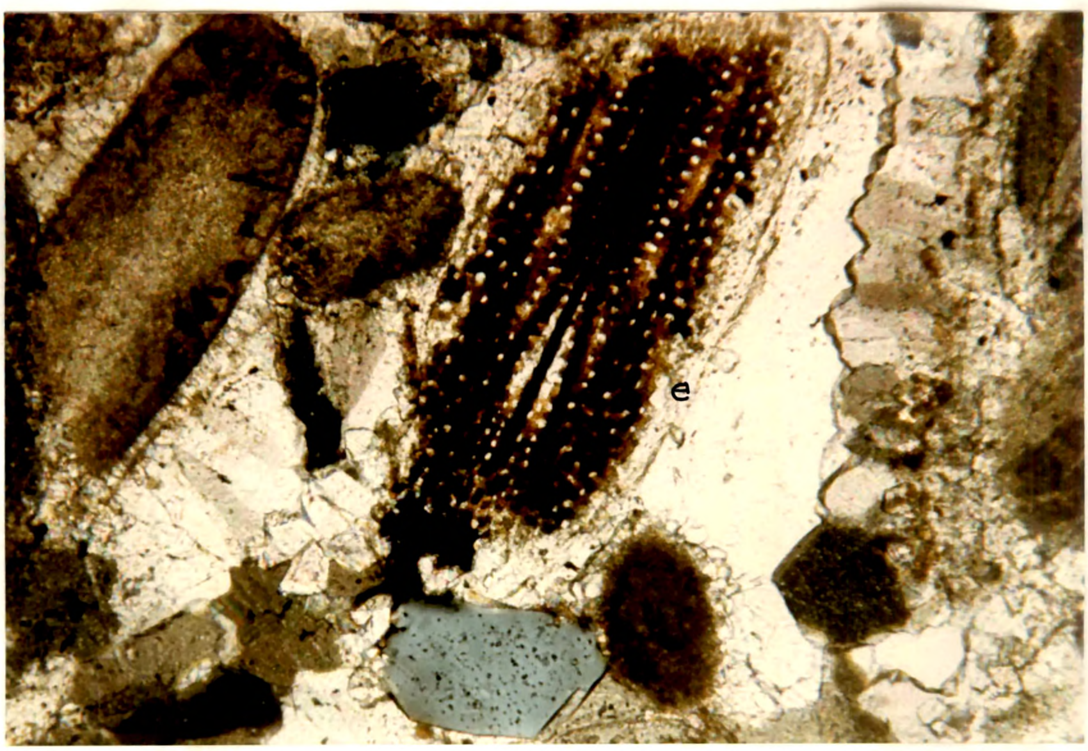
Photomicrograph of a foraminiferal test (Miliolid) : cross section showing chambers and typical wall structure (PPL, 230X)

Plate V.4



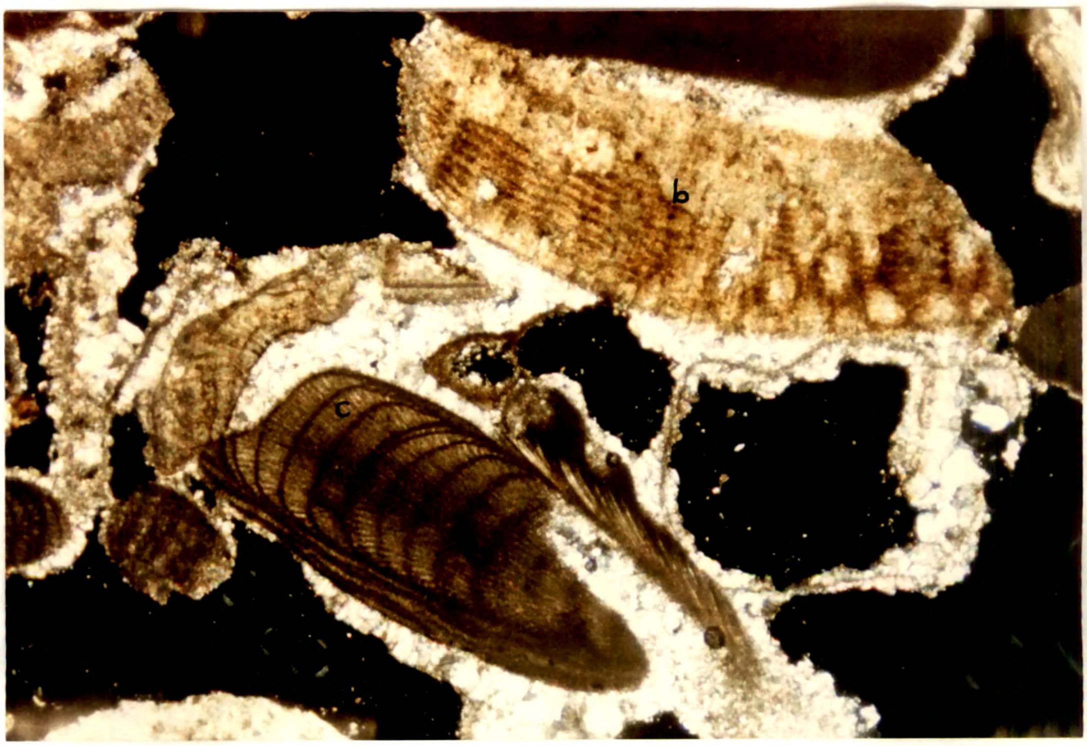
Photomicrograph of bryozoan (b) in miliolite showing their typical morphology (Crossed Nicols, 60X)

Plate V.5



Photomicrograph of echinoid spine (e) in miliolite showing optical continuity with cement (Crossed Nicols, 120X)

Plate V.6



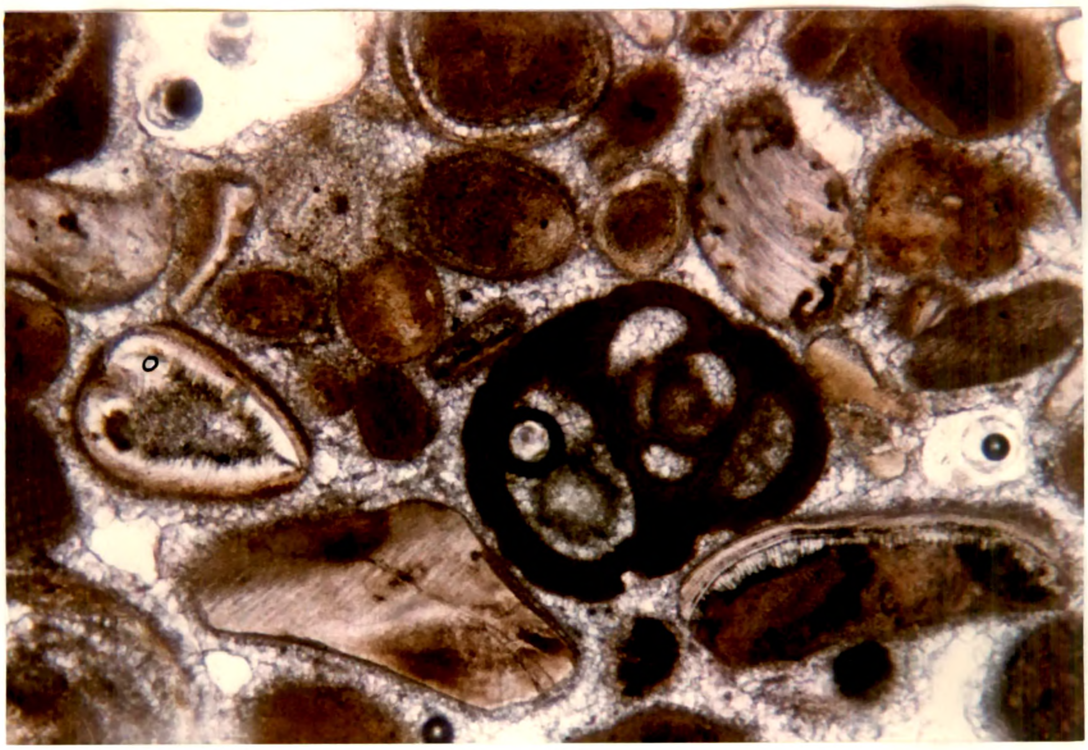
Photomicrograph showing calcareous algae : blue-green (b) and oralline (c) in beach rock (Crossed Nicols, 120X)

The amount of ostracod tests is much more less as compared to the other bioclasts. However, their relative abundance in dunal sands is high in comparison to beach rocks and miliolites, where their better survival is seen as their smooth as well as ornamented micro shells. In thin sections of miliolites and also to some extent in beach rocks, they occur as articulated and inarticulated very thin curved shells tapering at one end (Plate V.7). The coral fragments, calcareous sponges and sea cucumber grains are poorly preserved in miliolites and beach rocks (Plate V.8 & 9). The coral fragments are identified by their inclusion rich walls with poorly preserved septa. In beach rocks, their longitudinal and oblique sections show porous network of septal elements whereas in dunal sands these occur as chalky perforated fragments. The calcareous sponges and sea cucumber grains, though scarce and scattered, are noticed particualrly in the thin sections of beach rocks and coastal miliolites. The former is characterised by the thick walled globular/ vesicular structure while the latter by pentagonal flower like shape.

(ii) Peloids

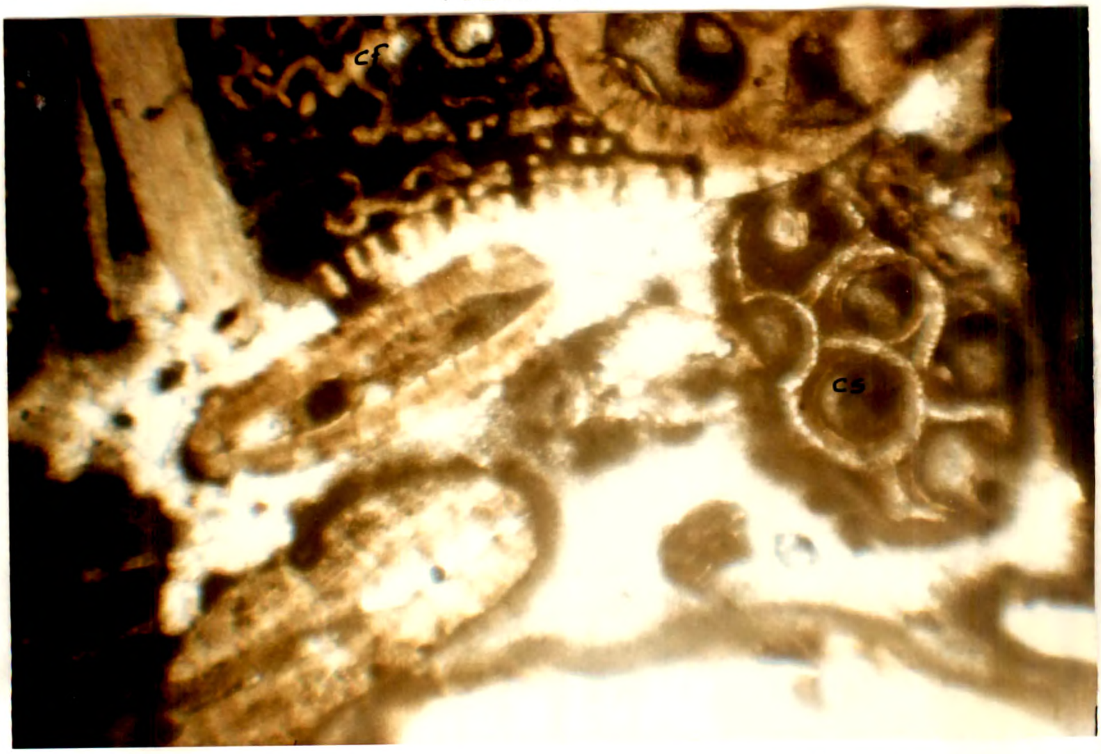
The term pellet is generally used as a synonym for 'faecal pellet' but now it is well understood that they can also be formed by abrasion and micritisation of bioclasts (Milliman, 1974; Bathurst, 1971; Scoffin, 1987 etc.). In light of this the author, following Mckee & Gutschik (1969), prefers to use the term 'peloid' instead. The peloids, unlike others, are devoid of any internal structure and appear as dark coloured micritic grains in

Plate V.7



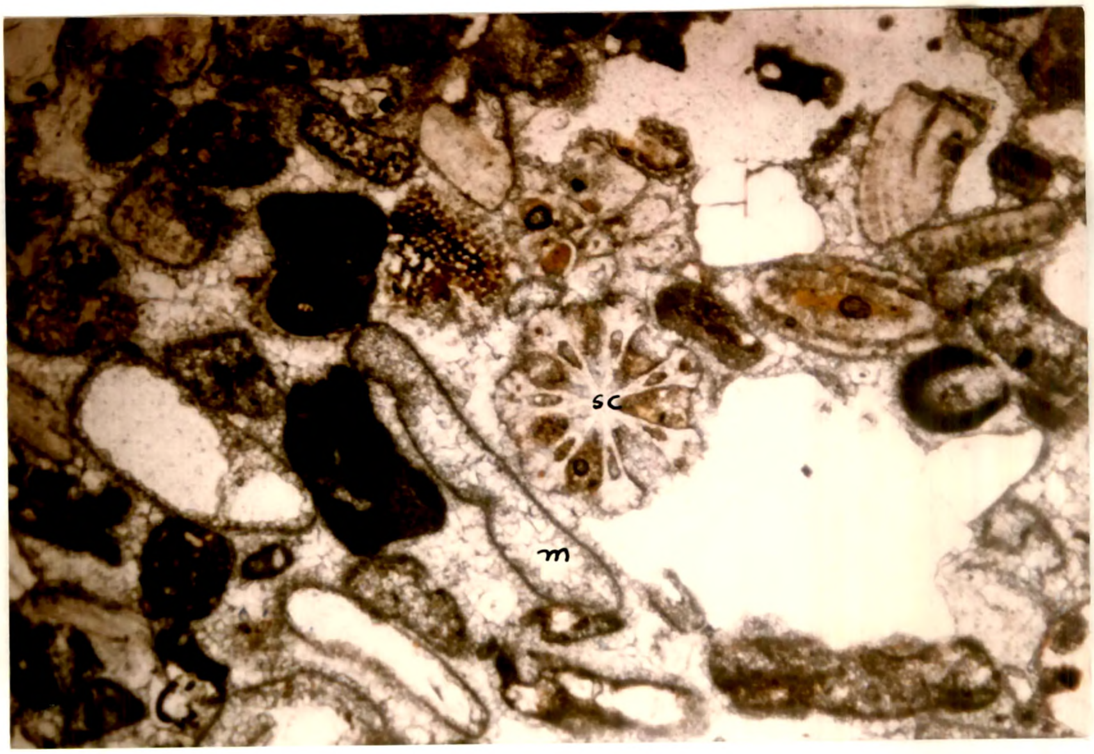
Photomicrograph of stained miliolite showing ostracod tests (o) tapering at one end (PPL, 60X)

Plate V.8



Photomicrograph showing coral fragment (cf) and calcareous sponge (cs) in beach rock (Crossed Nicols, 120X)

Plate V.9



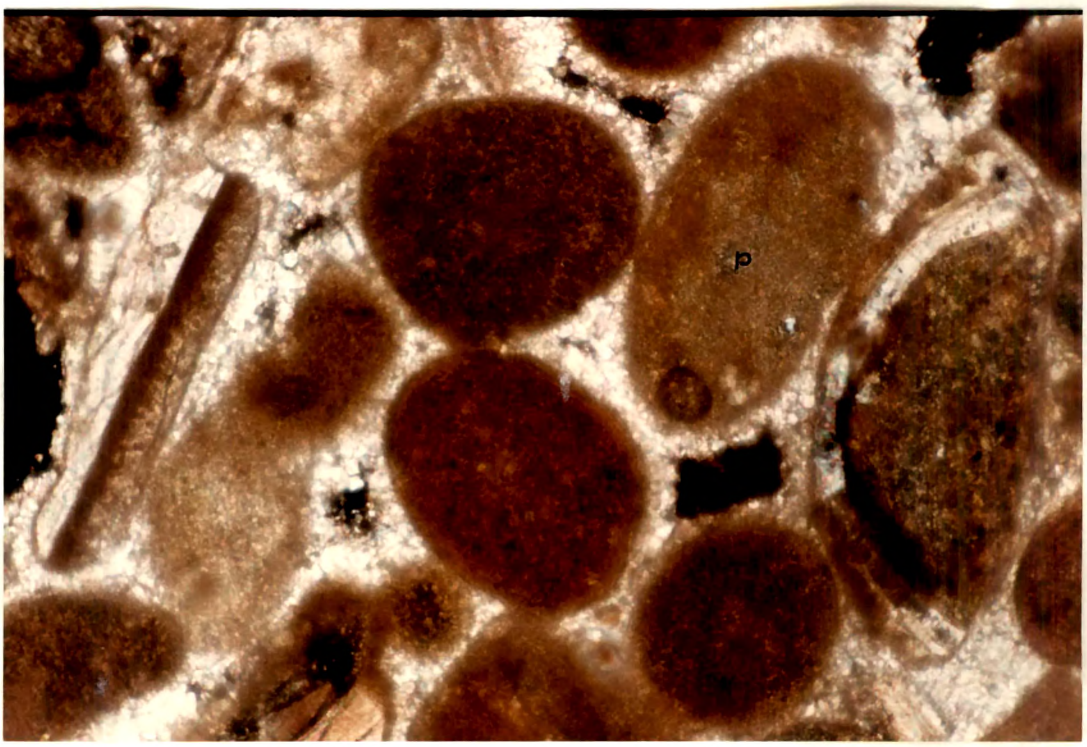
Photomicrograph of sea cucumber grain (sc) in miliolite showing its pentagonal shape. Also note the moulds of shell fragments (m) infilled with sparite (PPL, 120X) thin sections. They are mostly spherical, elliptical or cylindrical in shape and in the geological literature such grains are also named as 'bahamite' (Beales,1958; Gygi, 1969) and 'pelletoid grains' (Milliman,1974).

Peloids occur in all the three types of carbonate deposits of Saurashtra and range in size from 0.1 mm to 1 mm; their abundances vary from one outcrop to the other (Plate V.10). However, in beach rocks their occurrences are selective while in miliolites they are very common in both the types of deposits viz. dune deposits as well as sheet deposits. the detailed scrutiny of thin sections reveals that the white coloured (chalky) compact miliolite sheets of coastal plains show their higher frequency. Again their higher concentration in finely laminated layers of obstacle miliolites is very characteristic and it could be on account of selective wind sorting during their accumulation. It is rather difficult to say whether the peloids occurring in these deposits are the product of organic excreta (feacal) or the micritisation of allochems. The study reveals that majority of the peloids occurring in these deposits have been derived after different stages of abrasion and micritisation that caused the complete obliteration of the internal structures of various bioclasts.

(iii) Intraclasts

This term was introduced by Folk (1959) to designate the fragments of penecontemporaneous, generally weakly cemented, carbonate sediments that have been broken up and redeposited as

Plate V.10

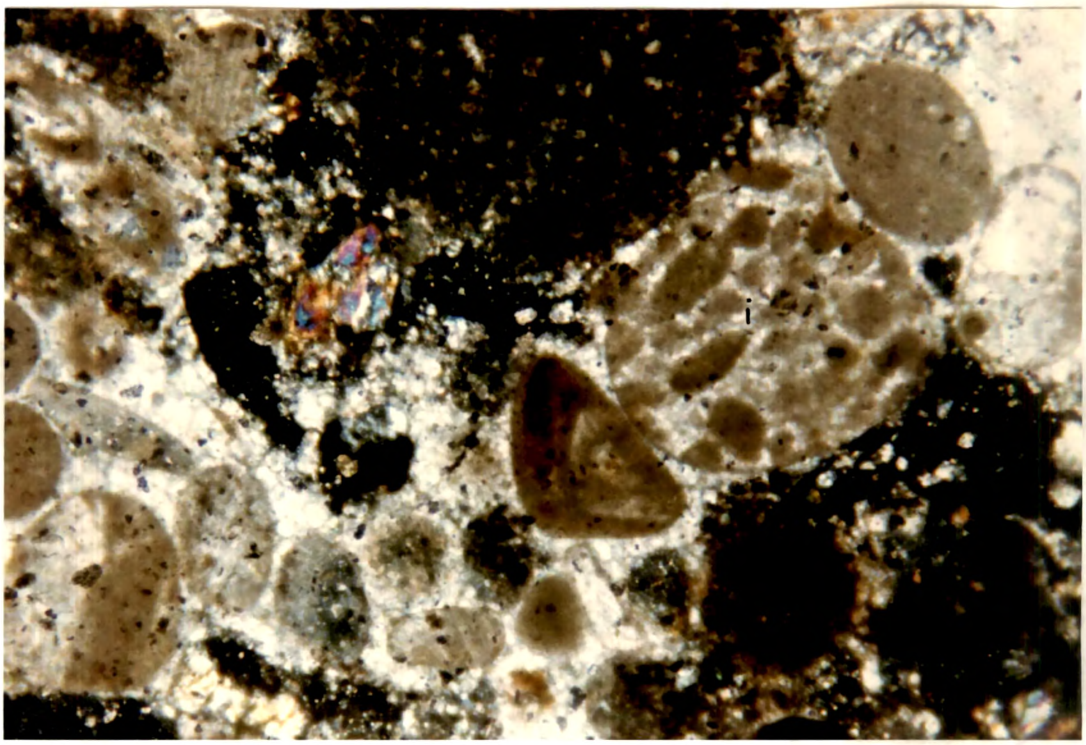


Photomicrograph showing peloids (p) in miliolite (Crossed Nicols, 120X) clasts in a new framework; their sizes range between fine sand upto large slablike pieces. In beach rocks and miliolites, the size of intraclasts in general ranges between medium to fine sand size particles. However, their occurrences as larger fragments of 5 to 10 cm are not uncommon in some beach rocks (Dwarka, Baradia, Navadra, Porbandar etc.). The finer intraclasts are difficult to recognise from the peloids, however, their aggregate grains with very thin micritic coatings are easy to identify from the latter (Plate V.11).

(iv) Coated grains

The term 'oolite' was defined for the first time by Lyell (1855) as "...small egg like grains, resembling the roe of a fish, each of which has usually a small fragment of sand as a nucleous around which concentric layers of calcareous matter have accumulated". Later on Heim (1916) introduced a new term 'oncoid' to describe the biogenically encrusted grains that possess non-concentric overlapping or separate envelopes, different shapes, compact structure and sharp boundaries. In the pursuit of modification of 'oolites', wolf (1960) suggested an English term 'coated grains' which includes ooids as well as oncoids. However, it was Teichert (1970) who used a more appropriate term 'ooids' for grains and 'oolite' for the rock that comprise the ooids. Recently, Peryt (1983) restricted the term 'ooids' to the (? bio) chemically precipitated coated grains formed in phreatic environment and introduced a new term 'vadoids' for those formed in vadose environment. But, in the same volume, Richter criticised such mixing of descriptive (ooid) and genetic (vadoid)

Plate V.11



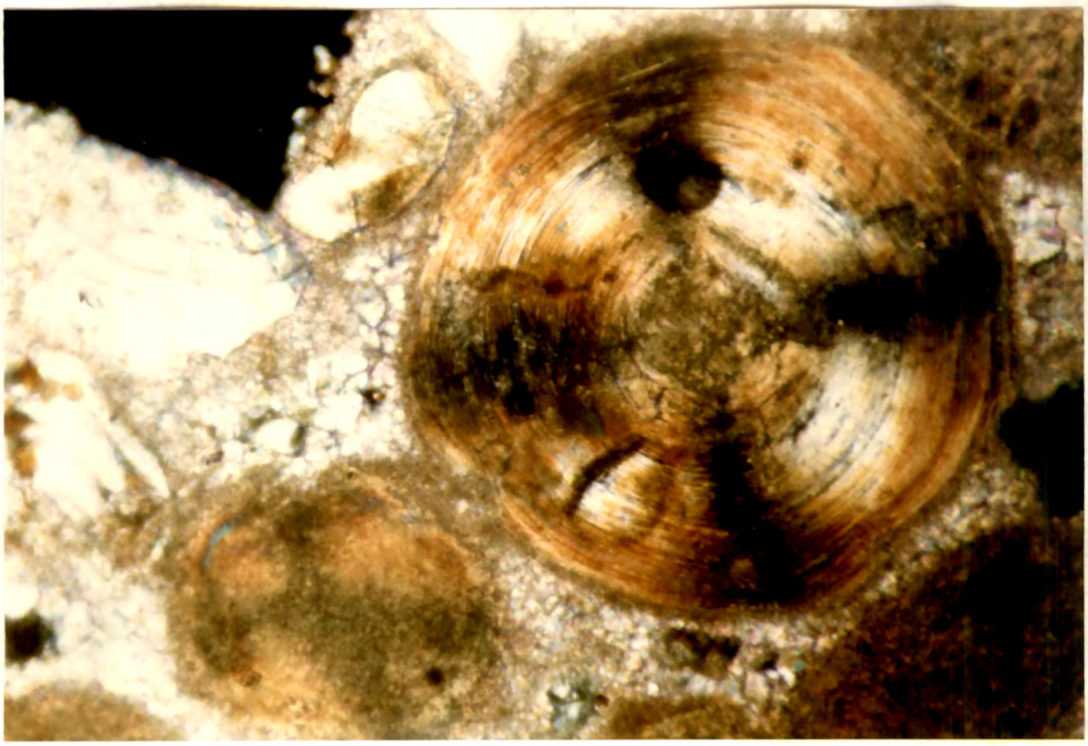
Photomicrograph of an intraclast (i) in miliolite (Crossed Nicols, 60X) terms, and preferred to use the old descriptive terms ooids and oncoids as they imply less mistakes. He further suggested that the so postulated grain size boundary between ooids & pisoids at a diameter of 2 mm (Choquette, 1978; Donahue, 1978) is not meaningful.

The author wishes to follow up Peryt's (1983) descripto-genetic classification for the coated grains encountered in the carbonate deposits of Saurashtra, especially in the miliolites, which include true marine/saline water ooids and diageneticlly formed vadoids. The former show a pseudouniaxial figure marked by a typical extinction cross (Plate V.12 a & b) and the latter alternate micrite/microsparite (dark) and sparite (light) cortices. These vadoids possess nucleii of peloids, foraminifera, molluscan shell fragments, coralline algae and even detrital grains. The shape of the vadoids varies from spherical to elliptical but it is more often controlled by the shape of nucleus. The cortices of these grains tend to grow sometimes upward or downward and does not show uniform layering (Plate V.13 a & b). Such diagenetically formed ooids are observed in miliolites, similar to one reported from South Africa by Siesser (1973), indicate their formation in seasonally phreatic and generally vadose meteoric conditions.

(2) Detritals

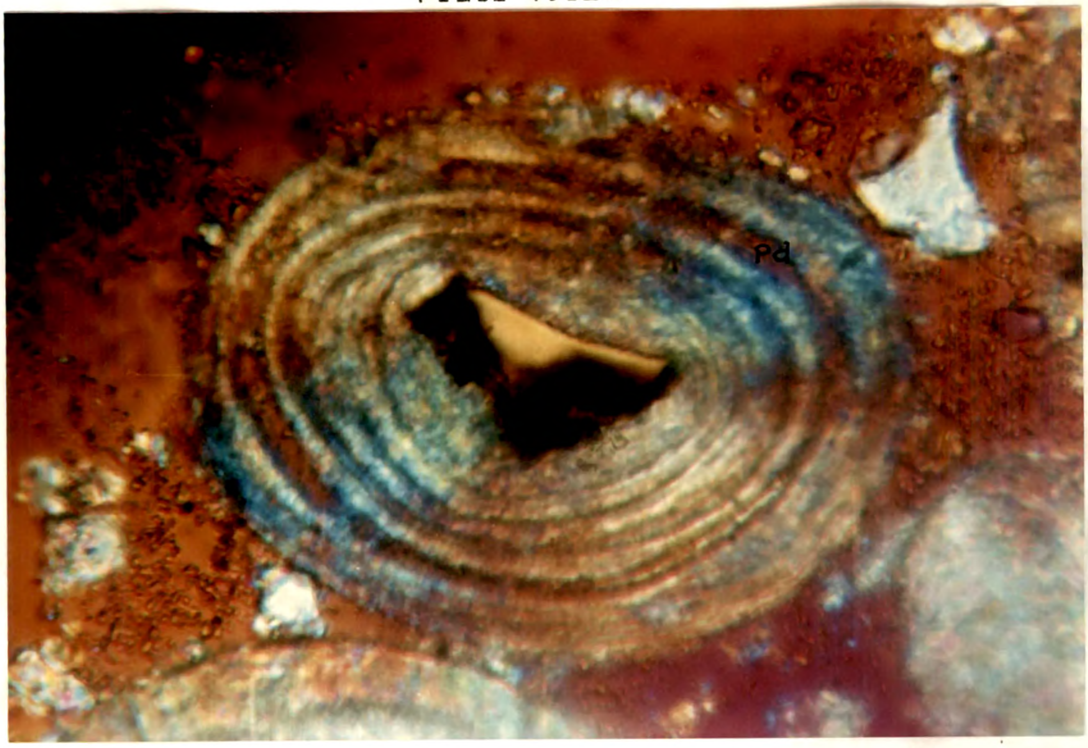
The detrital grains in these deposits comprise fragments of trappean rocks (basalt, andesite, granophyre etc.), laterites and Tertiaries (sandstone & limestone) as well as mineral fragmentw of

Plate V.12a



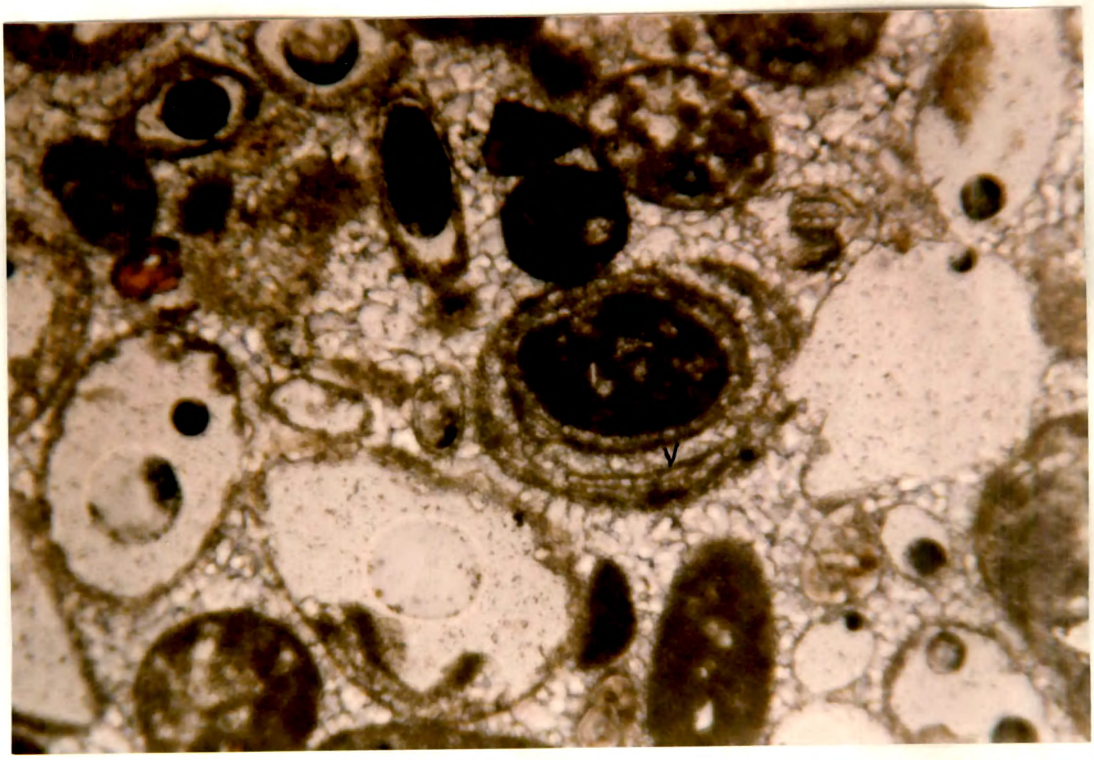
Photomicrograph of a marine ooid in miliolite showing pseudouniaxial figure marked by extinction cross (Crossed Nicols, 230X)

Plate V.12b



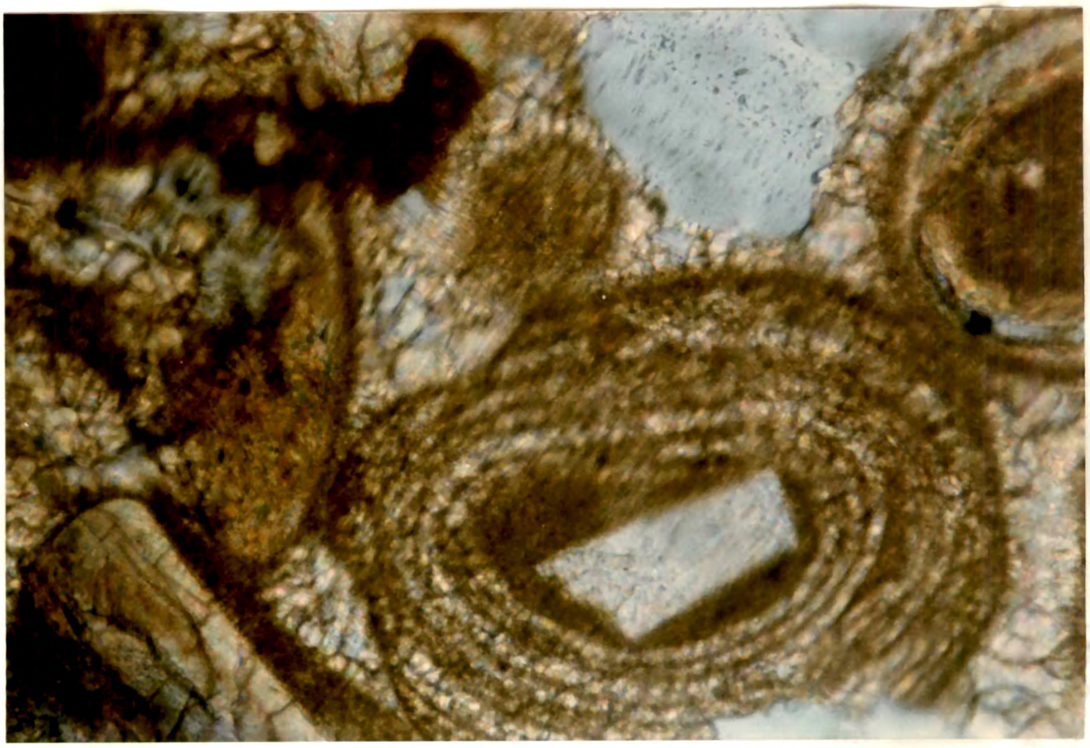
Photomicrograph of a marine ooid (with gypsum plate) showing preferential dissolution (pd) of aragonitic cortices (Crossed Nicols, 230X)

Plate V.13 a



Photomicrograph of a vadoid (v) in miliolite showing incomplete growth of cortices with downward thickening (PPL, 120X)

Plate V.13 b



Photomicrograph (with mica plate) of a typical multicortical vadoid with quartz nucleous in miliolite (Crossed Nicols, 230X) quartz, augite, feldspars and few dark coloured heavies - all derived from the nearby country rocks. They are angular to subangular and vary in size from 0.1 mm to as much as few centimeters. In miliolites the coarser and subangular detritals are accompanied by subrounded, well sorted, fine detrital sands (quartzose & trappean) suggesting their bimodal nature. The proportion of the detritals varies from 2 to 40%; the higher being in stabilised sand dunes. The quartz is a universal detrital occurring in all the three types of Quaternary deposits. In beach rocks, they are rather coarser, subrounded and little frosted, while in miliolites and dunal sands their occurrence is bimodal, some are angular to subangular while the others are rounded to subrounded suggesting their derivation from two different regime of distinct environment - fluvial and littoral. The nature of detritals is greatly influenced by the surrounding geology. For example, the fragments of Tertiary limestones & sandstones are encountered in the beach rocks and miliolites of western & southwestern coastal areas between Dwarka and Porbandar whereas those of trappean rocks are common in other areas. The fragments of magmatic derivatives of trappean rocks like those of granphyre, andesite, syenite etc. are met with in the obstacle deposits of miliolites in the vicinity of Alech, Osam, Girnar and Chamardi hills. Similarly progressive increase in the detritals (from 8 to 50% or more) is also observed in the stabilised dunes from Dwarka - Porbandar in NW to Mahuva - Gopnath in SE. The presence of vadose silt in thin sections of miliolites (calcareous as well as non-calcareous) is also worth noting. For more precise estimation of the non-calcareous detritals acid insolubles of the representative samples have been calculated.

(3) Cement

The word 'cement' includes all passively precipitated, space filling carbonate crystals which grows attached to a free surface (Bathurst, 1971). The various constituents of the beach rocks and miliolites are bounded together by the laterally precipitated calcareous (aragonitic and/or calcitic) cement while the dunal sands though stabilised, hardly show any cementation to form a compact rock. The careful scrutiny of number of thin sections of these bioclastic carbonate rocks, aided by etching and staining techniques recommended by Dickson (1965), Winland (1971) and Friedman (1971), has enabled the author to study the cement morphology as well as the mineralogy of various constituents and cements whether they are aragonitic or calcitic (low Mg/ high Mg and ferroan/ nonferroan). The morphology and mineralogy of the cements in beach rocks and miliolites reflect their diagenetic environments.

More than one generation of cements in carbonate rocks has been reported by several workers (Bathurst, 1958 & 1971; Oldershaw & Scoffin, 1967; Milliman, 1974; Flugel, 1982; Gardner, 1983 etc.). Following Flugel (op.cit.), first generation cement commonly shows fibrous habit growing normal to the grain surface and corresponds to the early diagenetic processes in limestone, whereas the second generation cement is usually coarser and characterised by isometric drusy or blocky mosaics that occur as pore filling crystals. It is often observed that the crystal size increases towards the center of the voids or openings which it fills. The two generations of cements are distinguishable from each other, provided there is an evidence is to indicate a time interval has separated the growth of the first from that of second. The first generation crystals, besides being smaller, are commonly scalenohedral in habit and the scalenohedral faces are preserved under the later overgrowth of second generation rhombohedra (Bathurst, 1971). Even where specific evidence of a time break is lacking, the sharp distinction in size and shape between the first generation and second generation crystals is strong presumptive evidence of a substantial time interval. With the help of staining solutions also, two generations of cement can be recognised if they possess different carbonate mineralogy eg. aragonite & non-ferroan calcite in beach rocks of Dwarka, Baradia & Porbandar.

The detailed morphology of the cement encountered in the carbonate rocks of the study area clearly reveals the presence of atleast two generations of cement; their boundries being visible mostly by very thin micritic and occasionally amorphous iron oxide layers. Based on their morphology, these cements in the study area are categorised into following types (Plate V.14) :

1. Meniscus cement,
2. Dripstone & Drapstone (gravitational) cement,
3. Dog-toothspar cement,
4. Syntaxial rim cement,
5. Isopachous drusy (circumgranular) rim cement,

6. Fibrous rim cement,

7. Micritic rim cement and

8. Blocky void-filling cement.

It is rather difficult to group the above listed cements whether they belong to first or second generation cement as their morphology does not restrict to one particular generation but is dependant on the diagenetic conditions (vadose/phreatic) in which it is precipitated.

The meniscus cement is so named by Dunham (1971) due to its formation by the meniscus of the liquid held at the grain contacts under shallow vadose condition (Plate V.14 a). It exhibits a curved surface, reflecting growth outward to capillary water-air curved interfaces of partially water filled pores. In the beach rocks and miliolites, this occurs as first generation cement and is characterised by aragonitic micrites in the former and low Mg, non-ferroan sparite in the latter.

The dripstone and drapstone cements characterise the deeper vadose zone where availability of solutions is relatively higher. The accumulation of the droplets of liquid on the bottom of grains gives rise to an incomplete rim of cement with downward thickening which causes typicl pendent or microstalactitic (Longman, 1980) cement. On the other hand, accumulation of the solution on the top of grains, dripping from the ceiling gives rise to the drapstone (microstalgmitic) cement that shows incomplete rim thickening upward. These cements reflect the shape of the gravity induced, convex downward/upward water-air interfaces and hence are

Explanation to the Plate V.14 (a to d)

(a) Meniscus cement (m) between various allochems in miliolite (with gypsum plate, Crossed Nicols, 35X)

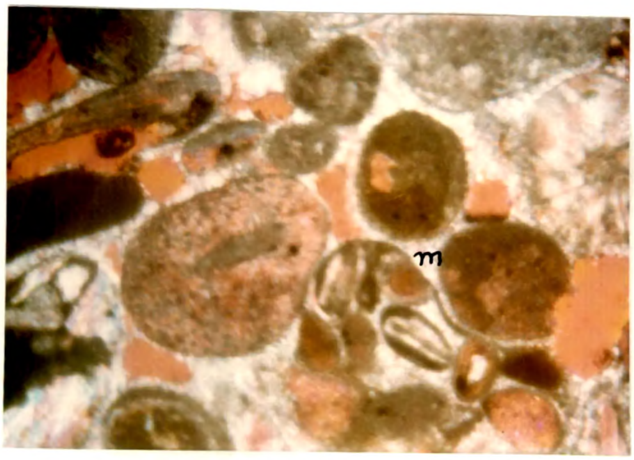
(b) Dripstone (x) and Drapstone (y) cement on single in miliolite (Crossed Nicols, 135X)

(c) Dog-toothspar cement (d) on a foraminiferal test in miliolite (Crossed Nicols, 65X)

(d) Syntaxial overowth (og) on a bioclast in miliolite. Also note the presence of dog-toothspar cement (d) and vadose silt (st) (Crossed Nicols, 35X)

Plate V.14 (a to d)

Photomicrographs of various types of cements in Quaternary carbonate rocks of Saurashtra



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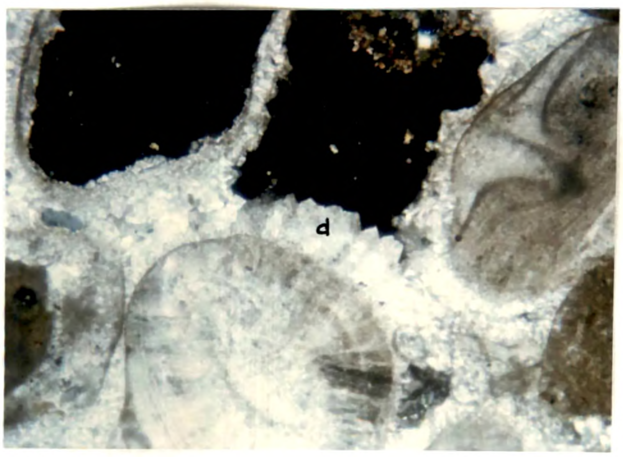

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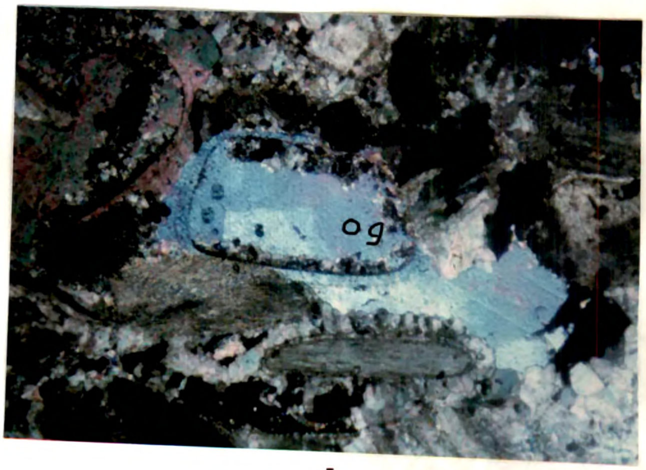


d

Explanation to the Plate V.14 (e to h)

(e) Isopachous drusy rim cement (dr) with first generation micritic rim (mr) in miliolite (Crossed Nicols, 35X)

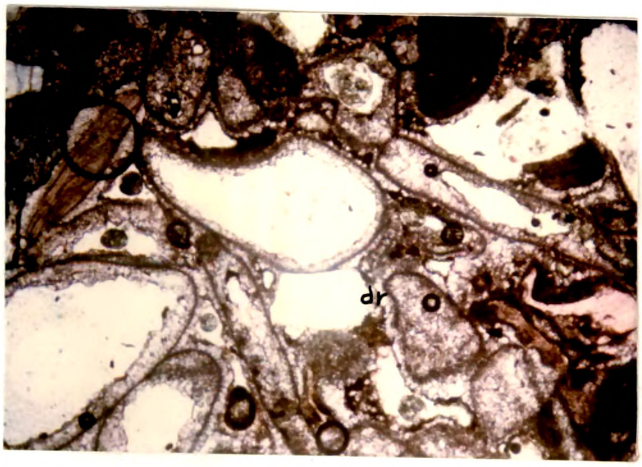
(f) First generation fibrous rim cement (fr) and second generation blocky pink coloured low Mg non-ferroan sparite (sp) in beach rocks (Stained, PPL, 65X)

(g) Blocky void filling cement in miliolite showing increase in crystal size towards the center of void (v) (Crossed Nicols, 65X)

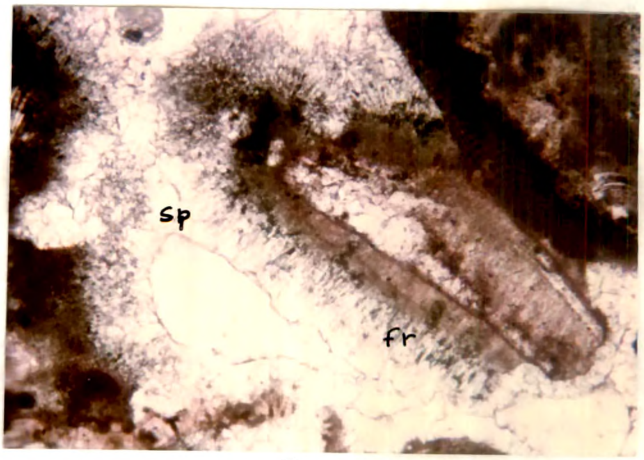
(h) Blocky void filling cement occluding the voids with calcite crystals in miliolite (Crossed Nicols, 65X)

Plate V.14 (e to h)

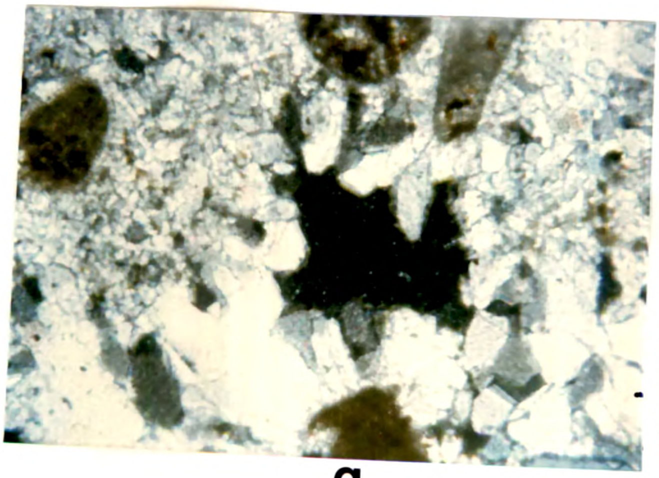
Photomicrographs of various types of cements in Quaternary carbonate rocks of Saurashtra



e



f



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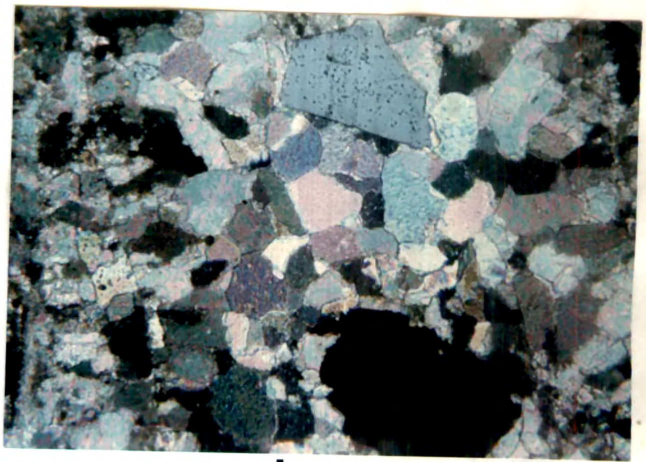


h

also termed elsewhere as gravitational cement (Bathurst, 1971; Flugel,1982). In miliolite rocks of Saurashtra, the dripstone and drapstone cements are often encountered as first generation low Mg, non-ferroan calcites and are also observed on the same grain (Plate V.14 b).

The dog-toothspar cement comprises small calcitype blocky cement with scalenohedral or incomplete rim over grains (Plate V.14 c). The low Mg calcite mineralogy in this cement is reflected by shorter growth of scalenohedrons while high Mg calcite shows their longer growth. Such cements have been reported by Flugel (1982) in the aeolianites and by Schneider (1977) in beach rocks. This cement is usually first generation & sporadically of second generation and is observed in some of the beach rocks and miliolites. In miliolites, some of the echinoid and bryozoan grains show optical continuation with the surrounding low magnesian sparite cements. Such cement morphology is generally described as syntaxial (or epitaxial) overgrowth (Plate V.14 d).

The cement precipitation that starts with the isopachous drusy linings in voids or coatings on grains is known as isopachous (or circumgranular) drusy rim cement. In number of thin sections of miliolites, this kind of cement is found forming first generation cement often overlain by the second generation blocky sparry cement (Plate V.14 e). Such rim cement in marine/saline water conditions is characterised by fibrous aragonite crystals described as fibrous rim cement which grows mostly on the crust of aragonitic micrites (Plate V.14 f). This cement is found only in the beach rocks of Dwarka, Baradia, Navadra and Porbandar area. In the beach rocks of Gosa, Mangrol, Veraval and Kadwar, the first generation cement is encountered in the form of thin micritic envelope around the grains which can be termed as micritic rim cement. Similar thin micrite rims are also encountered in some of the miliolites, particulary those of the South Saurashtra coast.

The occludation of primary as well as secondary porosity by the granular/blocky sparry calcite is known as the blocky void filling cement which tends to fill the voids rather than rimming them (Plate V.14 g & h). This type of cement is very common in both, ancient beach rocks as well as in miliolites, especialy in more consolidated forms, and occur as low Mg, nonferroan sparite. As obvious, it forms second or even the next generation of cement.

(b) CONSTITUENT FREQUENCY

The relative frequency of the various constituents was ascertained by modal analyses from the thin sections of beach rocks and miliolites of the representative localities. The bulk amount in volume percentage was determined by graduated eye-piece following the dual measurement technique of Dunham (1962). This was grouped under four broad heading viz. allochems, detritals, cement and porosity; the porosity mostly being intragranular (secondary). The intergranular (primary) porosity is also detected in the miliolites, the bulk amount of which hardly exceeds 8 - 10%. However, the intragranular porosity is negligible in beach rocks. Table V.2 gives the relative population of the three major constituents present in beach rocks and miliolites alongwith the absolute porosity in each of these rocks. The author at this juncture feels that some of the metastable allochems (molluscan shell fragments, coral, peloids, ooids, foram etc.), on dissolution during the various diagenetic processes operated upon them, show the development of intragranular porosity and in the present state occur as elliptical or rounded pores with thin micritic linings (Plate V.15). Because of this reason such grains have been accounted as allochems in considering the bulk constituents of the rock. The cement in these rocks is mostly endogenic, directly related to the dissolution of the allochems. Against this, the detritals are not in much relevance to the cementation. The relative proportion of allochems and cement is recalculated (after ignoring the detritals) and is also included in Table V.2. Their relative abundance in beach rocks and miliolites is shown in Fig. V.1 and V.2.

The above data reveal the following :

(i) The beach rocks and the coastal dune deposits of miliolites possess almost identical amount of allochems and cement suggesting their close affinity.

(ii) The obstacle dunes of the nearcoast and far inland areas contain relatively higher amount of allochems in comparison to the beach rocks and sheet deposits. However, their abundance is slightly higher in the leeward deposits in relation to the windward deposits.

TABLE V.2 : Relative population of major constituents in Beach rocks and Miliolites of Saurashtra

Sr. No.	Location	Ref.* No.	type of deposit	Constituents (vol. %) Allochem	Detrital	Cement	Absolute Porosity(vol. %)	Relative (vol. %) of Allochem	Cement
BEACH ROCKS									
1	Baradia	12	CS	45.20	14.45	40.35	12.45	52.83	47.16
2	Dwarka	47	"	49.13	18.65	32.20	20.35	60.41	39.59
3	Gosa	59	"	49.39	14.72	35.89	28.35	57.92	42.08
4	Harshad	63	"	53.95	18.16	27.89	18.25	65.92	34.08
5	Kadwar	73	"	46.39	21.61	32.00	26.15	59.18	40.82
6	Mangrol	107	"	45.24	18.11	36.65	24.50	55.24	44.76
7	Navadra	123	"	58.52	9.13	32.35	24.10	64.39	35.60
8	Porbandar	140	"	48.77	9.35	41.88	14.55	53.80	46.20
9	Sil	165	"	42.15	19.25	38.60	29.10	52.19	47.81
10	Veraval	193	"	44.69	26.53	28.78	30.45	60.83	39.17
MILIOLITES									
(a) Coastal									
11	Arena	7	CD	51.62	9.37	39.00	18.66	56.96	43.04
12	Chorwad	30	"	44.94	18.28	36.78	24.64	54.99	45.00
13	Diu	42	"	48.66	13.74	34.60	27.45	56.41	43.59
14	Gopnath	58	"	45.64	14.11	40.25	23.15	53.14	46.86
15	Gosa	59	"	50.38	12.11	37.51	24.02	57.32	42.68
16	Jafrabad	68	"	48.52	11.62	39.86	30.11	54.90	45.10
17	Jhanjhmer	71	"	48.03	16.87	35.10	18.75	57.78	42.22
18	Rajpura (Juna)	144	"	54.75	13.65	31.60	21.45	63.40	36.59
19	Khara Khetar	84	"	65.39	6.76	27.85	21.30	70.13	29.87
20	Madhavpur	98	"	45.39	24.18	30.43	26.25	59.87	40.13
21	Jegri Island	69	"	41.20	23.82	34.98	29.33	54.08	45.92
22	Naip	120	"	48.37	16.53	35.10	13.25	57.95	42.05
23	Navadra	123	"	51.92	14.33	33.75	25.40	60.60	39.39
24	Porbandar	140	"	57.58	9.88	32.54	19.69	63.89	36.11
25	Veraval	193	"	43.17	14.50	42.33	18.78	50.49	49.51

contd.

TABLE V.2 contd.

Sr. No.	Location	Ref. No.*	type of deposit	Constituents (vol. %) Alloches	Detrital	Cement	Absolute Porosity (vol. %)	Relative (vol. %) of Alloches	Cement
	[b] Inland - Near coast								
26	Desar	37	CD	58.80	11.32	29.88	16.33	66.31	33.69
27	Dolasa	45	"	52.47	16.13	31.40	13.69	62.56	37.44
28	Una	183	"	49.98	15.68	34.34	18.49	59.27	40.73
29	Aniyali	6	IS	55.71	3.97	40.32	8.55	58.01	41.99
30	Badalpur	9	"	55.42	21.48	23.10	11.45	70.58	29.42
31	Bhanvad	13	"	46.25	19.61	34.14	8.99	57.53	42.47
32	Kukaswada	90	"	60.36	3.57	36.07	7.58	62.59	37.41
33	Naliyadhar	121	"	50.54	3.85	45.61	12.50	52.56	47.44
34	Pedhwada	136	"	46.42	17.64	35.94	13.50	56.36	43.64
35	Sasan Gir	161	"	46.39	9.77	43.84	5.94	51.41	48.59
36	Sihan	167	"	38.38	30.11	31.51	10.64	54.91	45.08
37	Talala	175	"	51.11	17.34	31.55	14.45	61.83	38.17
	[c] Far Inland								
38	Adityana	1	WD	48.45	6.87	44.68	20.34	52.02	47.97
39	Bamanbor	11	"	48.47	21.10	30.43	17.25	61.43	38.57
40	Chamardi	21	"	46.81	19.15	34.04	23.87	57.90	42.10
41	Chotila	31	"	44.45	28.43	27.12	28.77	62.11	37.89
42	Dungarpur	46	"	61.25	14.61	24.14	29.77	71.73	28.27
43	Gop (Jam)	57	"	58.52	10.49	30.99	26.54	65.38	34.62
44	Junagarh	72	"	51.76	14.56	33.68	11.54	60.58	39.42
45	Ambla	4	LD	57.77	10.78	31.45	16.95	64.75	35.25
46	Chobari	28	"	56.33	24.89	18.78	23.80	74.99	25.00
47	Khatiya	85	"	58.27	18.13	23.60	18.25	71.17	28.83
48	Patan	133	"	61.81	4.58	33.61	21.36	64.78	35.22
49	Patanvav	134	"	59.38	12.73	27.89	19.74	68.04	31.96
50	Piparla	139	"	47.30	18.97	33.73	45.38	58.37	41.63
51	Rakka	146	"	54.69	12.66	32.65	15.50	62.62	37.38
52	Tapakeshwar	177	"	58.05	10.51	31.44	26.33	64.87	35.13
53	Anandpur	5	IS	44.49	19.40	36.11	13.53	55.20	44.80
54	Rajkot	143	"	43.44	24.53	32.03	12.43	57.56	42.44

* Ref. No. as per Fig.A

CS - Coastal Sheet
CD - Coastal Dune
IS - Inland Sheet
WD - Windward Dune
LD - Leeward Dune

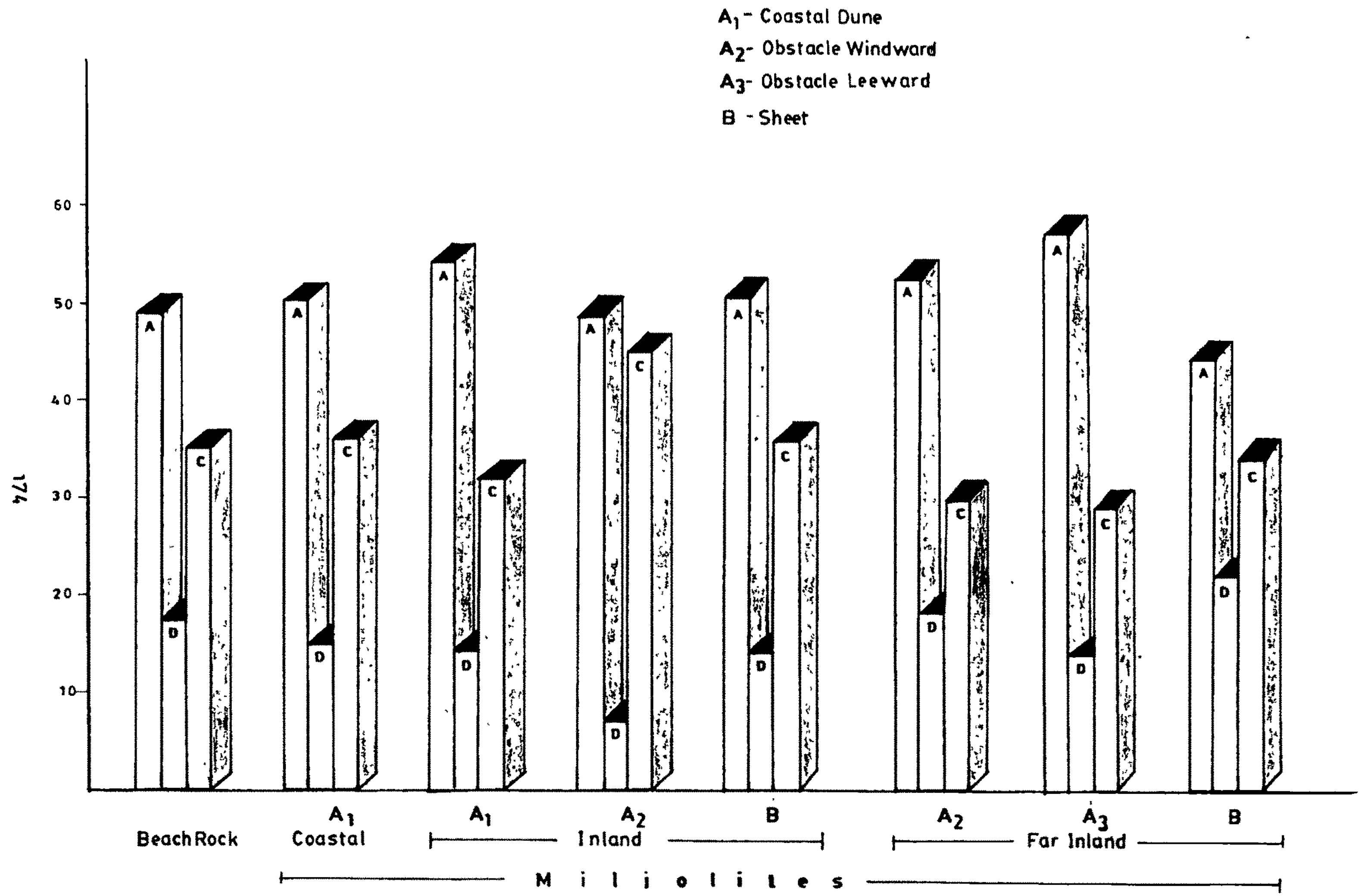


FIG .V.1 COLUMN GRAPHS SHOWING RELATIVE ABUNDANCE OF ALLOCHEM(A), DETRITALS(D) AND CEMENT(C)

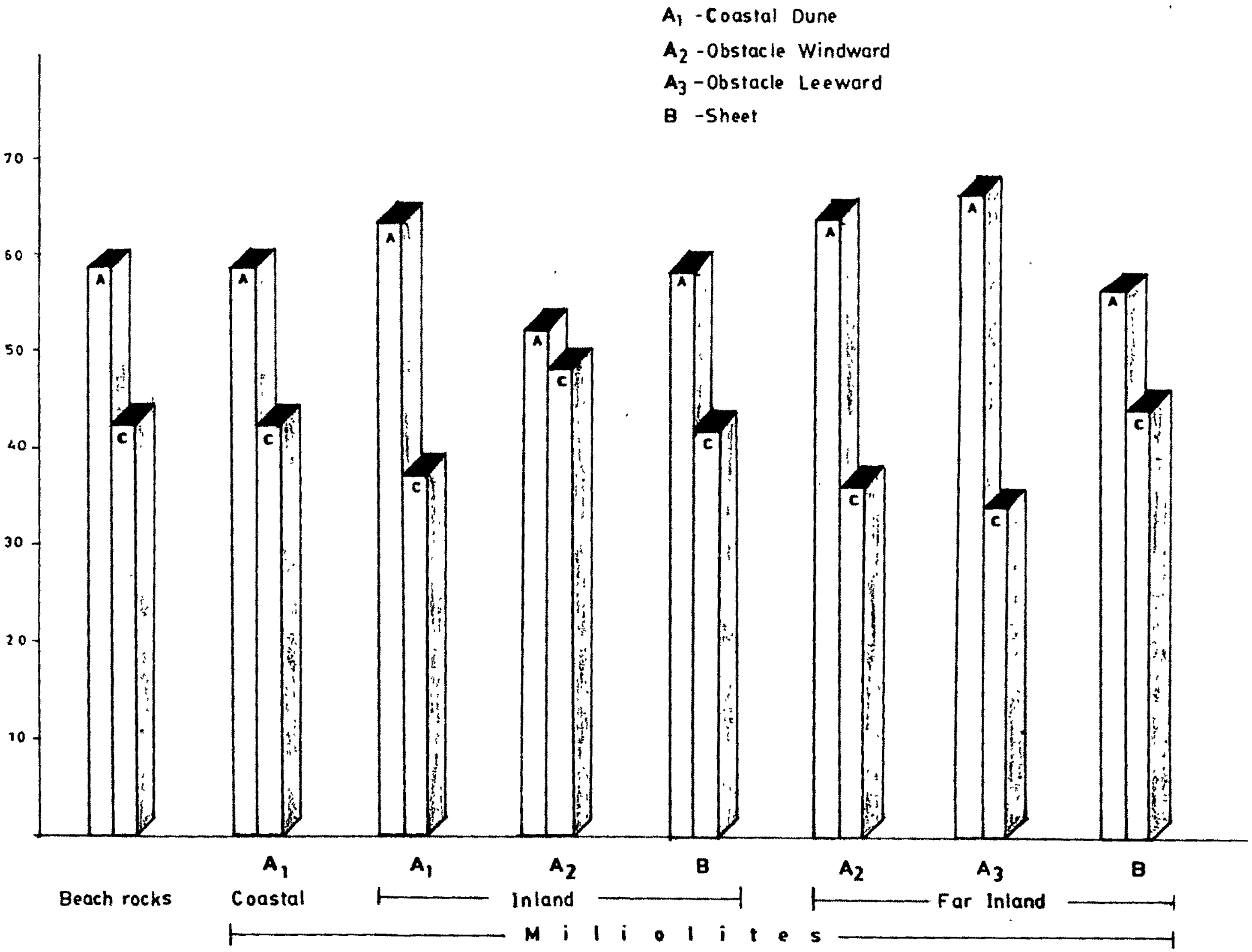
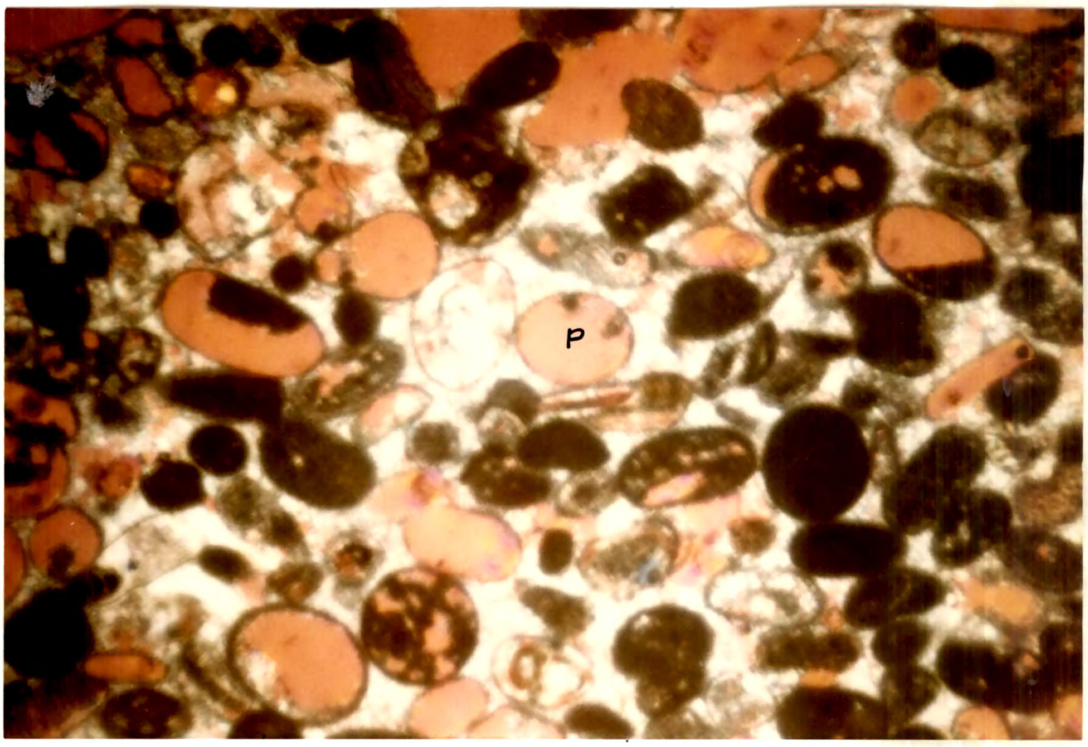


FIG. V.2 . RELATIVE ABUNDANCE OF ALLOCHEMS(A) AND CEMENT(C)

Plate V.15



Photomicrograph (with gypsum plate) showing development of intragranular (secondary) porosity (p) in miliolite (Crossed Nicols, 60X)

(iii) The amount of cement is higher in sheet deposits as compared to the obstacle dune deposits.

(iv) The overall increase in cement in these deposits is counterbalanced by the decrease in absolute porosity in all deposits.

(v) The detritals belong mostly to the locally derived country rocks and hence show no definite trend.

This variation in different constituents is mostly controlled by nature & source of the sediments, shoreline configuration, energy conditions, substrate geology & morphology, mode of deposition of calcareous sands, climatic conditions and their nearness to the ground waters.

The detailed frequenies of the various allochems in terms of bioclasts, peloids, intraclasts and coated grains (vadoids & ooids) were also determined and are given in Table V.3. These have prompted the author to follow the petrographic classification of Folk (1959, 1962). These data suggest that the beach rocks of the study area comprise the average proportion of bioclasts and peloids as 56:27 thus form their ratio 2:1 alongwith mostly micritc cement to classify them as biopelmicrites; the biomicrites are also not uncommon. Again in the miliolites, the proportion of bioclasts and peloids respectively is 20-50 and 40-65, forming their ratio as 1 : 1.5 to 2 with clear sparry calcite cement to include these rocks in biopelsparites of Folk (op.cit.).

TABLE V.3 : Table showing frequency of various allochems in beach rocks and miliolite limestones

Sr. No.	Location	* Ref. No.	Type of deposit	Bioclasts %	Peloids %	Intraclasts %	Ooids %	Vadoids %
BEACH ROCKS								
1	Baradia	12	CS	58.17	26.76	14.51	0.56	--
2	Dwarka	47	"	57.21	31.15	10.66	0.98	--
3	Gosa	59	"	52.61	26.77	18.31	1.68	0.63
4	Harshad	63	"	60.79	22.47	16.33	--	0.41
5	Kadwar	73	"	66.56	18.15	14.37	0.61	0.31
6	Mangrol	107	"	63.85	23.37	10.91	1.87	--
7	Navadra	123	"	51.28	36.11	11.64	0.65	0.32
8	Porbandar	140	"	53.42	30.45	13.58	2.53	--
9	Shil	165	"	56.24	26.85	15.13	--	1.78
10	Veraval	193	"	60.62	28.33	11.05	--	--
MILIOLITE LIMESTONE								
	[a] Coastal							
11	Arena	7	CD	37.75	40.83	4.51	15.38	1.53
12	Chorwad	30	"	29.52	60.93	6.68	2.05	0.82
13	Diu	42	"	26.40	55.58	8.57	3.38	6.14
14	Gopnath	58	"	23.79	50.78	14.81	8.11	2.51
15	Gosa	59	"	24.15	49.81	22.36	--	3.68
16	Jafrabad	68	"	52.60	39.90	7.05	--	0.45
17	Jegri Island	69	"	25.77	56.52	11.63	2.92	3.16
18	Jhanjhmer	71	"	28.83	54.18	11.05	5.94	--
19	Khara Khetar	84	"	41.24	51.56	4.11	0.78	2.31
20	Madhavpur	98	"	30.66	50.50	8.15	8.54	2.15
21	Naip	120	"	36.79	54.93	3.71	2.16	2.41
22	Navadra	123	"	31.58	51.18	12.49	3.44	1.31
23	Porbandar	140	"	38.75	55.13	8.61	--	2.51
24	Rajpura (Juna)	144	"	31.45	57.55	6.18	3.35	1.47
25	Veraval	193	"	25.38	61.20	11.24	1.72	0.46

contd.

TABLE V.3 contd.

Sr. No.	Location	* Ref. No.	Type of deposit	Bioclasts %	Peloids %	Intraclasts %	Ooids %	Vadoids %
	[b] Inland - Near coast							
26	Desar	37	CD	26.54	40.28	6.55	19.89	6.74
27	Dolasa	45	"	48.34	31.89	12.14	2.18	5.49
28	Una	183	"	36.28	58.30	1.87	2.41	1.14
29	Aniyali	6	IS	39.02	48.40	3.35	6.77	2.26
30	Badalpur	9	"	24.32	55.36	11.68	5.54	3.10
31	Bhanvad	13	"	23.24	31.64	13.34	30.78	—
32	Kukaswada	90	"	28.38	35.49	9.66	21.52	4.95
33	Naliyadhar	121	"	31.66	62.15	6.19	--	--
34	Pedhwada	136	"	23.18	54.57	12.11	10.14	—
35	Sasan Gir	161	"	34.81	59.71	4.18	1.30	--
36	Sihan	167	"	27.67	67.89	4.44	—	—
37	Talala	175	"	31.76	63.14	3.31	1.14	0.65
	[C] Far Inland							
38	Adityana	1	WD	35.75	48.86	2.89	6.85	5.65
39	Bamanbor	11	"	28.99	55.33	5.76	1.56	8.36
40	Chamardi	21	"	37.49	44.16	1.16	4.56	0.95
41	Chotila	31	"	26.65	69.08	1.18	1.91	0.48
42	Dungarpur	46	"	41.42	51.03	6.24	1.31	—
43	Gop (Jam)	57	"	30.05	44.45	2.00	22.17	1.33
44	Junagarh	72	"	32.44	60.55	5.47	0.96	0.58
45	Ambla	4	LD	28.56	56.51	9.05	--	5.88
46	Chobari	28	"	26.65	69.08	1.88	1.91	0.48
47	Khatiya	85	"	21.52	61.61	4.31	11.47	1.09
48	Patan	133	"	32.72	58.12	6.31	--	2.85
49	Patanvav	134	"	24.76	67.39	2.41	4.30	1.14
50	Piparla	139	"	21.31	52.42	2.16	15.53	8.58
51	Rakka	146	"	26.82	62.98	1.88	7.81	0.51
52	Tapakeshwar	177	"	27.42	64.89	4.62	2.35	0.72
53	Anandpur	5	IS	24.73	48.87	10.17	16.23	--
54	Rajkot	143	"	37.19	53.86	8.17	0.78	—

* Ref. No. as per Fig. A

CS - Coastal Sheet
CD - Coastal Dune
IS - Inland Sheet
WD - Windward Dune
LD - Leeward Dune

The stabilised sand dunes are almost uncemented and very much friable, and hence the frequency of their constituents was determined under binocular microscope by counting their relative numbers. Amongst the bioclasts in dunal sands, foram and shell fragments are dominant and easy to identify whereas, the other bioclasts viz. fragmnets of bryozoan, echinoid spines, ostracods, corals etc. occur very subordinately and are collectively grouped as Rest. the peloids form spherical to elliptical grains, with almost obliterated surface ornamentation and occur relatively in subordinate amount. Quartz is rich (more than 80%) in the detritals; the others being fragments of trappean rocks and minerals. The data of constituent frequency in stabilised dunal sands are shown in Table V.4.

On an average, the proportion of allochems in these dunal sands varies from 50% to as high as 90% while that of detritals 10 to 50%; their average being 70% and 25-30% respectively. This ratio (allochems/detritals), is higher in miliolites, but their relative abundances are comparable. In miliolites the cementation has taken place and most of the cement is derived at the cost of the allochems. Further, the data show progressive increase in detritals from Dwarka-Harshad-Porbandar coastal segment in NW to Kadwar-Jafrabad-Mahuva coast in SE, which could be related to the redistribution of the river sediments of Mainland Gujarat and those of South Saurashtra coast by strong tidal currents in the Gulf of Cambay.

TABLE V.4 : Table showing frequency of various constituents in stabilised sand dunes.

Sr. No.	Location	Ref. No.*	BIOCLAST (%) Foram	Sh.Frg.	Rest	PELOID (%)	DETRITAL (%)
1	Ahmadpur Mandvi	2	13.65	31.88	6.73	17.18	30.56
2	Chorwad	30	16.24	37.22	0.84	24.15	21.55
3	Diu	42	17.11	33.24	11.03	20.48	18.14
4	Dwarka	47	9.39	56.80	11.87	13.56	8.38
5	Harshad	63	21.75	36.31	10.03	23.28	8.63
6	Jafrabad	68	13.44	18.59	3.30	21.16	43.51
7	Jhanjhmer	71	11.65	24.18	1.30	27.52	38.35
8	Kadwar	73	8.92	41.53	8.00	11.39	30.16
9	Kodinar	89	4.69	18.38	3.04	8.51	65.38
10	Madhavpur	98	13.15	46.60	7.30	18.84	14.11
11	Mahuva	101	6.53	9.22	2.47	12.34	69.44
12	Navadra	123	14.38	48.12	1.98	27.35	8.17
13	Navibandar	124	8.54	55.37	7.80	14.76	13.53
14	Porbandar	140	12.17	44.20	7.06	26.43	10.14
15	Tarapur	178	8.39	6.33	1.98	34.74	48.56
16	Veraval	193	12.68	35.53	1.31	27.67	22.81

* Ref. No. as per Fig. A

The author further agrees with Patel & Desai (1988) and suggests that such dunal material after subjected to the various diagenetic processes in future span of time would give rise to the miliolitic limestones like those of Kutch and Saurashtra.

(c) INSOLUBLE RESIDUES

The estimation of absolute amount of non-calcareous and calcareous components present in beach rocks, miliolites and stabilised sand dunes were made following Ireland (1971). For this 25 gm of bulk sample was dissolvedin dilute (10%) hydrochloric acid till the total loss of $CaCO_3$. The dried residues were weighed and were studied under the binocular microscope to determine their composition. These comprise mainly quartz and rock fragments together with small amount of feldspar and pyroxene minerals. The rest residues include remaining heavies, limonitic lumps, foraminiferal & bryozoan casts, plant tissues etc. The data thus obtained are shown in Table V.5.

The absolute amount of insolubles range between 5 to 15% in beach rocks, 10 to 30% in miliolites and 5% to as high as 70% in the dunal sands. The relative amount of various residue products in general does not show any trend within each type of deposit. However, they are much higher in the stabilised dunal sands. The occurrence of these residues in individual deposit reflects their derivation from local source. While the inland miliolite deposits are characterised by the presence of coarse trappean sands, those of the coastal areas and beach rocks mostly comprise fragments of

TABLE V.5 : Insoluble Residues of Quaternary Carbonate Deposits of Sauashtra

Sr. No.	Location	Ref. No. ‡	$CaCO_3$ %	Residue %	Composition (%) Qz.	Fd.	Py.	R.F.	Casts	Rest
BEACH ROCKS										
1	Baradia	12	95.28	4.72	28.15	--	--	53.49	14.66	3.70
2	Gosa	59	93.48	6.52	38.50	4.61	5.15	35.14	11.35	5.25
3	Kadwar	73	88.59	11.41	53.15	--	3.50	20.99	14.25	8.11
4	Mangrol	107	93.69	6.31	55.33	--	--	28.75	10.65	5.27
5	Navadra	123	92.25	7.75	49.35	3.18	6.45	13.75	19.33	7.94
6	Porbandar	140	89.55	10.45	34.70	--	3.33	37.24	16.15	8.55
7	Shil	165	90.35	9.65	39.65	--	4.15	24.85	18.15	13.21
8	Tukada	180	94.53	5.47	31.45	1.53	3.75	40.25	8.33	14.69
9	Veraval	193	82.91	17.09	43.61	--	4.11	30.50	15.45	6.33
MILIOLITES										
10	Adityana	1	96.85	3.15	55.65	--	2.45	29.37	3.18	9.35
11	Aniyali	6	93.44	6.56	42.35	--	--	36.54	8.95	12.16
12	Baganbor	11	85.20	14.80	42.11	3.45	5.15	38.22	6.39	4.68
13	Chamardi	21	86.32	13.68	47.24	4.65	3.31	30.25	6.20	8.35
14	Chotila	31	77.82	22.18	31.40	5.35	4.25	43.47	5.00	10.53
15	Diu	42	90.40	9.60	36.85	--	6.89	42.15	5.22	8.89
16	Gop (Jam)	57	91.42	8.58	37.75	4.39	5.25	38.15	6.33	8.13
17	Gosa	59	93.41	6.59	56.45	--	3.25	27.37	4.78	8.15
18	Jafrabad	68	85.56	14.44	43.85	3.35	4.68	18.26	13.33	16.53
19	Junagarh	72	81.66	18.34	45.64	3.55	4.15	31.50	8.85	6.30
20	Madhavpur	98	77.62	22.38	46.20	2.15	4.55	28.58	6.19	12.33
21	Mahuva	101	70.20	29.80	38.44	4.66	7.18	31.80	11.39	6.55
22	Patan	133	63.40	36.60	31.75	6.18	9.50	30.22	14.11	8.24
23	Patanvav	134	88.50	11.50	33.46	3.16	8.31	32.68	10.14	12.25
24	Piparla	139	89.55	10.45	45.61	5.18	4.85	26.89	7.35	10.12
25	Rajkot	143	59.75	40.25	39.68	--	3.65	30.68	16.24	9.75
26	Rakka	146	85.67	14.33	48.85	3.68	4.11	23.70	8.15	11.50
27	Una	183	93.23	6.77	48.31	3.45	3.89	21.25	10.25	12.85
28	Varwala	190	81.92	18.08	51.65	--	--	38.20	8.35	1.80

contd.

Table V.5 contd.

Sr. No.	Location	Ref.* No.	$CaCO_3$ %	Residue %	Composition (%) Qz.	Fd.	Py.	R.F.	Casts	Rest
SAND DUNES										
29	Ahmadpur Mandvi	2	57.60	42.40	43.55	3.65	8.38	18.75	10.25	15.42
30	Diu	42	85.48	14.52	43.61	1.65	19.24	9.00	6.90	19.52
31	Dwarka	47	95.10	4.90	35.45	--	--	49.61	9.11	5.83
32	Ghugadva Creek	54	94.10	5.90	44.59	--	1.65	35.76	9.75	8.24
33	Harshad	63	93.40	6.60	37.35	7.65	13.17	20.50	14.35	6.98
34	Jafrabad	68	48.12	51.88	41.65	5.25	5.40	28.11	12.65	6.93
35	Jhanjhmer	71	61.40	38.60	37.95	3.11	21.19	20.18	11.25	6.32
36	Kadwar	73	67.60	32.40	51.35	4.15	11.20	21.66	6.15	5.49
37	Kodinar	89	30.40	69.60	42.55	0.31	10.35	38.75	4.18	3.86
38	Madhavpur	98	93.15	6.85	60.75	--	1.33	17.67	9.15	11.10
39	Mahuva	101	28.10	71.90	25.45	8.11	18.54	41.25	3.78	2.87
40	Mangrol	107	89.00	11.00	40.76	4.21	8.10	27.37	13.25	6.31
41	Navadra	123	88.30	11.70	45.69	1.03	3.53	32.00	8.21	9.45
42	Navibandar	124	87.12	12.88	39.15	--	3.55	36.17	11.58	9.55
43	Porbandar	140	91.25	8.75	52.14	2.76	6.15	28.11	3.65	7.19
44	Tarapur	178	43.80	56.20	48.24	1.33	3.45	25.65	6.75	14.58
45	Veraval	193	75.38	24.62	43.30	2.54	4.15	35.40	8.98	4.72

* Ref. No. as per Fig.A

tertiary sandstones, laterites and geods. The feldspars and pyroxenes are generally accompanied with the basaltic & lateritic rock fragments derived from the trappean country. The quartz forms the major insoluble residue in all the three types of these deposits and show 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 (Glennie, 1970; Davis, 1983).

(d) X R D STUDIES

The detailed carbonate mineralogy of beach rocks, miliolites and stabilised sand dunes of the study area was made by X-ray diffraction (XRD) following Griffin (1971). The powdered (-230 mesh) bulk samples of these deposits were subjected to this study using the Phillips X-ray diffractometer with Cu target and CuKα radiation. All these samples were scanned between 25° and 31° 2θ range at a speed of 2° per minute with chart speed of 2 cm per minute; the range being $1X10^4$ C/S. The d-spacings and intensities were calculated and compared with ASTM standard charts for the mineral identification. These diffractograms reveal the presence of calcite, quartz, feldspars and aragonite (Fig. V.3). Their 'relative' abundances were determined from the intensity of the standard (100) peak of individual mineral. The major peak of calcite that occurs at different d-spacings in individual samples

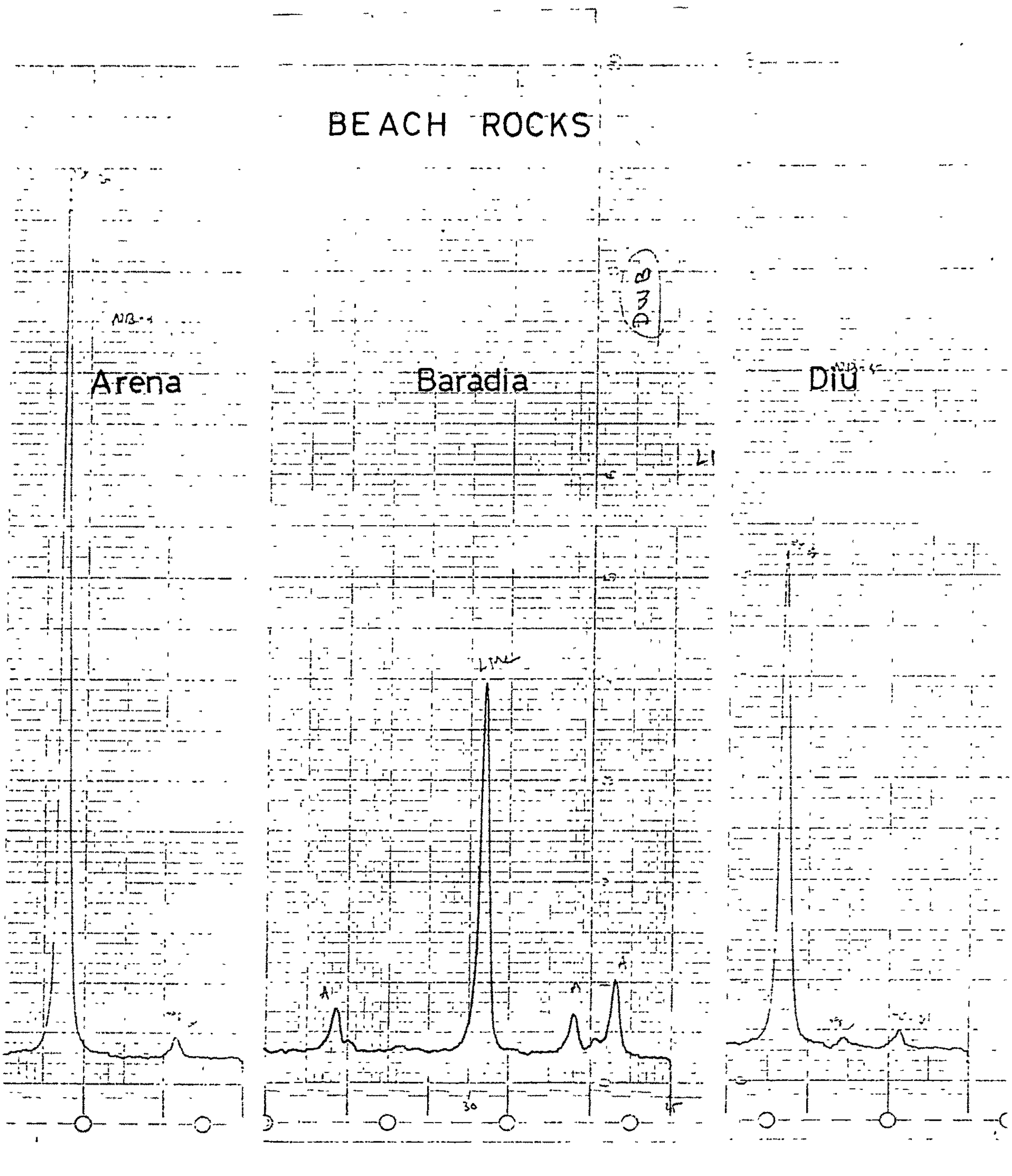


FIG. V.3. **XRD** CURVES OF QUAT. CARB. DEPOSITS OF STUDY AREA

Fig. V3 Contd

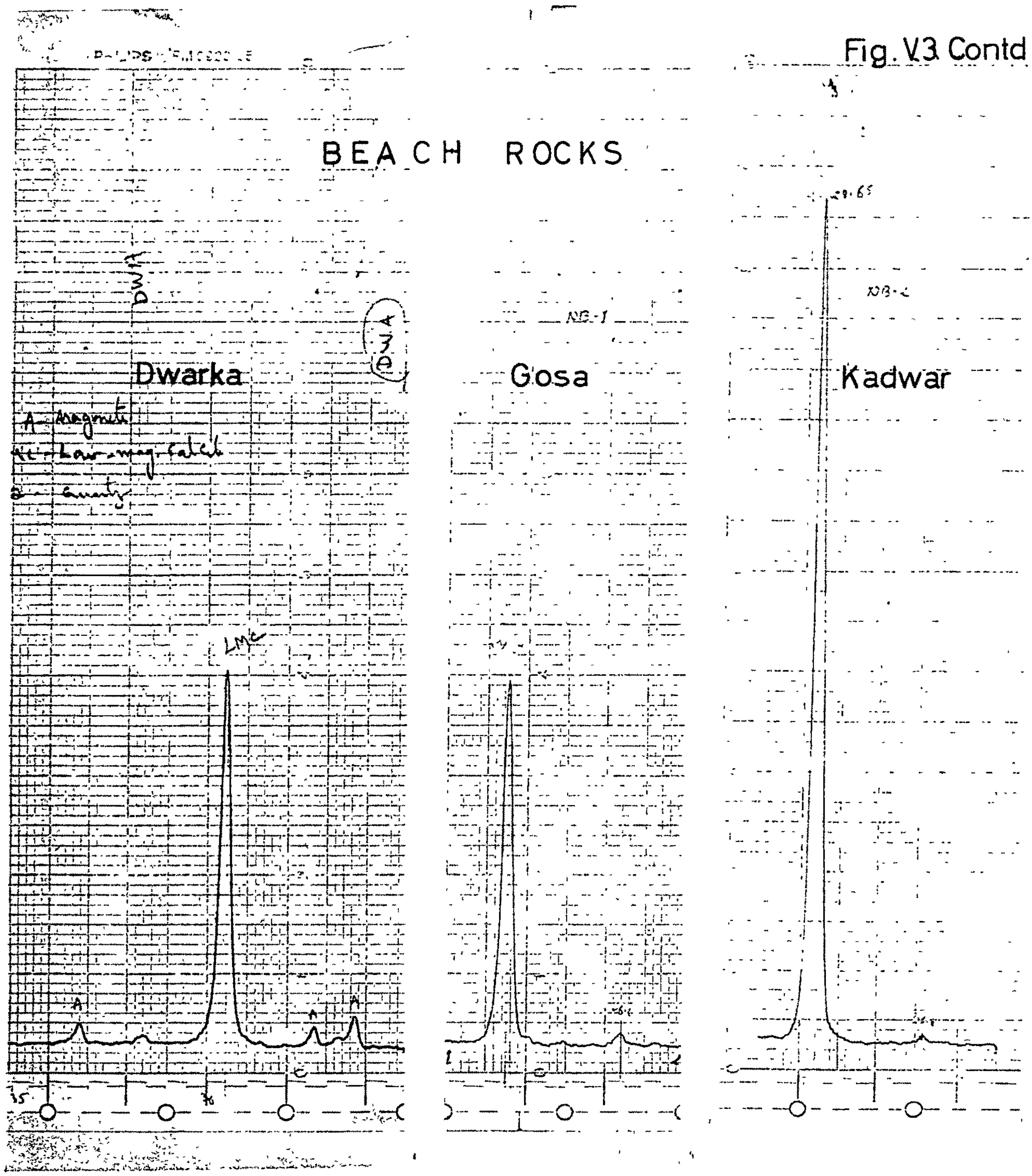
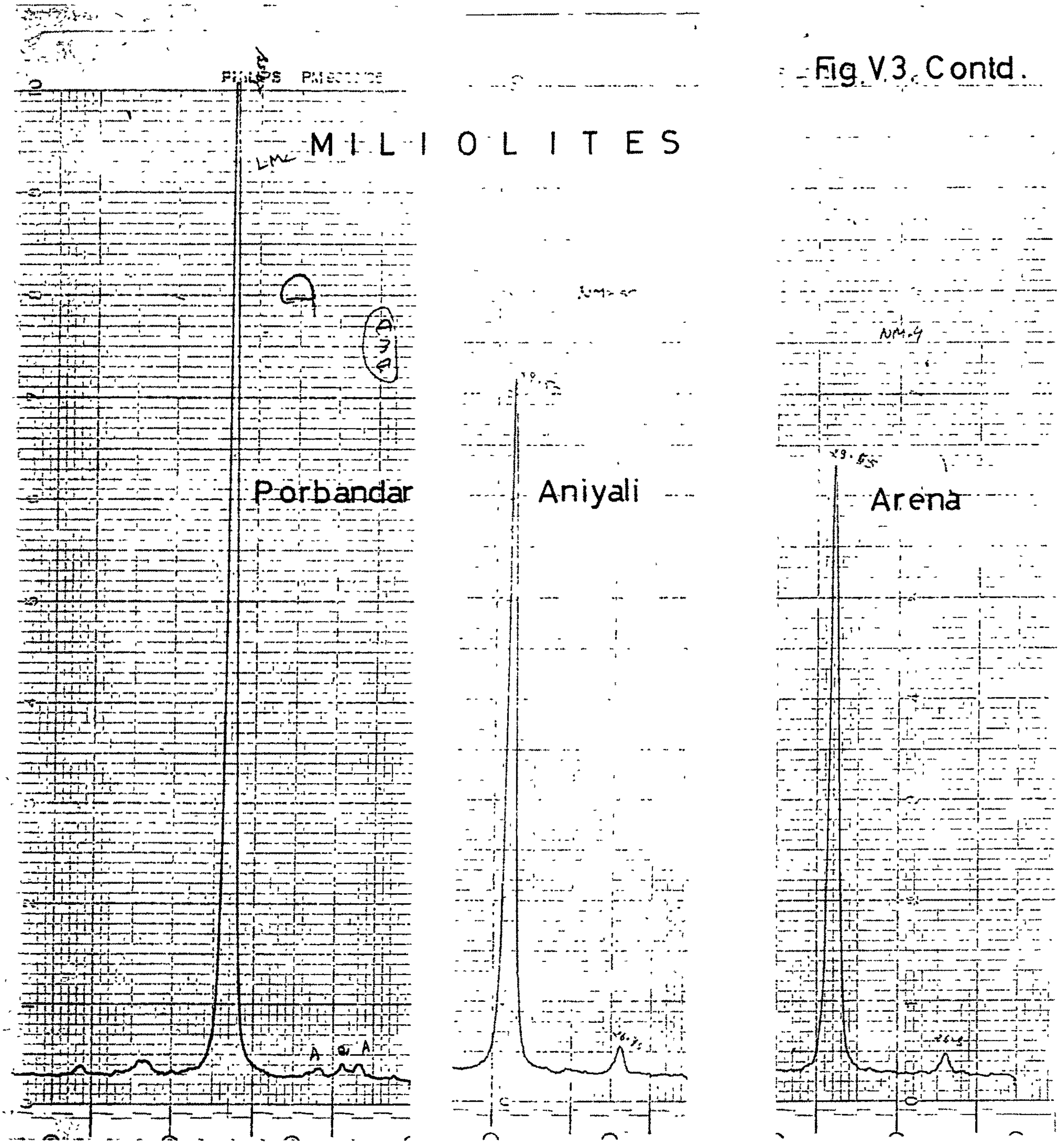


Fig. V.3. Contd.



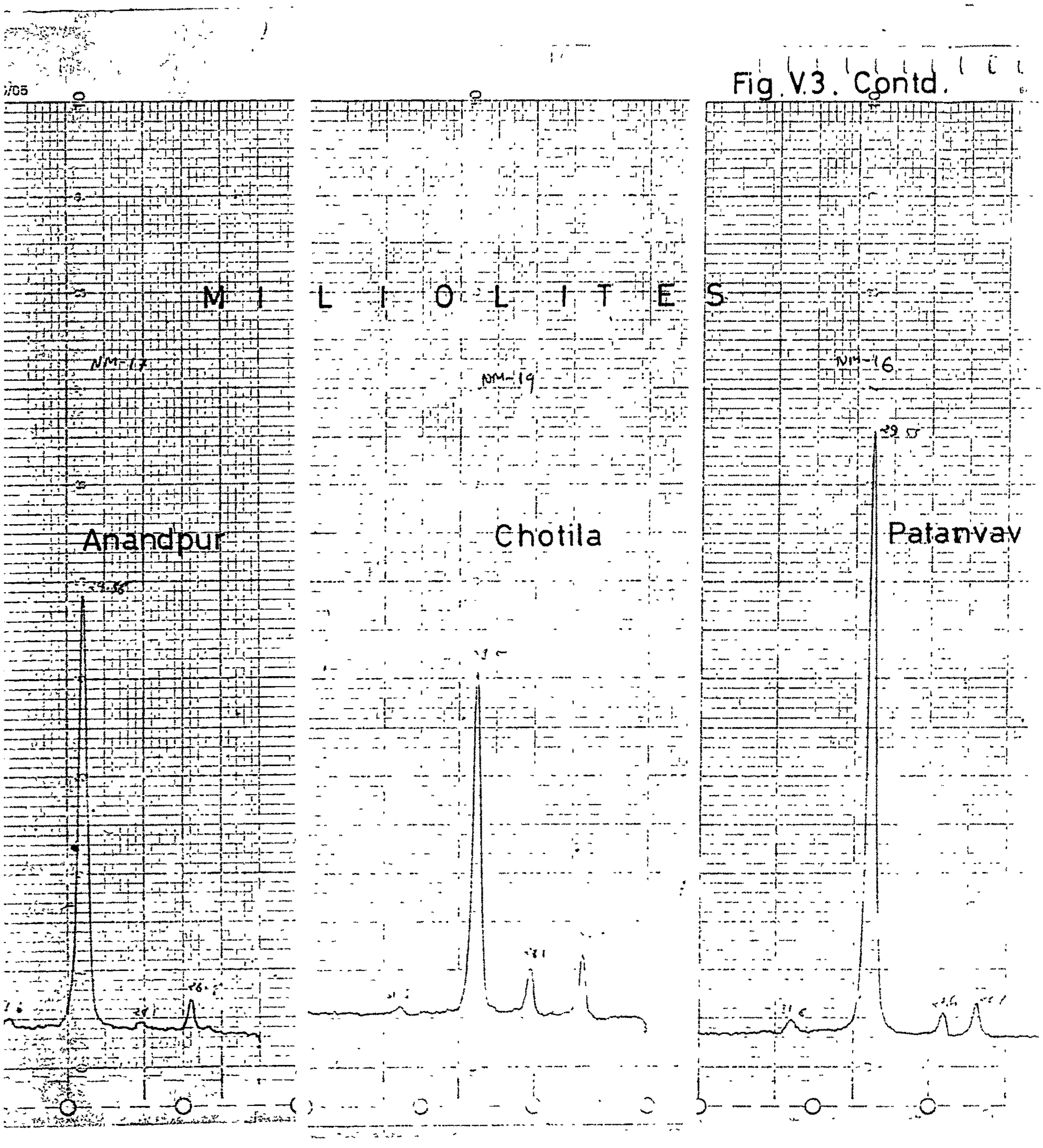


Fig. V.3. Contd.
M I L I O L I T E S
NM-17
NM-19
NM-16
Anandpur
Chotila
Patanvav

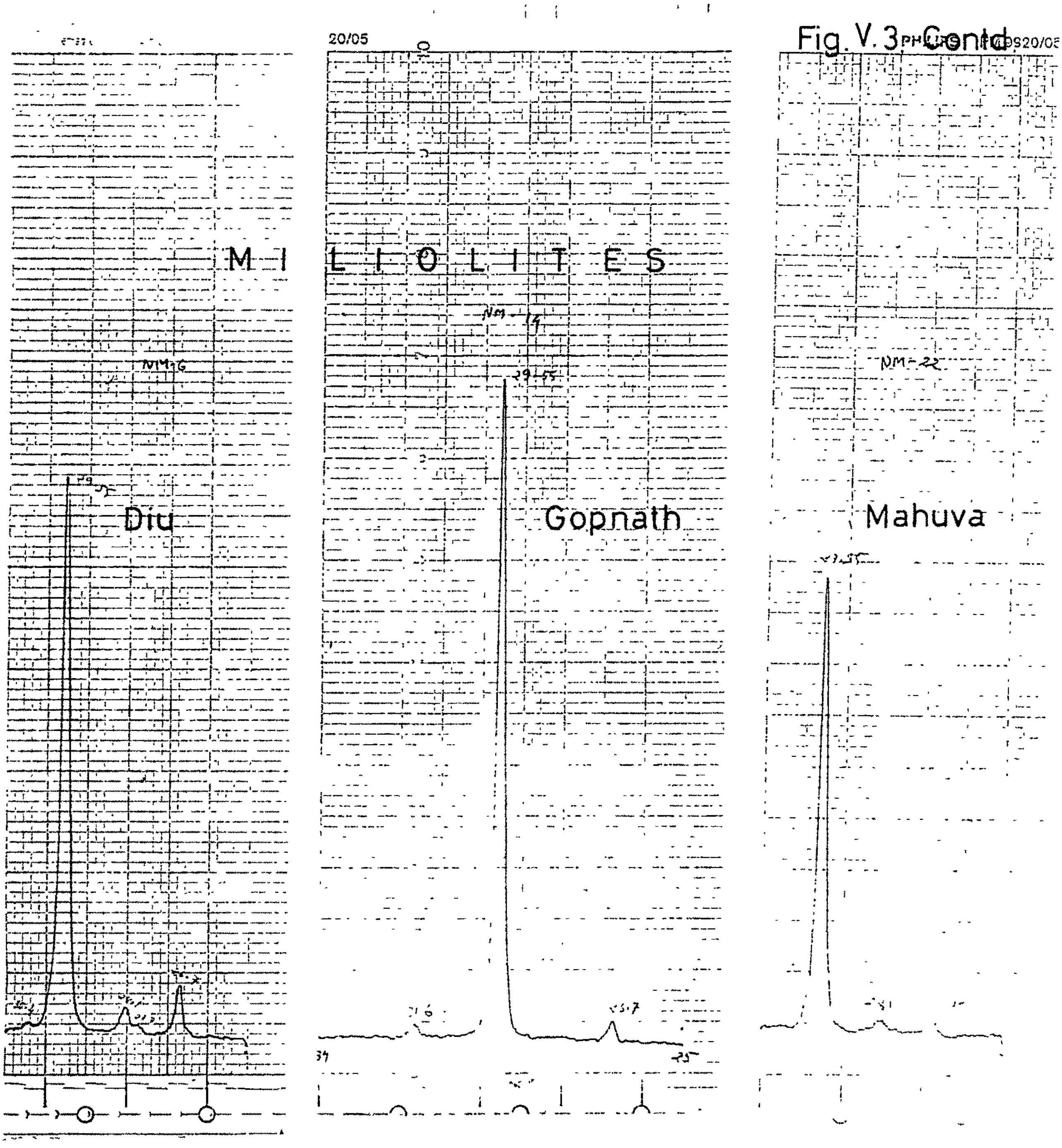
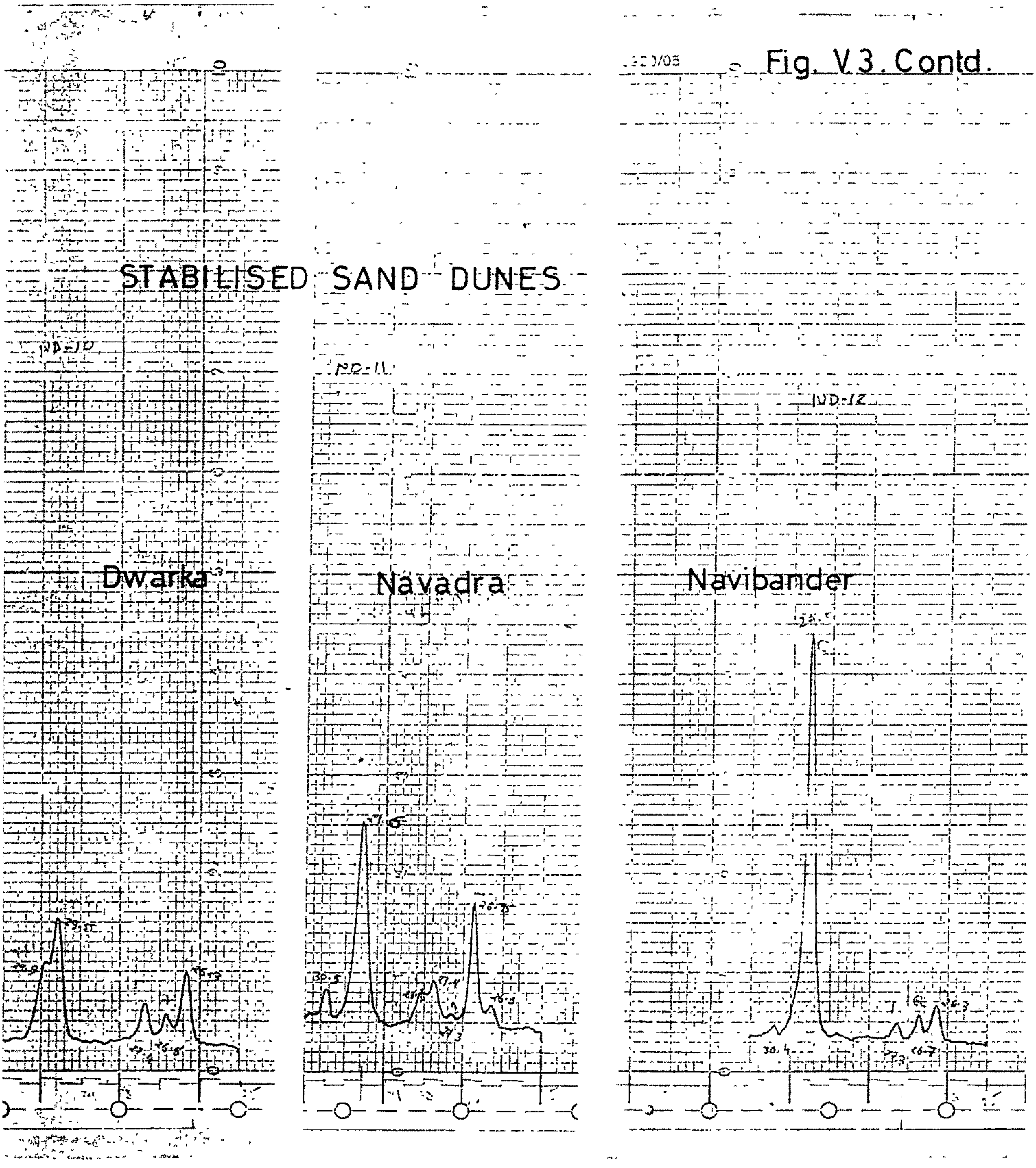


Fig. V. 3 Contd
M I L I O L I T E S
Diu
Gopnath
Mahuva

Fig. V.3. Contd.



suggests the presence of Mg in its crystal lattices. The Mg wt% present in each sample were then calculated after Chave (1952) from the d-spacings of the major calcite peaks. The results are shown in Table V.6.

The data shows abundance of calcite and quartz in all three type of deposits. The percentages of calcite ranging between 60 to 90 and quartz 3 to 25; the amount of quartz being highest in stabilised dunal sands. In some of the beach rocks, the aragonite peaks are frequently encountered showing 4 to 15% relative abundance. The feldspars are almost negligible in these rocks. The miliolites are characterised by 80 to 95% of calcite and 4 to 6% of quartz. The aragonite peaks are scarce and are seen occasionally only in few inland obstacle deposits of much friable miliolites (Ambla, Bamanbor, Dungarpur, Piparla etc.). The coastal consolidated miliolites on the other hand do not show aragonite. The feldspars which range between 2 to 6% in miliolites suggest their derivation from the nearby trappean country. The diffractograms of stabilised sand dune samples characteristically show the presence of considerable amount of aragonite (4 to 8%) alongwith high magnesian calcite (5 to 25%). The amount of quartz is also considerably higher upto 20% and that of feldspar 5-10% in these sands.

The Mg% reflected by the deflection of 100 peak of calcite in each kind of the deposits is also of much significance. In beach rocks, the Mg% in calcite lies between 6% and 9% while in miliolites it is mostly around 3% and occasionally reaches upto

TABLE V.6 : X-Ray Diffraction Data of Quaternary Carbonate Deposits of Saurashtra

Sr. No.	Location	Ref. No.	Calcite d Å	Calcite %	Aragonite d Å	Aragonite %	Quartz d Å	Quartz %	Feldspar d Å	Feldspar %	Mg wt% in calcite
	BEACH ROCKS										
1	Arena	7	3.0178	98.28	--	--	3.3416	1.71	--	--	6.25
2	Baradia	12	3.0079	81.32	3.3759	15.38	3.3344	3.30	--	--	9.50
3	Diu	42	3.0079	94.23	--	--	3.3386	3.85	3.1754	1.92	9.50
4	Dwarka	47	3.0178	88.23	3.3885	8.24	3.3264	3.53	--	--	6.25
5	Gosa	59	3.0278	97.30	--	--	3.3510	2.70	--	--	3.50
6	Kadwar	73	3.0079	99.11	--	--	3.3264	0.88	--	--	9.30
7	Porbandar	140	3.0178	97.56	3.3885	1.46	3.3264	0.97	--	--	6.25
8	Veraval	193	3.0281	91.16	3.2666	4.65	3.3403	3.26	3.2090	0.93	3.50
	MILIOLITES										
[a]	**Coastal**										
9	Aniyali	6	3.0278	96.48	--	--	3.3403	3.52	--	--	3.50
10	Arena	7	3.0278	96.77	--	--	3.3264	3.23	--	--	3.50
11	Diu	42	3.0278	88.00	--	--	3.3386	8.00	3.1754	4.00	3.50
12	Gopnath	58	3.0278	97.01	--	--	3.3386	2.98	--	--	3.50
13	Khara Khetar	84	3.0278	90.00	--	--	3.3386	10.00	--	--	3.50
14	Mahuva	101	3.0178	93.10	--	--	3.3403	4.18	3.1754	2.72	6.25
15	Naip	120	3.0278	97.22	--	--	3.3386	2.77	--	--	3.50
16	Veraval	193	3.0278	96.08	--	--	3.3403	3.92	--	--	3.50
[b]	**Inland**										
17	Ambla	4	3.0178	72.35	3.3885	17.94	3.3264	5.98	3.1754	3.74	6.25
18	Anandpur	5	3.0178	91.75	--	--	3.3264	6.70	3.1754	1.55	6.25
19	Bamanbor	11	3.0278	92.09	3.3885	4.65	3.3264	1.40	3.2090	1.86	3.50
20	Chotila	31	3.0278	75.53	--	--	3.3386	13.83	3.1754	10.64	3.50
21	Dungarpur	46	3.0278	86.36	3.3885	6.82	3.3386	4.55	3.2203	2.27	3.50
22	Patan	133	3.0278	100	--	--	--	--	--	--	3.50
23	Patanvav	134	3.0178	91.51	--	--	3.3386	5.12	3.2318	3.37	6.25
24	Piparla	139	3.0178	81.01	3.3885	4.22	3.3386	8.02	3.2318	6.75	6.25
25	Rajkot	143	3.0278	72.22	--	--	3.3386	27.77	--	--	3.50
	STABILISED DUNES										
26	Dwarka	47	3.0178	42.37	3.3885	23.73	3.3264	6.78	--	--	6.25
			2.9882	27.12							15.30
27	Jafrabad	68	3.0178	53.28	3.3885	4.72	3.3403	31.50	3.2090	10.50	6.25
28	Navadra	123	3.0281	62.72	3.3885	3.48	3.3403	23.00	3.2203	4.88	3.00
			2.9980	5.92							14.00
29	Navibandar	124	3.0278	87.23	3.3885	7.45	3.3386	5.32	--	--	3.50
30	Veraval	193	3.0178	69.10	3.3759	7.54	3.3264	12.56	3.1754	10.80	6.25

* Ref. No. as per Fig.A

6%. In the stabilised dunal sands it reaches upto 15%, especially in those of Dwarka, resolving a separate peak for high Mg calcite around 2.9882 A^o d-spacing.

The aragonite and high magnesian calcite are metastable carbonate minerals and their presence in the deposits indicates their mineralogical instability. Accordingly the dunal sands and beach rocks are immature as compared to the miliolites. The same relation exists between inland miliolites and coastal/sheet miliolites. The beach rocks, of littoral to spray zone deposits containing large sized bioclasts, reveal that their diagenesis is relatively inhibited on account of the marine waters as compared to the mililites so typically formed under meteoric water conditions. Again the sheet deposits including the coastal dunes, were more in contact with the fresh water (meteoric & groundwater) than the obstacle deposits like the climbing dunes and falling dunes of inland areas. It is because of these factors the relative survival of unstable aragonite is seen in beach rocks, miliolites and stabilised sand dunes.

(e) T L STUDIES

The thermoluminescence (TL) study is of considerable use in earth sciences, especially the Quaternary deposits. The representative samples of beach rocks, miliolites and dunal sands were subjected to the thermoluminescence study by using a conventional TL glow curve recording system that throws a considerable light on the relationship between the various carbonate deposits of Saurashtra (Patel et al., 1992). The natural samples were powdered in agate mortar and 15–20 mg of 80–120 ASTM mesh fraction was loaded on the heater plate. The heating rate was kept at 200^{0} C/min. The TL glow curves for virgin samples (NTL) as well as natural powder irradiated with 1000 Rds B-dose of Sr^{90} source for three minutes (NTL + ATL) were also obtained. Finally after removing the NTL by heating, the natural powder was irradiated with same dose for the same time and glow curves (ATL) were obtained. The glow curves for NTL, NTL+ATL and ATL of the representative samples of beach rocks, miliolites and stabilised sand dunes from different parts of Saurashtra were superimposed to compare the TL glow peak intensities (Fig. V.4). The values for the glow peak temperatures and intensities for each sample were calculated and are presented in Table V.7.

The studies reveal the presence of prominent NTL and NTL+ATL glow peaks around 300^{0} C in beach rocks and miliolites and suggest the laterally precipitated calcite & aragonite in these rocks. However, their better resolution is seen in the glow curves of beach rocks in comparison to the miliolites, perhaps indicating the presence of higher Mg calcite and/or protodolomitisation (Johnson, 1960). The absence of NTL glow peaks in the dunal sands could be due to the solar bleaching of TL during the period of successive transportation and accumulation of the sediments (Sankaran et al., 1980). The presence of Mg impurities in the crystal lattices deflects the TL glow peaks of calcite (Nambi & Mitra, 1978). This is also observed in the TL glow curves of the carbonate deposits of the study area in concordance to the XRD results discussed earlier.

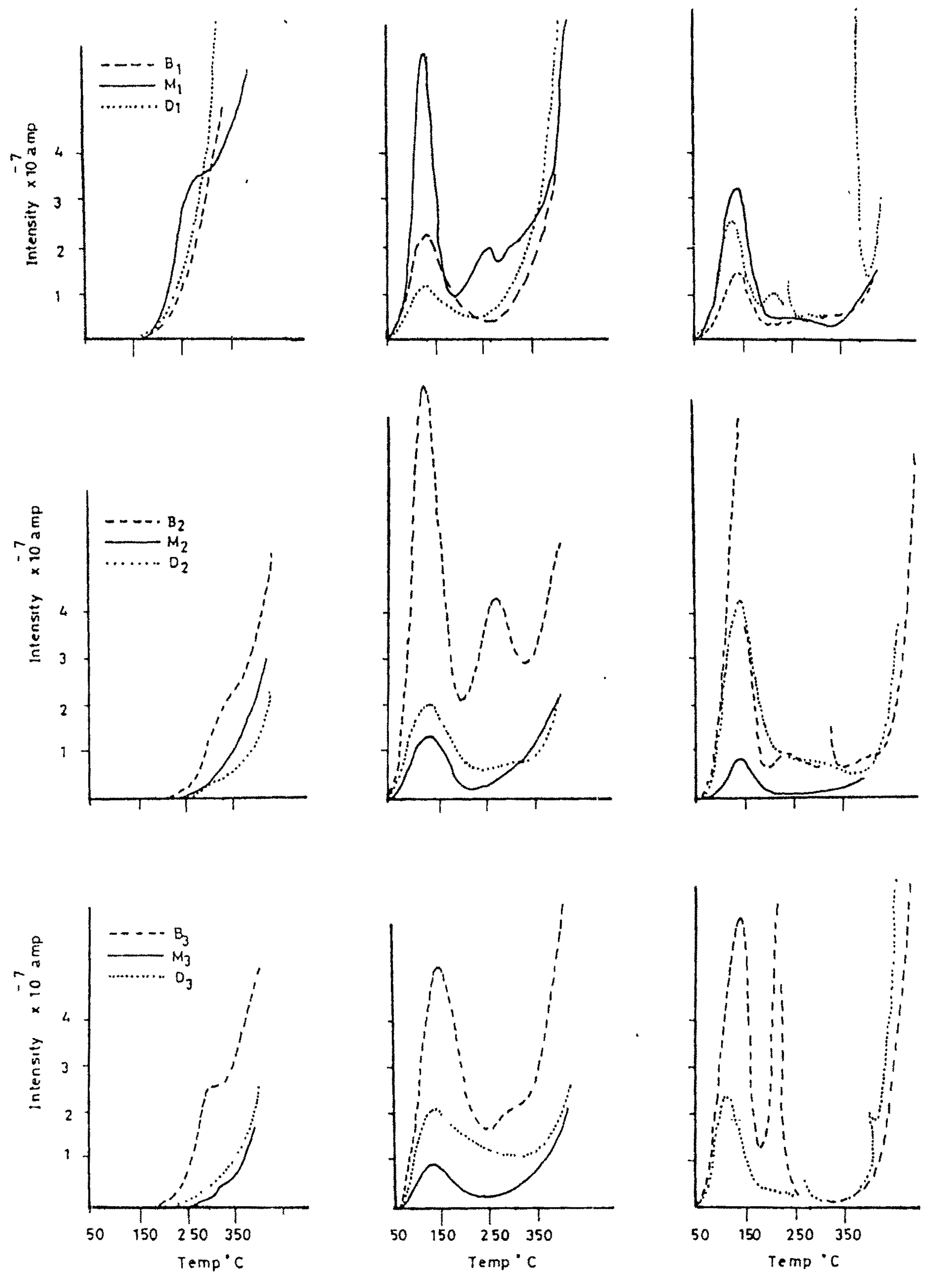


FIG. V.4. TL GLOW CURVES OF BEACH ROCKS (B) MILIOLITES (M) & STABILISED SAND DUNES (D)

TABLE V.7 : TL Glow Peak Temperatures and Intensities of Quaternary Carbonate Deposits of Saurashtra

Location	NTL Temp. ^{o}C	NTL Intensity $\times 10^{-7}$ amp	NTL + ATL Temp. ^{o}C	NTL + ATL Intensity $\times 10^{-7}$ amp	ATL Temp. ^{o}C	ATL Intensity $\times 10^{-7}$ amp
BEACH ROCKS						
Baradia (B1)	--	--	150	2.10	150	1.50
					260	0.40
Gosa (B2)	300	2.00	140	8.60	140	3.70
			285	4.10	230	1.00
					300	1.65
Kadwar (B3)	320	2.60	145	5.10	140	6.10
			300	2.10	210	4.80
MILIOLITES						
Adityana (M1)	330	3.30	140	5.85	130	3.00
			280	1.80	240	0.50
Dungarpur (M2)	--	--	140	1.30	130	0.85
					245	0.20
Piparla (M3)	330	0.50	140	1.05	130	1.20
					238	0.20
SAND DUNES						
Dwarka (D1)	--	--	140	1.10	130	2.40
					220	1.00
					260	1.30
					350	6.80
Jafrabad (D2)	--	--	140	1.90	130	4.10
			320	0.70	230	1.00
					300	0.85
Tarapur (D3)	--	--	140	2.10	130	2.35
					270	0.60
					370	0.40
					400	2.20

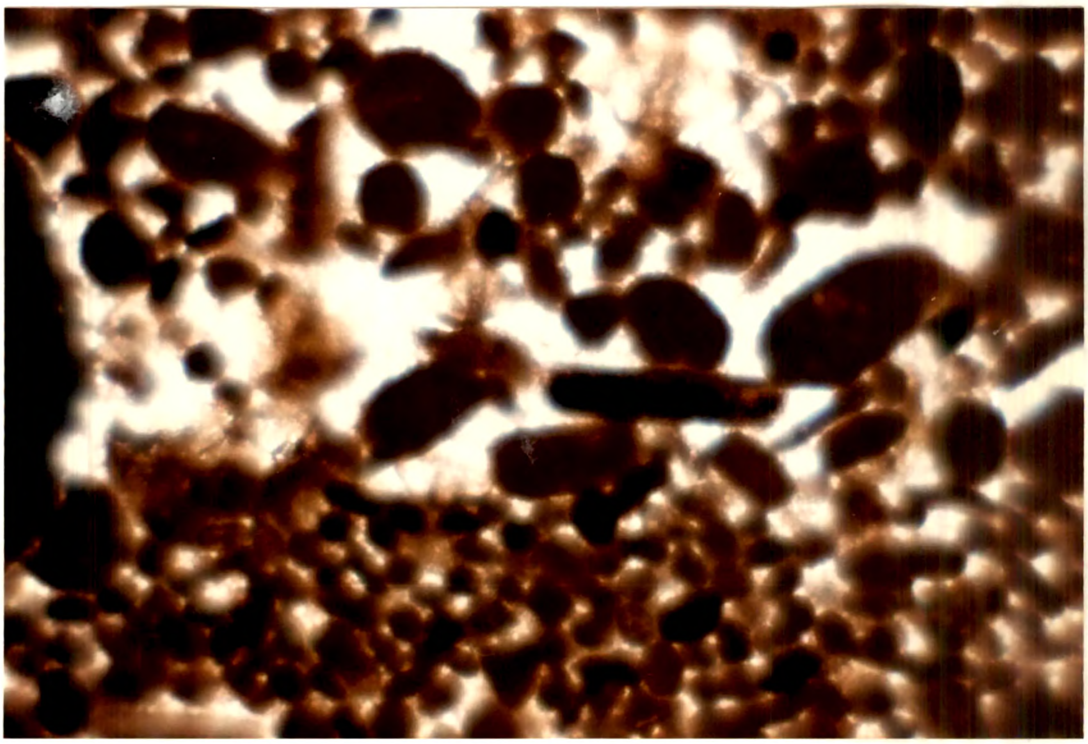
(B) TEXTURAL STUDIES

(f) SIZE AND SHAPE OF SEDIMENTS

The beach rocks and miliolites, as stated earlier, comprise various allochems & detrital grains cemented together by calcareous cement (aragonite/ calcite). On account of the calcareous nature of their constituents and cement, they are not suitable for mechanical or chemical treatment of disintegration and thus are not ideal for conventional granulometric analyses. Alternatively for the miliolites, the author has followed the procedure adopted by Krumbein (1935), Rossenfeld et al.(1953), Friedman (1958) and Hotzl (1966) by measuring the longest apparent diameters of various bioclasts and peloids in thin sections as they form the doubtless initial sediments in these rocks. The beach rocks being very much heterogenous (sizewise & shapewise), are ignored for such studies. However, the hand specimens and thin section studies of beach rocks reveal the size of their constituents in general varying from few mm to as big as 1.5 cm or even more, to group them as calcirudites after Grabau (1904).

The thin sections of miliolite from individual locality show better sorting or rounded to well rounded organogenic sands. The detritals, on the other hand, are very poorly sorted in size and shape indicating their bimodal nature. They occasionally show alternate medium and fine grained laminae and parallel & imbricated arrangement of elongated grains to form the distinct laminations (Plate V.16). Such features are also observed by Glennie (1970) in other desert deposits of the world, and are formed by the selective wind sorting.

Plate V.16



Photomicrograph showing alternate coarse and fine sand laminations in miliolite (PPL, 60X)

Table V.8, 9 & 10 clearly show that the size of the various bioclasts and peloids in miliolites vary from 0.12 mm to 0.5 mm to designate them as calcarenites of Grabau (1904). Again to obtain the trend of grain size variation in these rocks from South Saurashtra coast to inland areas, the average length of the bioclasts viz. foraminifera, molluscan shell fragments, bryozoa, echinoid spines and coralline algae, and peloids were plotted against the distance from coast along three sections namely AA′ (Porbandar – Rajkot), BB′ (Mangrol – Chotila) and CC′ (Diu – Chamardi), after projecting the nearby localities on a respective section (Fig. IV.3 and V.5 to V.7).

The data shows that, there is an overall decrease in the grain size from SW to NE – the prominent palaeowind direction. A close relationship between the grain size and topography along these sections has also been noticed. It is seen that the northeastward fining of the various constituents is erratic especially in the areas adjacent to hilly terrain. On the windward slope of the hills the size is relatively coarser than that of the leeward side. The topographic highs have acted as barriers to the southwesterly miliolitic sand laden winds to deposit the coarser sands on windward side of these hills to form climbing or echo dune deposits. The relatively finer particles then after crossing the crestal portion through the wind gaps deposited on leeward side to occur as falling dune deposits. Again, the occurrence of heterogenous sized particles within the individual domain of windward and leeward deposits suggest that

TABLE V.8 : Average length of Bioclasts and Peloids in Miliolites along Section A-A'

Sr. No.	Location	Dist. from coast (km)	Ref. No.*	Foram 1	Shell frag. 2	Bryozoa 3	Echinoid spines 4	Coralline algae 5	Peloids (mm) 6
				Bioclasts (mm)					
1	Porbandar	1.00	140	0.25	0.30	0.28	0.26	0.24	0.20
2	Navadra	1.20	123	0.26	0.33	0.25	0.25	0.26	0.22
3	Kukaswada	1.50	90	0.33	0.36	0.28	0.25	0.21	0.24
4	Gosa	2.00	59	0.25	0.28	0.28	0.23	0.25	0.23
5	Adityana	12.00	1	0.23	0.30	0.25	0.22	0.21	0.27
6	Bhanvad	35.10	13	0.31	0.29	0.21	0.22	0.28	0.23
7	Gop (Jam)	40.44	57	0.23	0.30	0.24	0.22	0.26	0.18
8	Patan	45.00	133	0.31	0.38	0.21	0.23	0.22	0.19
9	Tapakeshwar	48.30	177	0.28	0.33	0.31	0.23	0.30	0.18
10	Rakka	77.20	146	0.23	0.25	0.26	0.22	0.24	0.18
11	Khatiya	80.11	85	0.25	0.28	0.24	0.23	0.23	0.21
12	Rajkot	110.00	143	0.25	0.28	0.18	0.23	0.17	0.20

* Ref. No. as per Fig.A

Fig. V.5

Grainsize variation along section A-A'

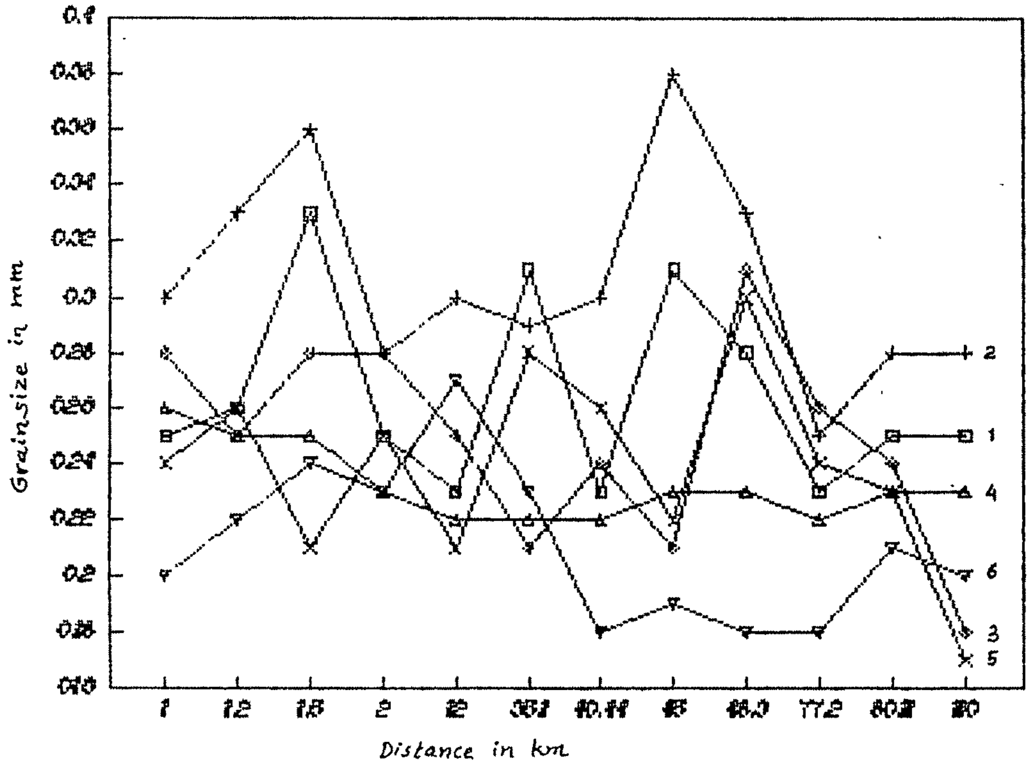


TABLE V.9 : Average length of Bioclasts and Peloids in Miliolites along Section B-B'

Sr. No.	Location	Dist. from coast (km)	Ref. No.*	Bioclasts (mm) Foram 1	Shell frag. 2	Bryozoa 3	Echinoid spines 4	Coralline algae 5	Peloids (mm) 6
1	Mangrol	0.50	107	0.31	0.35	0.28	0.25	0.27	0.22
2	Chorwad	0.80	30	0.39	0.48	0.39	0.49	0.48	0.35
3	Veraval	1.00	193	0.23	0.38	0.25	0.28	0.23	0.26
4	Arena	2.50	7	0.31	0.41	0.28	0.40	0.29	0.42
5	Pedhwada	11.10	136	0.25	0.32	0.26	0.24	0.28	0.22
6	Talala	17.80	175	0.30	0.38	0.33	0.30	0.25	0.20
7	Sasan	26.65	161	0.19	0.24	0.23	0.21	0.23	0.18
8	Anandpur	45.20	5	0.26	0.33	0.24	0.24	0.32	0.25
9	Dungarpur	50.30	46	0.33	0.73	0.42	0.35	0.33	0.30
10	Junagarh	53.00	72	0.31	0.38	0.40	0.32	0.36	0.27
11	Patanvav	55.00	134	0.23	0.25	0.19	0.19	0.28	0.19
12	Bamanbor	130.00	11	0.26	0.31	0.36	0.30	0.33	0.25
13	Chobari	144.50	28	0.22	0.26	0.19	0.22	0.25	0.21
14	Chotila	152.00	31	0.31	0.26	0.22	0.23	0.23	0.21

* Ref. No. as per Fig.A

Fig. V.6

Grainsize variation along section B-B'

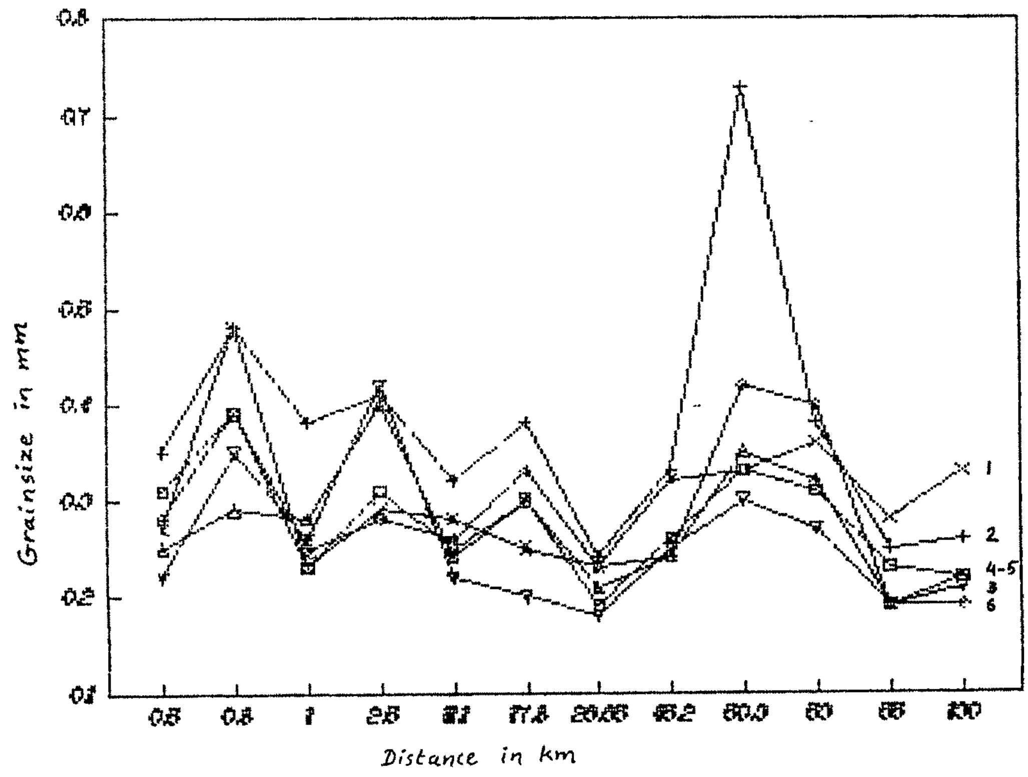


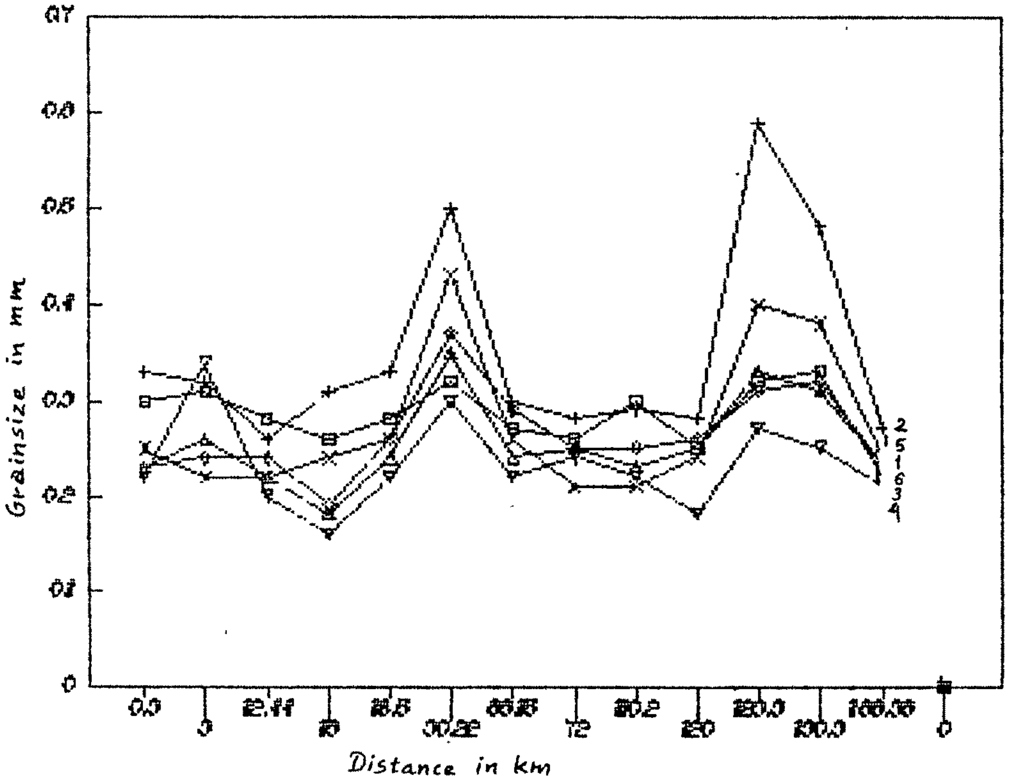
TABLE V.10 : Average length of Bioclasts and Peloids in Miliolites along Section C-C'

Sr. No.	Location	Dist. from coast (km)	Ref. No.*	Foram 1	Shell frag. 2	Bryozoa 3	Echinoid spines 4	Coralline algae 5	Peloids (mm) 6
				Bioclasts (mm)					
1	Diu	0.30	42	0.30	0.33	0.23	0.23	0.25	0.22
2	Badalpur	3.00	9	0.31	0.32	0.24	0.26	0.22	0.34
3	Dolasa	12.44	45	0.28	0.26	0.24	0.22	0.22	0.20
4	Una	16.00	183	0.26	0.31	0.19	0.18	0.24	0.16
5	Desar	18.50	37	0.28	0.33	0.26	0.24	0.26	0.22
6	Jafrabad	30.22	68	0.32	0.50	0.37	0.35	0.43	0.30
7	Mahuva	66.15	101	0.27	0.30	0.29	0.24	0.26	0.22
8	Naip	72.00	120	0.26	0.28	0.25	0.25	0.21	0.24
9	Juna Rajpura	110.20	144	0.30	0.29	0.25	0.23	0.21	0.22
10	Gopnath	120.00	58	0.25	0.28	0.26	0.25	0.24	0.18
11	Piparla	123.30	139	0.32	0.59	0.31	0.33	0.40	0.27
12	Chamardi	130.30	21	0.33	0.48	0.32	0.31	0.38	0.25
13	Mitli	166.36	112	0.22	0.27	0.23	0.23	0.24	0.21

* Ref. No. as per Fig.A

Fig. V.7

Grainsize variation along section C-C'



the deposition of miliolite sands by winds was not at a stretch, but they were deposited there in instalments under variable energy conditions in span of time.

As the stabilised sand dunes are very loosely cemented, they can be disintegrated very easily even by finger pressure and hence they have been analysed by conventional sieving method. A fixed weight (50 mg) of sample was subjected to sieving for 15 minutes using ASTM standard sieves at half phi (Ø) interval between -1 and 4 phi (i.e. 10 to 300 ASTM mesh). From the retained weight of individual sieves, the cummulative weight percentage were calculated for each phi fraction. The cummulative frequency curves were then prepared by plotting the particle size (Ø) against cummulative wt% on probability graph paper. These curves were used to determine various statistical parameters like Graphic mean (Mz), Inclusive graphic standard deviation (σ- I), Inclusive graphic skewness (SK_I) and Graphic kurtosis (K_G), following Folk & Ward (1957).

The graphic mean (Mz) gives the average grain size in phi value. The inclusive graphic standard deviation (σ- I) is a measure of the degree of sorting and reflects prolonged effect of a particular mode of transportation and deposition. This degree of sorting is decided from the following Ø values of σ- I.

< 0.35	Very Well Sorted	(VWS)
0.35 - 0.50	Well Sorted	(WS)
0.50 - 0.71	Moderatly Well Sorted	(MWS)
0.71 - 1.00	Moderatly Sorted	(MS)

1.00 – 2.00	Poorly Sorted	(PS)
2.00 – 4.00	Very Poorly Sorted	(VPS)
> 4.00	Extremly Poorly Sorted	(EPS)

The inclusive graphic skewness (SK_I) shows the characters of the coarse and fine tails of a grain size frequency curve and thus suggest the impact of mode of transport on the sediments. Their range is as under :

+1.00 to +0.30	Very Fine Sksewed	(VFS)
+0.30 to +0.10	Fine Skewed	(FS)
+0.10 to –0.10	Nearly Symmetrical	(NS)
–0.10 to –0.30	Coarse Skewed	(CS)
–0.30 to –1.00	Very Coarse Skewed	(VCS)

The graphic kurtosis (K_G) represents the peakedness of the grain size distribution. It is a ratio of the central portion of the frequency curve to that of the coarse and fine tails. The nature of the grain size distribution is inferred from the following values of kurtosis:

< 0.67	Very Platykurtic	(VPK)
0.67 – 0.90	Platykurtic	(PK)
0.90 – 1.11	Mesokurtic	(MK)
1.11 – 1.50	Leptokurtic	(LK)
1.50 – 3.00	Very Leptokurtic	(VLK)
> 3.00	Extremly Leptokurtic	(ELK)

The eigen vectors V_1 and V_2 were then recalculated following Sahu (1983) for multigroup linear discrimination of their depositional environments by using the values of statistical parameters thus obtained for these deposits. The values of the various statistical parameters and eigen vectors are given in Table V.11. In general these statistical parameters for the stabilised dunal sands clearly reveal the followings:

(a) The mean size (Mz) values for more than 70% of the dunal samples show a range between 2 and 4 Ø indicating their fine to very fine sand size while the others, especially those of Dwarka - Veraval coast, showing less than 2 Ø Mz value suggest their medium to nearly coarse grained nature.

(b) There is a progressive fining of the sediments from Dwarka - Veraval coast to Kadwar - Gopnath coast (NW to SE) perhaps related to the variation in the energy conditions - higher towards the Dwarka coast.

(c) The value of inclusive graphic standard deviation (σ_I) lie between 0.35 to 0.92 phi suggesting overall well sorted to moderately well sorted nature of the sediments.

(d) The inclusive graphic skewness (SK_I) values fluctuate from +0.20 to -0.30. The majority (75%) of the samples show nearly symmetrical to fine skewed and only occasionally coarse skewed nature suggesting their deposition by the currents of moderate velocity.

(e) The grain size distribution curves are mostly mesokurtic (K_G 0.9 to 1.11) and subordinately leptokurtic (K_G 0.69-0.82) or platykurtic (K_G 1.12 to 1.25). These clearly reveal that the dunal sands of Saurashtra have been deposited by southwesterly onshore winds mostly with moderatly fluctuating wind velocities.

TABLE V.11 : Statistical Parameters from Granulometric Analysis of Stabilised Sand Dunes of Saurashtra

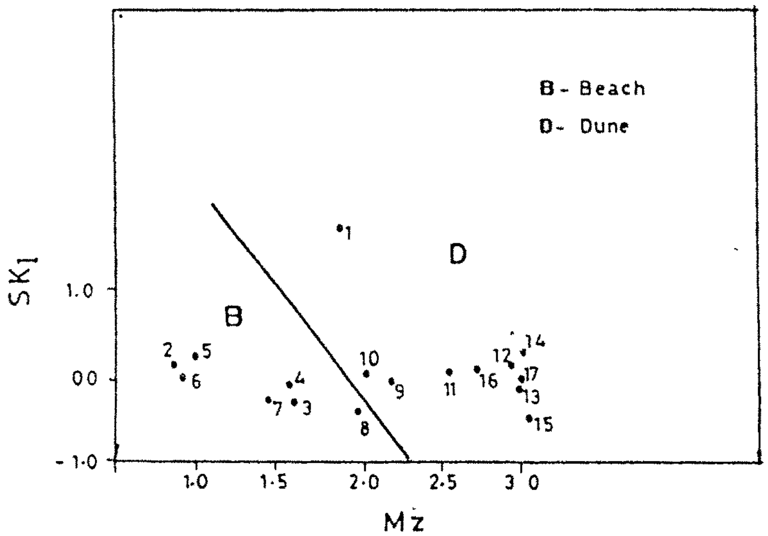
Sr. No.	Location	Graphic Mean M_z	Incl. Gr. Std. Dev. σ_I	Incl. Gr. Skewness Sk_I	Graphic Kurtosis K_G	Eigen vectors V_1	V_2	Remark
[a] Dwarka - Veraval coast								
1	Dwarka	1.96	0.47	+ 1.69	0.99	2.36	1.37	WS, FS, MK
2	Navadra	0.83	0.44	+ 0.13	0.91	1.13	0.78	WS, FS, MK
3	Harshad	1.65	0.47	- 0.12	0.82	1.40	0.86	WS, CS, PK
4	Porbandar	1.64	0.64	- 0.003	0.92	1.59	0.88	MWS, NS, MK
5	Navibandar	1.07	0.61	+ 0.26	1.25	1.56	1.07	MWS, FS, LK
6	Madhavpur	0.89	0.91	+ 0.09	1.06	1.50	0.70	MS, NS, MK
7	Chorwad	1.53	0.63	- 0.35	1.04	2.01	0.90	MWS, CS, MK
8	Veraval	2.03	0.92	- 0.24	0.69	1.76	0.62	MS, CS, PK
[b] Kadwar - Gopnath coast								
9	Kadwar	2.22	0.82	- 0.08	1.01	1.99	1.00	MS, NS, MK
10	Kodinar	2.10	0.48	- 0.005	0.98	1.74	1.11	WS, NS, MK
11	Diu	2.61	0.32	+ 0.04	1.12	1.97	1.44	VWS, NS, LK
12	Ahmadpur Mandvi	2.94	0.49	+ 0.11	0.95	2.19	1.31	WS, FS, MK
13	Jafrabad	2.98	0.58	- 0.18	1.07	2.20	1.33	MWS, CS, MK
14	Mahuva	3.15	0.36	+ 0.13	0.94	2.21	1.42	WS, FS, MK
15	Juna Rajpura	3.27	0.42	- 0.46	1.08	2.33	1.29	MS, VCS, MK
16	Jhanjhmer	2.74	0.42	+ 0.17	1.64	2.38	1.88	WS, FS, VLK
17	Tarapur	3.10	0.66	+ 0.02	1.02	2.36	1.31	MWS, NS, MK

In order to understand the influence of the depositional environments, the various plots were prepared using the statistical parameters obtained for these deposits. The plots of mean size (Mz) against inclusive graphic skewness (SK_I), following Folk & Ward (1957) suggest that the majority of the samples fall in dune field while a few samples fall in the beach domain indicating their close affinity to the high energy beach sands (Fig. V.8 a). The same relation was obtained when the values of inclusive graphic standard deviation (σ_I) were plotted against those of inclusive graphic skewness (SK_I) after Friedman (1979) (Fig. V.8 b). Again these observations are further supplemented when the eigen vectors V_1 and V_2 - calculated after Sahu (1983) were plotted for multigroup discrimination of depositional environments in the field of optimal discrimination plane bounded by V_1 and V_2 at the angle 74.4° (Fig. V.9).

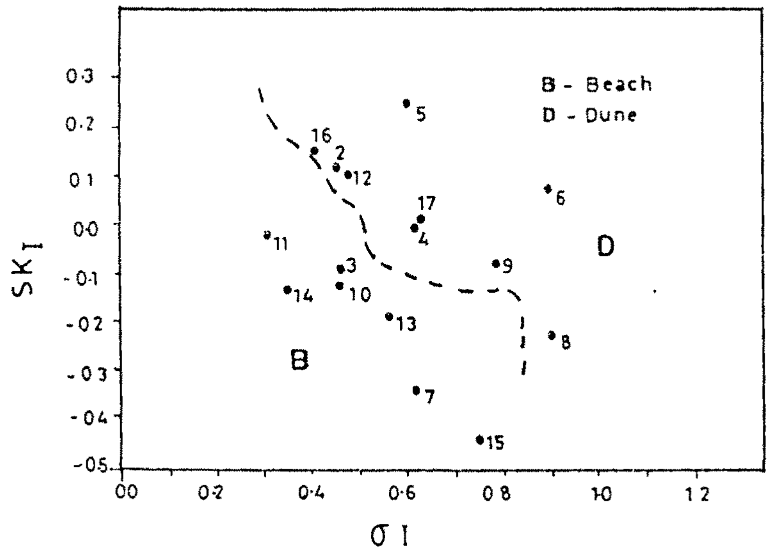
The proximity of the dunal sands to the beach sands substantiates their derivation from the latter to occur then as the coastal dunes and thus support the field observations.

(g) S E M STUDIES

The ultrastructures in beach rocks and miliolites including the cement growth have been studied from their polished slabs (slightly etched) alongwith the surface textures of the quartz grains present in these deposits, using the JEOL JSM-T300 Scanning Electron Microscope (SEM) after vaccum coating of gold over them.



(a) After Folk and Ward (1957)



(b) After Friedman (1979)

FIG. V. 8 POSITION OF STABILISED SAND DUNES (1 to 17) IN BEACH AND DUNE FIELDS

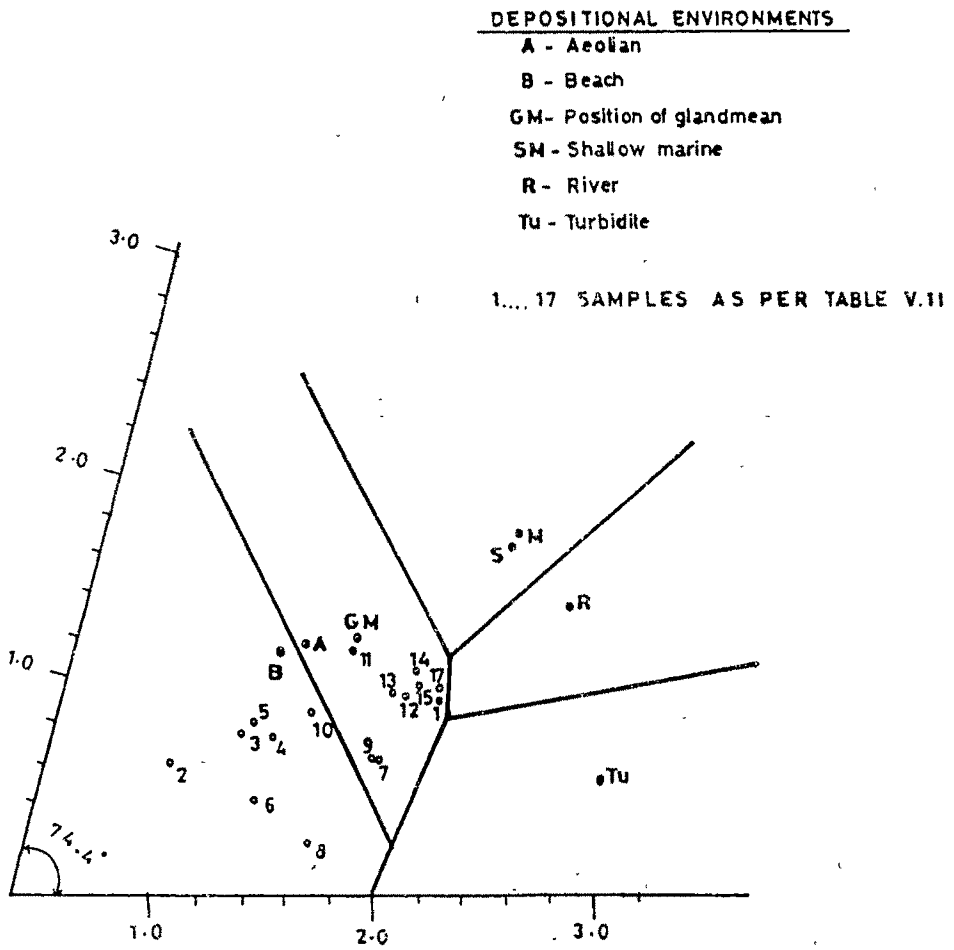


FIG. V. 9. POSITION OF STABILISED SAND DUNES FOR MULTIGROUP DISCRIMINATION OF DEPOSITIONAL ENVIRONMENTS (After Sahu , 1983)

The SEM studies of beach rocks (Dwarka, Baradia & Porbandar) suggest the presence of atleast two generations of aragonitic cements between various constituents. The first generation micritic cement possesses poorly developed tiny aragonite plates whereas that of second generation is characterised by long and elongated aragonite fibers (Plate V.17 a & b). Both these cements in beach rocks suggest their precipitation in active intertidal/ beach environment (Moore, 1973; Davies & Kinsey, 1973; Milliman, 1974; Scoffin, 1987 etc.).

On the other hand, the aragonite cement was not detected in any of the miliolite samples and their place has been taken by fine meniscus & drusy calcite cements as clearly seen in the miliolites of Harshad, Adityana, Veraval, Dungarpur, Piparla etc. The precipitation of these cements between two constituents commences from the calcareous substrates (allochems) with almost equant tabular calcite crystals suggesting the low magnesian nature of cement (Plate V.17 c & d). Such calcite crystals often show single step growth (Plate V.17 e), thus substantiating their precipitation by mild solutions in meteoric environment (Bennema & Gilmer, 1973; Morse & Mackenzie, 1990).

The scanning of some of the allochems, especially the foraminiferal test from the miliolites shows progressive loss of their surface ornaments from the coastal areas (eg. Veraval, Somnath, Mangrol, Porbandar) to inland areas (eg. Patan, Junagarh, Chotila, Chobari, Sanosra). This perhaps suggest their rolling and polishing during the aeolian transportaion (Plate V.17 f).

Explanation to the Plate V.17 (a to e)

(a) First generation aragonite cement around quartz grain in beach rocks

(b) Fibrous aragonite cement in beach rock

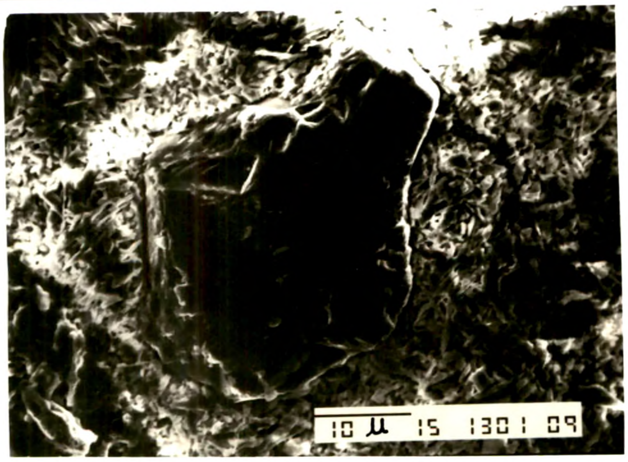
(c) Growth of calcite cement on calcareous substrate in miliolite. Note the absence of cement precipitation on quartz grains (q)

(d) Equant tabular growth of low Mg calcite cement in miliolite

(e) Single step growth in low Mg calcite cement in miliolite

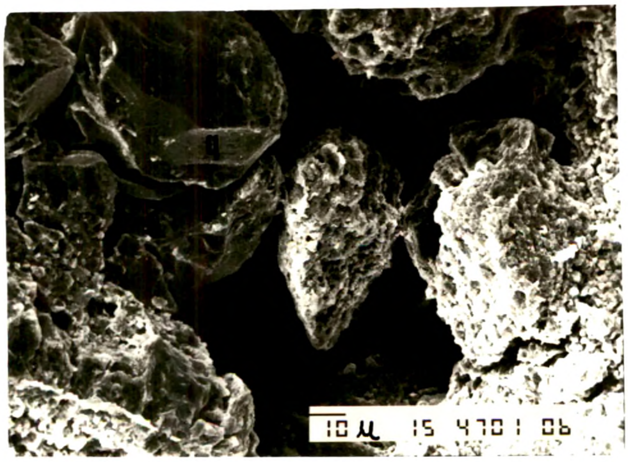
Plate V.17 (a to e)

SEM micrographs of Quaternary carbonate deposits of Saurashtra



a

b



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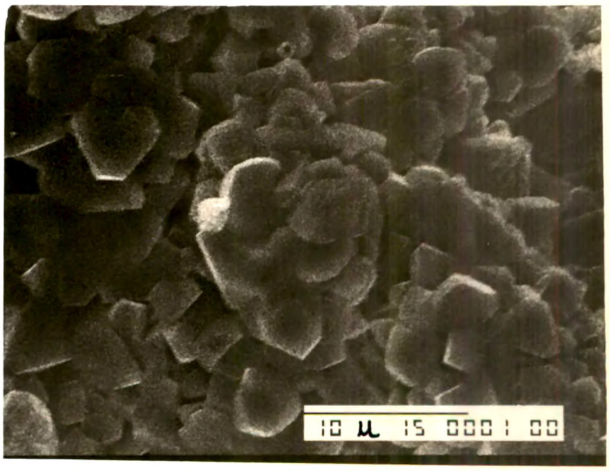

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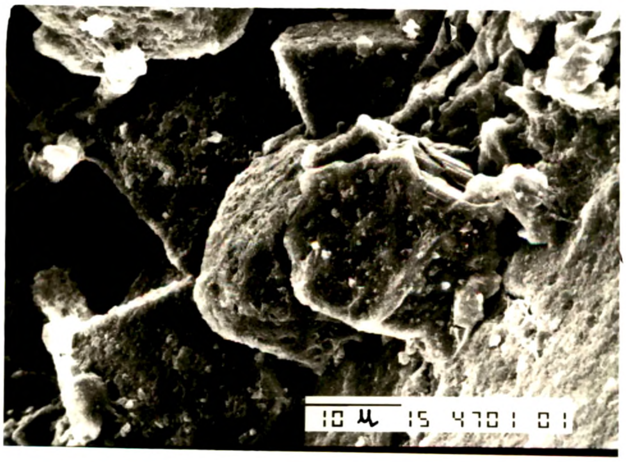


e

Explanation to the Plate V.17 (f to h)

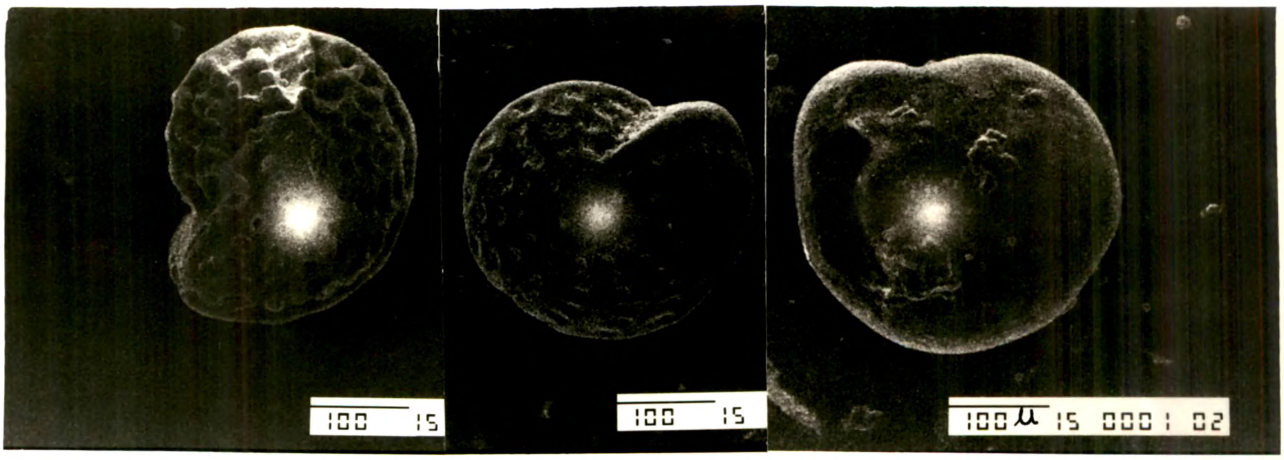
(f) Foraminiferal tests showing loss of ornamentation with increase in distance of transport from coast (1) to landward areas (2 & 3). (1) Somnath, (2) Junagarh and (3) Chotila

(g) Vadoid in miliolite showing downward growth of cortices with increase in crystal size

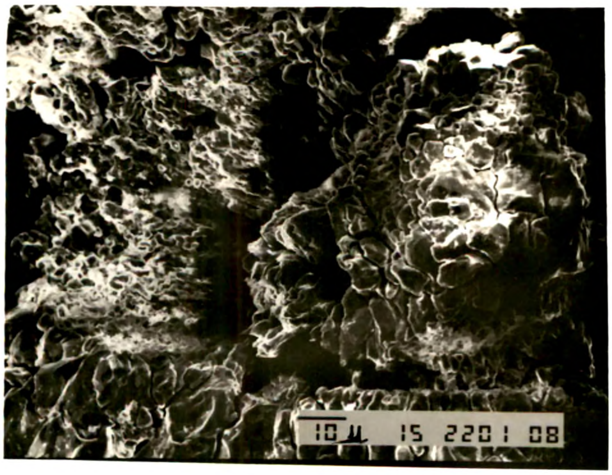
(h) A cortex of vadoid showing higher frequency of enfacial triple junctions between calcite crystals

Plate V.17 (f to h)

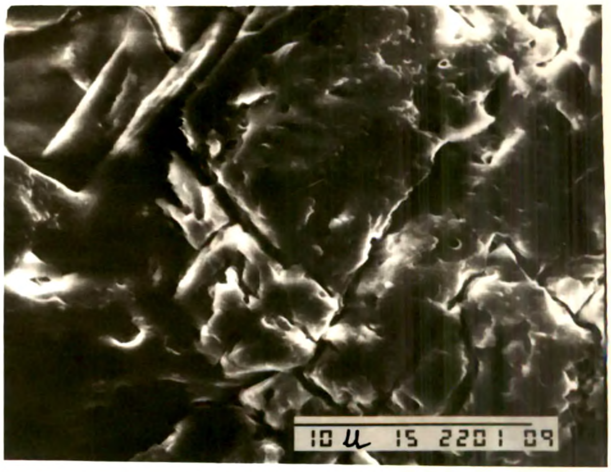
SEM micrographs of Quaternary carbonate deposits of Saurashtra



f



g



h

Explanation to the Plate V.17 (i to l)

(i) Chemical etching on quartz grain from beach rock

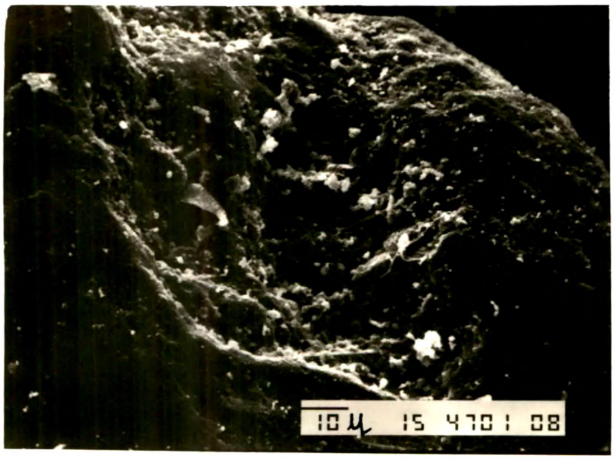
(j) Quartz grain from miliolite showing curved faces and polished nature

(k) Quartz from miliolite showing graded arcs and upturned cleavage plates

(l) Initial precipitation of calcite cement (c) in stabilised dune sediments

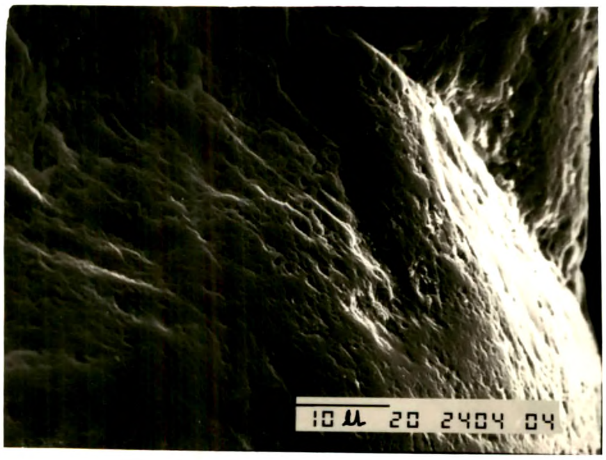
Plate V.17 (i to l)

SEM micrographs of Quaternary carbonate deposits of Saurashtra

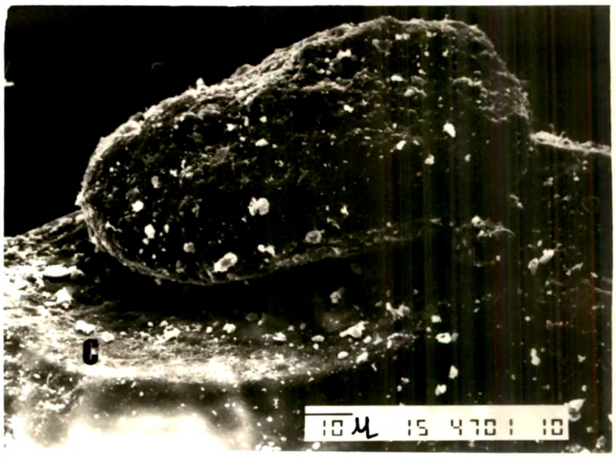


i

j



k



l

The SEM studies of some of the coated grains, especially the vadoids in miliolites, show their alternate micritic & microsparitic cortices, both made up of low Mg calcite with downward thickening (Plate V.17 g). A closer view of one of such cortex shows high frequency of enfacial triple junctions between calcite crystals (Plate V.17 h), suggesting their formation by precipitation from $CaCO_3$ solution and not due to neomorphism of originally aragonitic ooids (Bathurst, 1971). This substantiates the formation of the vadoids encountered in miliolites, under vadose meteoric diagenetic conditions. The cement mineralogy ascertained from their ultrastructures under SEM is thus in agreement with their thin sections and XRD studies.

The SEM photomicrographs of quartz grains from beach rocks of Baradia, Gosa, Veraval and Kadwar areas exhibit randomly oriented 'V' shaped indentations with straight or slightly curved grooves. This suggests their formation in high energy coastal regime under turbulent aqueous conditions (Krinsley & Donahue, 1968). The chemical etching as encountered on some of the quartz grains perhaps suggests the action of chemically active fluids during their diagenesis (Plate V.17 i).

The study of quartz grains from the coastal (Harshad, Porbandar, Veraval & Mahuva) as well as inland (Junagarh, Patanvav, Tapkeshwar & Chobari) miliolite exposures of the study area shows their bimodal nature. One, that occurs with curved faces and well rounded, polished nature which on closer view shows graded arcs, upturned cleavage plates and meandering ridges, and the other angular to subangular with conchoidal fractured faces (Plate V.17 j & k). The former indicate their aeolian transport while the latter, though occur in subordinate amount, suggest their derivation from fluvial regime. The SEM studies of quartz grains from some of the miliolite deposits of Saurashtra by Agrawal & Roy (1977) and Agrawal et al. (1978) also support their aeolian nature.

The scanning of some of the stabilised dunal sands (Veraval, Ahmadpur Mandvi & Jafrabad), at their grain contacts, show scattered precipitation of fine calcite suggesting the development of early cement in shallow vadose condition (Plate V.17 l).