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Sedimentological and Mineralogical Investigation of Beach Sediments of a Fast Prograding Cuspate Foreland (Point Calimere), Southeast Coast of India

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Abstract: Beach sediments from the Point Calimere coast are studied for composition and for deciphering their origin and mode of deposition. The sediments are medium to fine sand. Heavy mineral suits are pyroxenes, amphiboles, muscovite, staurolite, ilmenite, sillimanite, zircon and garnet. The presence of pyrite under XRD indicates chemical precipitation under anoxic conditions. Quartz, orthoclase and oligoclase are lighter minerals identified under XRD. SEM micro-morphological features of quartz grains show both high wave and low energy conditions chemical actions. The conchoidal features, breakage blocks are inherited from the source itself before its deposition at Point Calimere while vast majority of chemical features like etch vs, precipitation features etc originate after deposition.

Key words: Grain size, heavy minerals, XRD, SEM, quartz micro morphology

INTRODUCTION

Study of coastal ecosystem has attracted many researchers of the world. Grain size parameters provide an insight in to the nature and the energy flux of the multivarious transporting agents and their purview of depositional environment. This helps in understanding the various processes effecting erosion and deposition. Differentiation of depositional environments has been carried out based on size distribution of sedimentary particles (Mason and Folk, 1958; Hodson and Scott, 1970). The constituent composition of the sediments, particularly the heavy mineral concentration, helps in unraveling the provenance of the deposits. Surface texture of sand sized quartz grains with SEM technique has emerged in to a major approach for interpreting sedimentary environment and transport mechanism (Krinsley and Funnel, 1965; Margolis and Krinsley, 1974; Krinsley and Doorakamp, 1973; Krinsley and McCoy, 1977; Krinsley and Marshall, 1987) and differentiating various sedimentary environments such as littoral, aeolian, glacial and digenetic origin (Krinsley and Donahue, 1968; Coch and Krinsley, 1971; Krinsley and Smalley, 1973; Krinsley and McCoy, 1977; Krinsley and Doorkamp, 1973; Moral Cardona *et al*., 1996; Bull, 1981; Mahaney, 1995; Mahaney *et al*., 1996). Hence the aims of the present study are to document the characteristics of grain size, total heavy mineral content, mineralogical assemblages and morphological variation of quartz grains from the Point Calimere-cuspate- coast, thereby to characterize the sediment source in view of the peculiar environment set up.

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MATERIALS AND METHODS

Study Area

The study area between Akkrapallivasal and Serthalaikkadu lagoon (10° 20' N -10° 25'N latitude and 79° 25' E -79° 50' E longitude) is a fast emerging typical cuspate foreland located at the southern periphery of Cauvery delta and formed primarily by the deposition of sediments by the southward longshore currents and wave activities both from Bay of Bengal and the Palk Bay. The nearest major sediment source for this coastal segment is the Vellar and Coleroon river which is the major/main distributary of Cauvery, respectively joining the sea at about 225 and 250 km north of Point Calimere. Other than Coleroon, non of the other distributaries of Cauvery such the proper Cauvery, Arasalar, Vettar, Vennar and Maharajasamudram do not contribute much sediments to the coast as they are mainly irrigation canals with low water supply from the main stream. The small ephemeral streams and rivulets (Agniyar, Paminiyar and Mullipalam) joining the northern and north western Palk Bay do contribute to a limited extend as they drain mainly the Cuddalore sandstone, the recent coastal alluvium and other coastal uplands. The Cauvery river drains primarily the Precambrian gneisses and charnockites in the upstream and the Cretaceous of Trichirappalli in the downstream.

The study area is one of the least studied areas of the Tamil Nadu coast pertaining to sediment characteristics and its mineral composition. Mohan *et al*. (2000) reported the sediment texture of a few samples of the Point Calimere coast while studying the regional distribution of sediments in Palk bay region. The prominent coastal geomorphic features of the study area consists of a mud and sand flats with scrub, beach ridges, low dunes, wide beaches between Vedaranyam to Point Calimere and mangroves, salt marshes, saltpans, swales, spit, barriers and lagoons between Point Calimere and Serthalaikkadu lagoon (Shanti Devi and Rajamanickam, 2000). The tidal flat extends northward from the Palk Bay up to 4 km. Sand dunes with varying heights of 2-4 m are distributed all along the coast behind high water line extending up to 1 km inland. In the tidal flat area, sand dunes with 2-3 high are seen. West of Point Calimere the Serthalaikkadu and Mullippalam lagoons run in an east west direction and separated by narrow spit. The northern Tamil Nadu coast beyond Vedaranyam is a typical wave dominated but microtidal coast. In contrast, the Point Calimere coast is a moderate to low wave energy coast while the Palk Bay is a highly wave sheltered but still a microtidal coast as the tidal wave in the southern Tamil Nadu vary from 0.5-1.0 m. The nearshore bathymetry along the Bay of Bengal coast north of Point Calimere is relatively steep, straight and parallel to the coast. The alignment of the 5 m depth contour is more or less parallel to coast at a distance of 1 km from the shore but the 10 m contour from Vedaranyam is considerably farther away and cut across the Palk Strait and hence the 10 m depth contour considerably arrest the propagation of major currents from the Bay of Bengal into the Palk Bay. During NE monsoon from October to January extreme wave conditions occur due to severe tropical cyclone and hence the predominant transport of sediment by longshore current is towards south.

Beach sediments from 9 stations (Fig. 1a, b) were collected from Point Calimere coast in 2004. At each station, sediment samples were collected up to a depth of about 50 cm from the berm environment using hand auger, were initially washed and dried for further laboratory analysis. After coning and quartering, carbonates, organic matter and ferruginous coatings were removed from the samples by treating it with 1:10 HCl, 30% by volume H_2O_2 and $SnCl_2$, respectively. The dried samples were then sieved at a +GF+ DIN 4188 sieve shaker for 15 min at half Phi interval (Folk and Ward, 1957). The grain size parameters like Graphic Mean (M_z), Inclusive Graphic Standard Deviation (σ_1), Inclusive Graphic Skewness (Sk_1) and Graphic Kurtosis (K_G) were determined using the package Grain. Heavy mineral separation was carried out using bromoform (Milner, 1962) and the count percentage of heavy minerals from selected samples was calculated. The 1-2, 2-3 and 3-4 Ø size heavy fractions were mounted on slides (~250 grains) and counted under polarized light using a Leitz

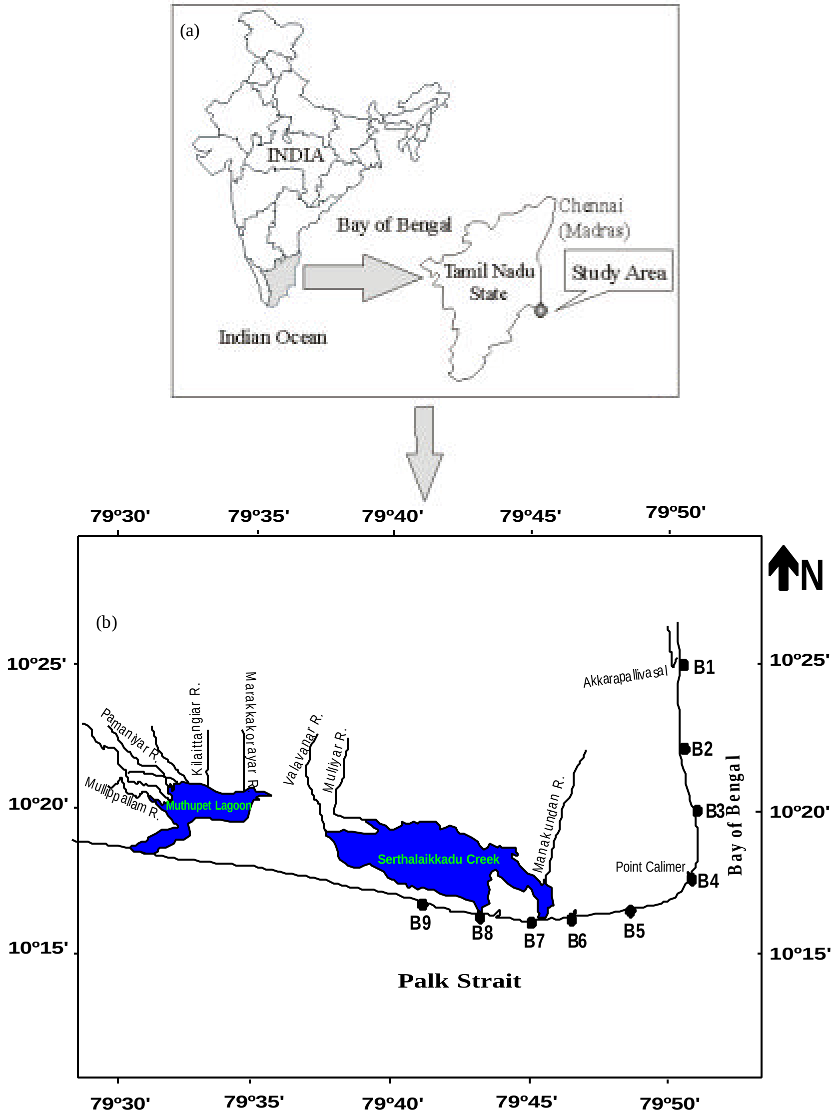


Fig. 1: Study area

orthoplan microscope by the line counting method (Galehouse, 1969). X-ray diffraction for heavy and light minerals using Phillips (X'pert pro) powder diffractometer, (2 Ø min^{-1} from 10° to 45°) and SEM studies using Jeol-JSM 5600 LV microscope on quartz samples were also carried out to understand the surface micromorphology. For convenience of discussion and in relation to the existing coastal oceanographic parameters, the study area is divided into three sectors; i.e., sector I consists of stations 1 to 3 representing a relatively high energy oceanographic conditions of Bay of Bengal, sector II with stations 4-6 denote the mixed regime of both Bay of Bengal and Palk Strait, while sector III (stations 7-9) indicates a typical Palk strait conditions with very low energy condition associated with flat beaches.

RESULTS

Granulometry

The phi mean size of sediments ranges from 1.35 to 2.46 ϕ; the average being 2.02 ϕ (Table 1). Except samples 1 and 8, the remaining samples are unimodal in nature with peak at 3 ϕ (Fig. 3). The bimodal distribution in samples 1 and 8 show their peaks at 1.5 and 3.5 ϕ for sample 1 and 1.75 and 3 ϕ for sample 8. The cumulative curves of the sediments show an over all dominance of saltation load than suspension and traction loads in all the three sectors (Fig. 4). The truncation points between traction and saltation occur predominantly around 1, 1.5, 2 and 2.5 ϕ and that of saltation to suspension is at 3 and 3.5 ϕ for all the sediments. Visher (1969) had put forward the effectual usage of log probability using the three types of sub population viz., the traction, saltation and suspension. The sorting of sediments vary from very well to moderately sorted nature (0.26 - 0.79 ϕ; av. = 0.44 ϕ) which may be due to the fluvial influx or wave convergence (Table 1). The skewness of the sediments is closely related to the environmental energy (Duane, 1964). The presence of negative skewness implies high energy and winnowing action whereas the positive skewness is attributed to lower energy condition with accumulation of finer sediments. In the study area both negative skewness and positive skewness are observed. These indicate that the area has been subjected to both high energy

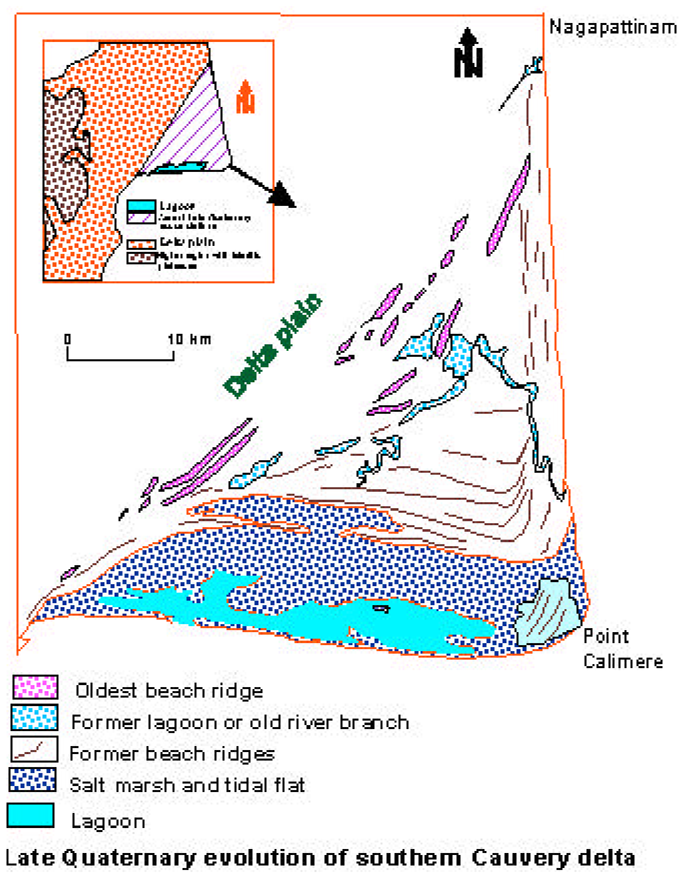


Fig. 2: Evolution of barriers at Point Calimere and along the Muthupet-Serthalaikkadu lagoon segment

Table 1: Textural parameters of Vedaranyam coast

Sample No.	Mean	SD	SK	KU	FP
1	1.99	0.79	-0.26	0.95	0.05
2	2.33	0.32	0.50	0.82	1.17
3	2.46	0.33	-0.22	0.89	1.71
4	2.31	0.26	0.47	0.59	1.53
5	2.03	0.31	-0.28	2.55	1.01
6	1.96	0.32	-0.25	0.89	1.05
7	1.90	0.35	-0.53	0.87	0.58
8	1.35	0.77	0.18	0.72	0.00
9	2.05	0.57	-0.32	1.81	-0.43
Average	2.04	0.44	-0.07	1.12	0.74

SD: Standard Deviation, SK: Skewness, KU: Kurtosis, FP: First Percentile

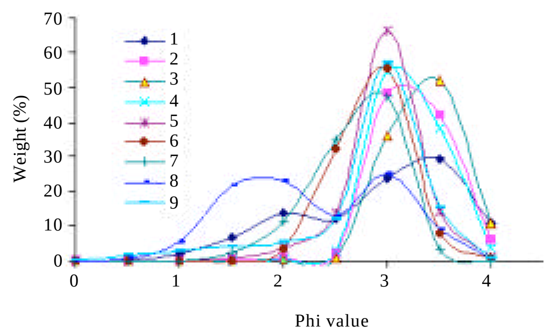


Fig. 3: Frequency curves of beach sediments

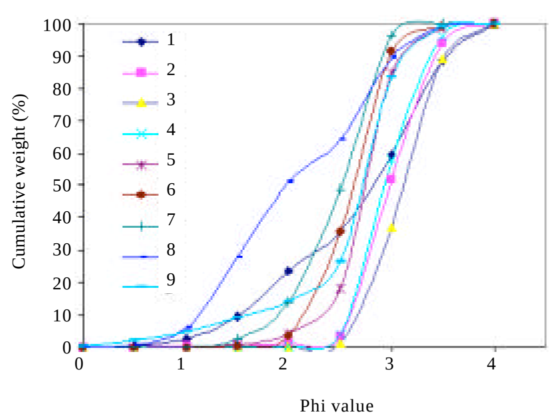


Fig. 4: Cumulative curves of beach sediments

winnowing action and low energy accumulation of finer sediments. The mean size vs skewness plot (Fig. 5) clearly show the dominance of inland and beach. Some of the samples 2, 4 and 8, indicate the offshore.

Heavy Minerals

Weight percentage of heavy minerals varies from 3.84 to 25.44% (av. (9.48%); samples 6-8 register a significant enrichment of heavy minerals (Table 2). The heavy mineral suite consists

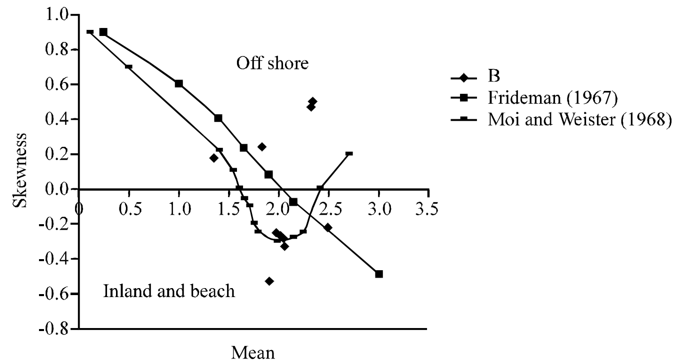


Fig. 5: Scatter plot of mean vs skewness

Table 2: Heavy mineral weight percentage of Vedaranyam coast

Sample No.	Heavy mineral wt. (%)
1	2.75
2	8.14
3	6.75
4	9.76
5	3.84
6	25.44
7	21.30
8	11.69
9	2.50

mainly of uneconomical minerals such as muscovite, hornblende, glaucophane, sillimanite, chlorite, opaques, staurolite, actinolite, zircon and epidote. Muscovite is highly enriched in the medium sands of sector I (94.20%) and II (85.11%) whereas other minerals are enriched in the fine and very fine sands (Fig. 6). Sillimanite is concentrated in appreciable amount in all fractions of the three sectors (Fig. 6). Hornblende content in the fine fraction ranges between 19.30 and 27.78%. Low concentration of hornblende is found in the medium sands of sector III. Appreciable concentration of actinolite is found in medium (0 to 16.67%), fine (5.56 to 8.77%) and very fine (2.5 to 12%) sand fractions in all three sectors. Significant zircon is found in fine and very fine sand fractions in sector I, very low percentage of zircon is recorded in very fine fraction in sector II while appreciable percentage of zircon is shown in medium and very fine fractions of sector III. The very well rounded zircon is wide spread in all sediments Glacophane is concentrated in appreciable amount in the fine and very fine sands of sector I and II, but only in fine fraction of sector III. Appreciable amount of hypersthene, chlorite, staurolite and opaque minerals are also present in all the three sectors. Kyanite and epidote are either least distributed or absent in some samples. Opaque, one of the widely distributed minerals along the Indian coast, is very negligible in sector I and II but is present up to about 10% in sector III.

Factor Analysis

The R-mode factor analysis is to identify the causes for the variation of the total heavy mineral distribution and its influences on the environment of deposition (Fig. 7). Factor I is influenced by actinolite, hornblende, hypersthene, sillimanite and zircon with high order of positive score whereas, muscovite, epidote and glaucophane shows negative scores. The factors of these minerals represent a dominant influence of mixture of low graded metamorphic rock and recycled sediments from alluvium. Factor II is represented by actinolite, chlorite, epidote, glaucophane, hornblende and staurolite with high positive scores while muscovite, hypersthene and zircon with negative scores. These mineral assemblages indicate derivation of sediments from Cuddalore sandstone, alluvium and igneous rocks along with recycled sediments. Factor III designates the presence of chlorite, hornblende, sillimanite

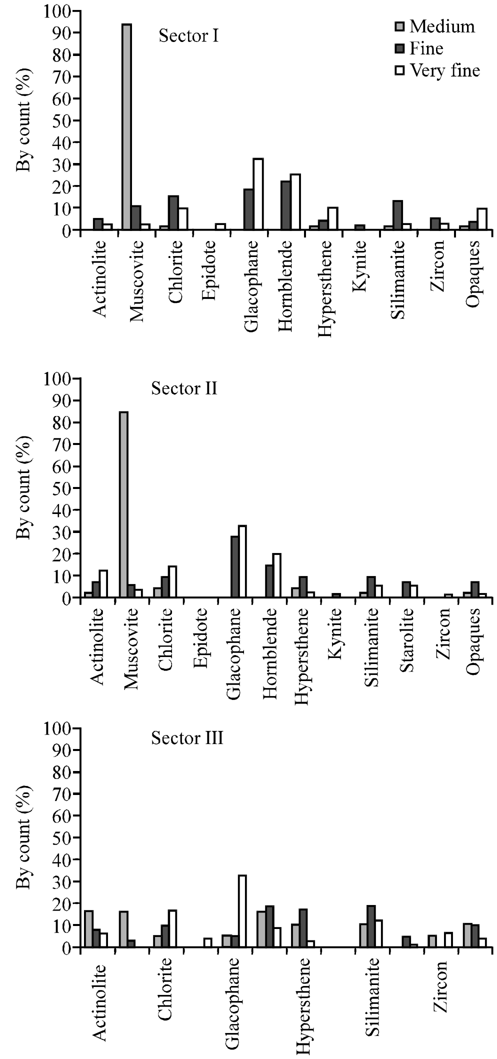


Fig. 6: Weight percentage distributions of heavy minerals

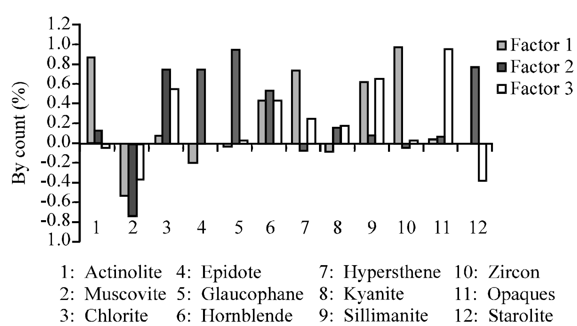
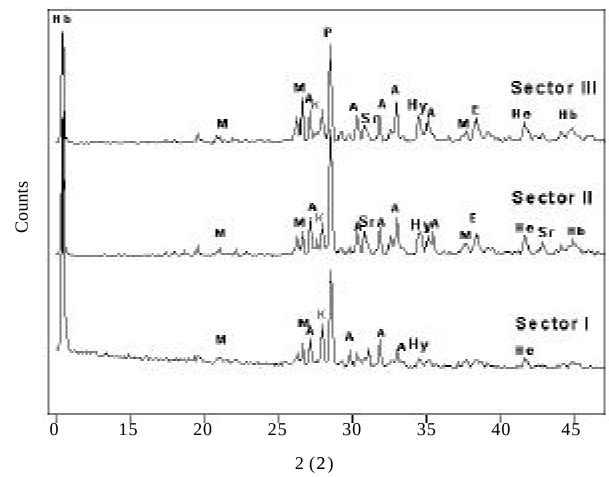


Fig. 7: R-mode factor analysis for total heavy mineral data

and opaque, with high positive scores while actinolite, muscovite and staurolite show negative scores. The factor of these assemblages designates the influence of low-grade metamorphic rock in addition to igneous rocks and recycled sediments.

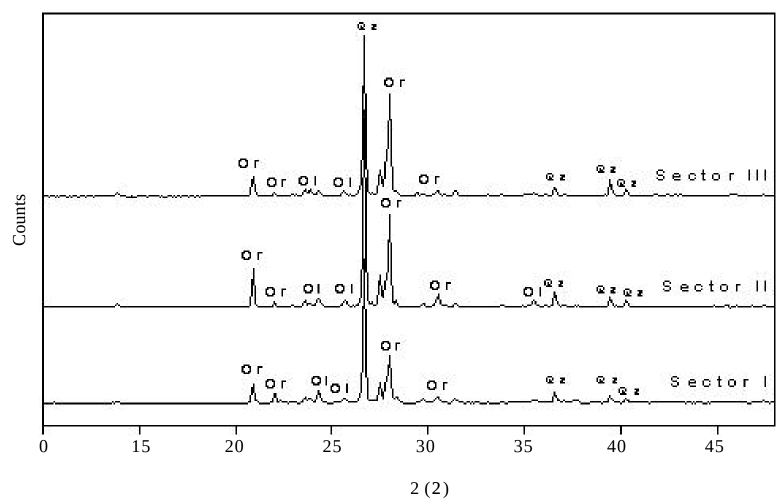
XRD of Heavy and Light Minerals

X-ray diffraction pattern of the heavy minerals of the three sectors show the presence of hornblende, muscovite, actinolite, kyanite, pyrite, hypersthene and hematite. In sector I staurolite and epidote are absent while in other sectors they are present (Fig. 8). X-ray diffraction patterns of the light minerals concentrate show the presence of quartz, orthoclase and oligoclase (Fig. 9) in all sectors, among which quartz occupies the major part.



A: Actinolit, M: Mouscovite, E: Epidote, P: Pyrite, S: Starolite, Hb: Hornblede, Hy: Hypersthene, He: Hematite

Fig. 8: X-Ray diffractrograms of representative heavy minerals concentrate of the three sectors



Qz: Quartz, Or: Orthoclase, Ol: Oligoclase

Fig. 9: X-Ray diffractrograms of light minerals

Sem of Quartz Grains

Micro-morphology of quartz grain surface is an indicator of transportation history of a sedimentary deposit. A variety of micro-features are observed on quartz grains of the study area. Conchoidal fractures are very commonly observed in all the sectors of the study area (Fig. 10 a, b, e; 11e, 12a, b, f). The broken surfaces of quartz grains show concave structures with varying size. Breakage blocks are recorded in a few grains (Fig. 10d, 12d) and are restricted to grain surfaces. Mechanically produced irregular pits are found in some grains (Fig. 10c, d, 11a, b, 12c). Impact v's are recorded on elevated surfaces of grains (Fig. 11d). Grooves are found very common in the quartz grains of this study area (Fig. 10c-e, 11a-d, 12c-f). In some cases, the grooves are modified by the fracture of weak planes and further modified by solution activities (Fig. 10a, 12 a). Etch vs are one of the dominant micro features found all the sectors and formed by chemical activity (Fig. 10d, e; 11c, 12c-f). Solution pits of crescent and rounded shape are found in quartz grains of sector II and III (Fig. 10 a, c-e, 11 a, c, d). Precipitation features are mainly authigenic origin's or adhering particles (Fig. 10a-e, 11a, d).

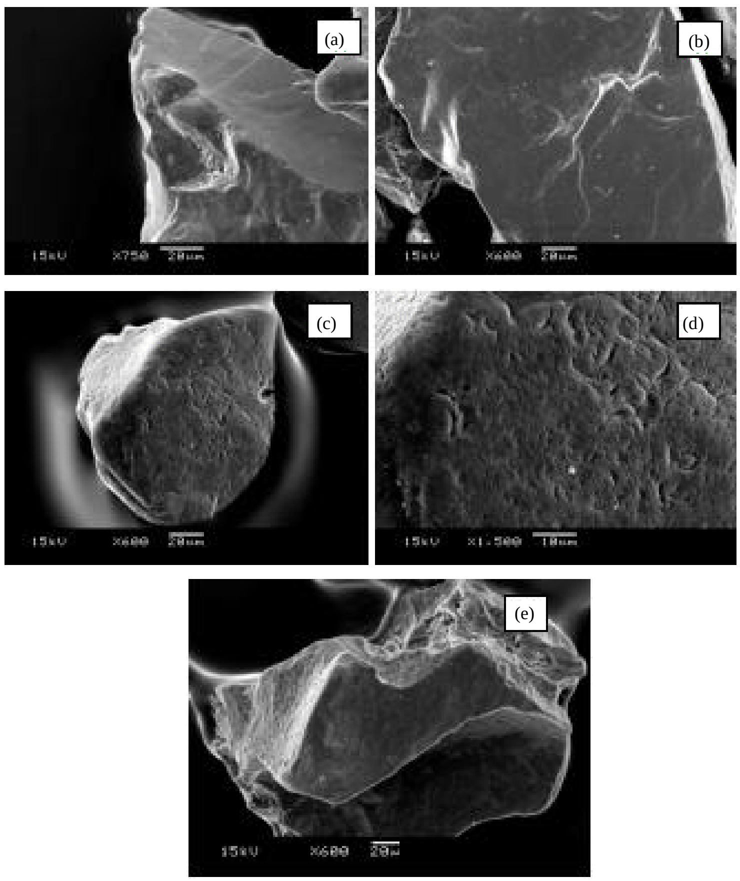


Fig. 10: SEM photos of representative quartz mineral grain -Sector I, (a) Irregular angular and conchoidal fracture, (b) Fresh conchoidal fractures and polished surface, (c) Sub rounded grain showing smooth edges, irregular impact marks, (d) Grain showing irregular marks, straight and curved marking and (e) Sub angular grains with conchoidal fracture and etchs

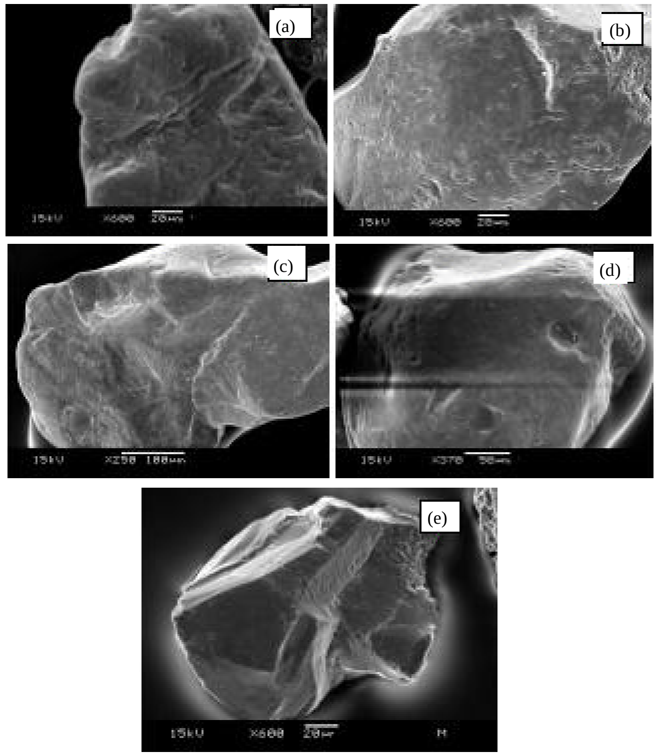


Fig. 11: SEM photos of representative quartz mineral grain - Sector II, (a) Irregular deep impact marks covered with silica precipitation, (b) Grain showing conchoidal fractures filled with silica precipitation and etchs, (c) Surface of the grain shows many curved impact marks and etchs, (d) Microphotograph showing irregular, many impact marks on the surfaces of the grain and etchs and (e) Sub-rounded grain shows smoothen out border due to precipitation

DISCUSSION

The cuspate foreland at Pont Calimere is one of fast emerging coastal landform, which is prograding at rate of 29 m year^{-1} (Ramasamy *et al*., 1998) primarily through sediments brought from the north by longshore currents. According to Loveson *et al*. (1990) the formation of several shoals, low bars, spits and the subsequent evolution of barriers at Point Calimere and along the Muthupet-Serthalaikkadu lagoon segment, west of Pont Calimere (Fig. 2) are due to heavy deposition of sediments brought by the southward moving longshore currents. Jena *et al*. (2001) reported that the 150 km long coastal stretch between Nagapatnam and Poompuhar has been severely eroded ranging from 150-200 m wide since 1963 and the materials are transported southward and deposited along the Palk Bay region. The net quantum of littoral sediment entering in to the Palk Bay from the Nagapatnam coast, according to Sanil Kumar *et al*. (2002), is 0.27×10^6 m^3. Hence, the fast growth of Point Calimere coast is due to material supplied from the coastal erosion consisting of late Holocene coastal alluvium, paleobeach ridges and dunes as well as recently supplied sediments from the Cauvery and Vellar rivers. However, in view of through sorting by waves and longshore currents, the range of sediments available in the study area vary from fine to very fine sands which resulted in the unimodality of frequency

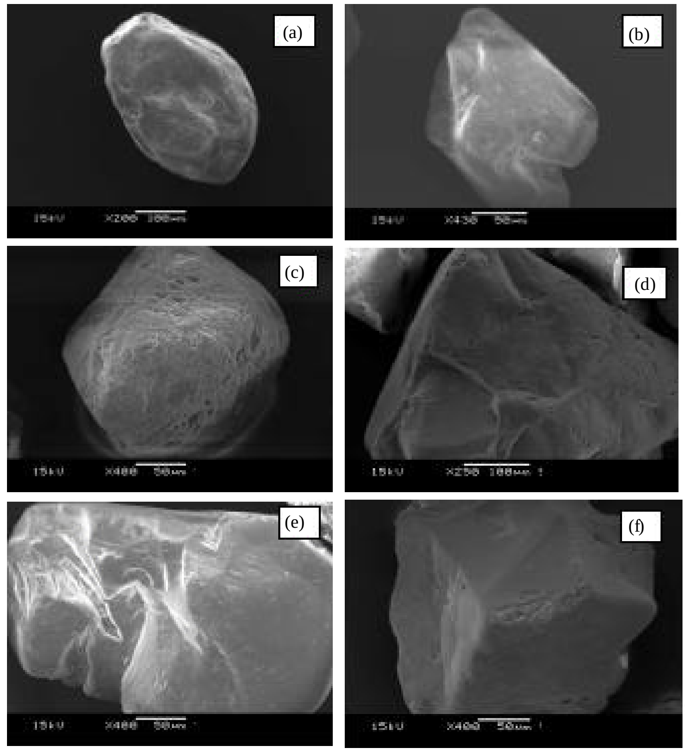


Fig. 12: SEM photos of representative quartz mineral grain - Sector III, (a) Crescent structures and pits produced by solution activity, (b) Conchoidal fracture and step like structures, (c) Sub-rounded grain showing irregular impact marks, (d) Conchoidal breakage showing smooth edges, grooves and impact pits, (e) Smoothed walls due to precipitation and (f) Blocky conchoidal breakage upturned plate and silica precipitation

curves (Fig. 3) and exhibiting moderate sorting. Coarse and medium sands are sparsely distributed. The exceptional bimodality of the frequency curves of samples 1 and 8 denote that some coarse sediment are added to the beach either nearby source or that the local oceanographic parameters effected a change to the sediments in these stations. Since the coast west of Point Calimere is one of low energy environment, the bottom clay bed is exposed at many places and the fine and very fine sands form only a thin carpet over the clay bed (Fig. 13).

The major mineral constituent of the beach sediments are quartz and feldspars. As the Cauvery deltaic coast north of Point Calimere undergoes severe erosion (Jena *et al*., 2001), it is expected that the longshore shore currents, particularly during the NE monsoon, bring primarily the lighter minerals to the study area leaving behind most of the denser heavy minerals as lag deposits resulting in the occurrence of thick placer deposits along the coast between Vellar and Karaikkal (Seralathan, 1979; Mohan, 1995; Chandrasekar and Rajamanickam, 2001). The faster growth of the Point Calimere coast (Ramasamy *et al*., 1998) implies that the waves and currents are unable to sort out the sediments resulting in the poor concentration of heavies in the sediments. It is known that any fast prograding coastal segments will have lower heavy mineral concentration. Muscovite is the only predominant mineral present in the medium sands of sector I and II which is a clear indication that the present coast is one of low energy prograding coast. On the other hand the sediments of sector III in

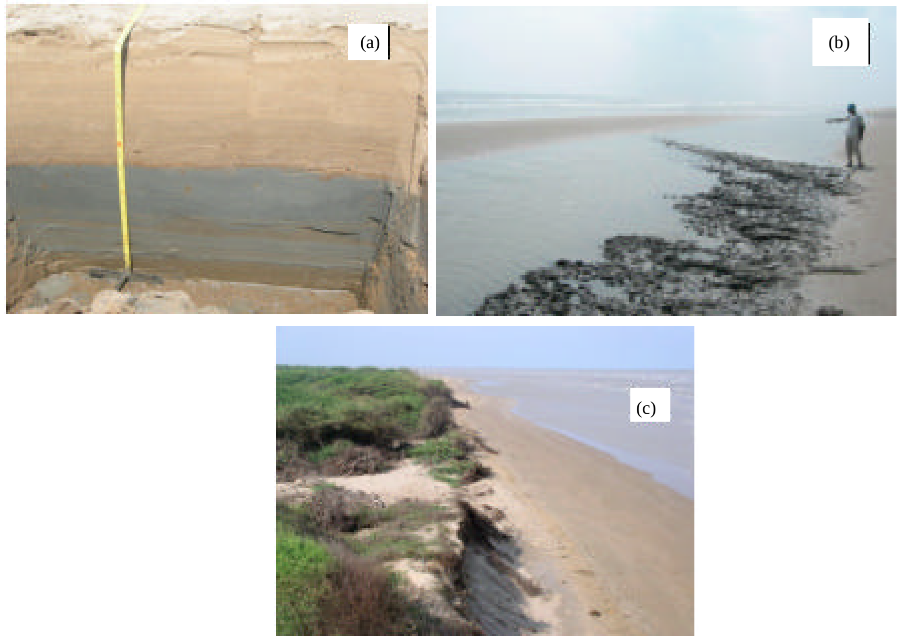


Fig. 13: (a, b, c) The bottom clay bed is exposed at many places and the fine and very fine sands form only a thin carpet over the clay bed

the Palk Bay coast, a much lower energy coast than sector I and II, reveals the presence of most of the minerals in the three sediment grades namely medium, fine and very fine sands. This indicates that a portion of the sediments of this sector could be derived through the ephemeral streams draining the costal alluvium and the Cuddalore sandstones from the western sides of Palk Bay. The variations in the heavy mineral suits are well exemplified by factor analysis as well which indicates a mixed source for the area. Factor I reflects the derivation of sediments from Cuddalore sandstone as well as low-grade metamorphic rocks. Factor II reflects the influence of recycled sediments from Cuddalore sandstone, alluvium, granite, granite gneiss and charnokites. Factor III represent the role of low-grade green schist facies, granite, granite gneiss along with recycled sediments in contributing the sediments.

The surface texture of quartz grains by SEM indicates a variety of forms formed by both mechanical and chemical activities. The quartz grain in sector I consists of irregular, angular surfaces and with fresh conchoidal fractures within the polished surfaces (Fig. 10a, b). Blocky conchoidal breakage patterns are developed due to intense action of high-energy environment in the surf zone which can be smoothen out with time by natural processes (Krinsley and Donahue, 1968). Being established that the present Point Calimere coast is one of very low to low wave activity, the conchoidal fractures would not have formed at the site of deposition due to local wave activity but developed elsewhere during their transport before deposition. Thus the predominant fresh conchoidal fractured quartz grains with high angularity indicates that the sediments might have either through recent fluvial supply and brought to the area by longshore currents or from the near by coastal alluvium and dune sediments which are subjected to severe erosion in the later part of 20th century (Jena *et al*., 2001). According to Higgs (1979) conchoidal fracture are characteristic of either glacial environment or crystalline sources. The abundance of conchoidal fractures in different sizes indicates that these quartz grains are derived from crystalline rocks. The highly smoothened conchoidal surfaces of quartz grain (Fig. 10-12) indicate that these grains are of recycled nature from the coastal alluvium.

Chemical features and precipitation features are common, along II and III sectors of the Point Calimere coast along with mechanical impact features. However, presence of combination of features such as impact V's, etch marks, small breakage blocks and controlled edges signify high grain impingement during sediment movement either in a marine or beach zone environment. In general the quartz grains of sector II are moderately smoothened, with deep groves whereas in sector III the grains bear more rounded surfaces with solution pits. Solution pits of crescent and rounded shape are found in quartz grains of sector II and III (Fig. 10a, c-e, 11a, c, d). As the nearshore of Palk Bay coast is very wide, shallow and with muddy beaches (<5 m depth up to 4 km offshore) and highly wave sheltered, even then conchoidal breakages are seen. Grooves and impact pits are product of high energetic sub-aqueous collision in a littoral environment (Mallik, 1992). They also develop in a high energy to turbulent fluvial environments. The presence of upturned plates with blocky conchoidal and impact structures is a clear indication that these are formed due to primarily by aeolian activities while the breakage blocks and parallel striations are the result of highly abrasive grain fracturing and or aeolian activity (Krinsley and Doorkamp, 1973). These are clear indications that these features are formed in the earlier phases of deposition on the northern side of Point Calimere coast. Further the presence of thick mangrove system along the banks of the two lagoonal system namely the Muthupet and Serthalaikkadu with high organic carbon in the sediments imparts an acidic nature to the sub-bottom, so chemical leaching of quartz grains predominate over mechanical action in sectors II and III. The XRD patterns of heavy mineral grains (Fig. 8) indicate the presence of predominant pyrite peaks which indicates that the environment is one of anoxic. The low wave activity leads only traction- rolling of sand grains on the beach and therefore majority of the quartz grain do not have any angularity but all were rounded or smoothened. Hence, smoothening of grain with pitted surface indicates high sub-aqueous solution activity in a calm low energy environment. Krinsley and Smalley (1973) and Krinsley and Doorkamp (1973) have stated that the surface texture of quartz grain from medium to low energy surf zone are of mechanical v-forms, which are produced by chemical etching of straight or slightly grooves; in addition there are texture of silica precipitation and solution. On the other hand in case of high energy surf zone the v-indentation is some what larger and deeper and dense. They are often found in combination of with small scale conchoidal breakage pattern. V shaped indentations are most frequently found on the grains of sub-aqueous environment. The rounded edges may be due to prolonged grain transport. Chemical process and low energy sub aqueous environment contribute to the above features (Fig. 10d, e; 11c, 12c, d, f). Small globular deposits seen on the quartz grain surfaces (Fig. 10a-e, 11a, d) might have deposited over the grains in the medium to low energy intertidal zone through periodic evaporation of inter-granular waters rich in saturated silica.

CONCLUSION

The present Point Calimere coast receives sediments primarily by longshore currents which are of recent fluvial as well as recycled -wave eroded -sediments of late Holocene ages. The sediments are primarily unimodal, fine to very fine sands. The constituent light mineral suit consists of quartz, orthoclase and oligoclase which are also evidenced in the XRD pattern. The total heavy content varies from 3.84 to 25.44% (av. 9.48%). The heavy minerals suit consists mostly of uneconomical category such as muscovite, glaucophane, sillimanite, chlorite, opaques, epidote, hypersthene, hornblende, actinolite, kyanite, zircon and staurolite. Most of these minerals are enriched in the fine and very fine sand than in the medium sand. The predominant muscovite attest a low energy set up. The presence of pyrite and hematite are indicated in the XRD pattern of heavy mineral grains in addition to other heavy minerals.

As the area is one of low energy coast quartz grains with high % angularity, impact Vs etc indicates that these mechanical features would have formed at the site of deposition but developed elsewhere. However, chemical features such as etch Vs, precipitation features are of local origin developed in a relatively calm environment.

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