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GRANULOMETRIC ANALYSIS & HEAVY MINERAL PROVENANCE STUDY IN THE CORE SEDIMENTS FROM THENGAPATTANAM ESTUARY, SOUTH WEST COAST OF INDIA

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Abstract: Granulometric analysis and heavy mineral distribution as proxies were used to investigate the depositional environment and provenance of sediments in the Thengapattanam estuary. The core sample was collected over a one-meter range, accompanied by sub samples at 4cm intervals, for a total of 25 samples. The bivariate plot was plotted with the data obtained from the study to find the depositional environment, which reveals that the estuary contains beach type sands. The sorting of the sediments ranges from moderately well sorted to well sorted. The presence of beach-type sediments indicates that the estuary is current-dominated, with constant sediment reworking under a micro-tidal regime. The odd samples were chosen from the 25 subsamples to study the heavy mineral variation in order to determine the source rock for the sediments and the heavy mineral potential in Thengapattanam estuary sediments. The average percentage of opaque minerals is 65.5 percent, followed by sillimanite > garnet > augite > kyanite > tourmaline > zircon> monazite. The presence of a higher average percentage of metamorphic minerals (sillimanite, garnet, and kyanite) in the sediments clearly indicates that they derived from high-grade metamorphic rocks.

Keywords: Granulometric analysis, Heavy mineral, Beach sediments, Thengapattanam estuary

1. INTRODUCTION

Paleo-environmental research gives us an insight into the major geological events that occurred in that area, such as marine transgression, regression and tectonism. The choice of proxy to investigate in order to reconstruct geological history can differ based on the objectives of the study.

Textural parameters of the grain size will help us to differentiate the depositional environments such as rivers, estuaries, beach and dune (Udden, 1914; Mason & Folk 1958; Friedman 1961, 1967; Moila & Weiser 1968; Passega 1957, 1964; Angusamy & Rajamancikam, 2007, 2006). Median is effective parameter to differentiate the depositional environments (Chandrasekar, 1992). Mohan & Rajamanickam, (2001) the core sediments of Mahabalipuram beach ridges and stated that resulted sedimentation shows fluvio-monsoonal conditions.

Granulometric analysis will provide us a window to differentiate the paleo-depositional environments (Folk & Ward, 1957). Grain size characteristics are influenced by the function of transporting and depositional agents such as rivers, streams, waves and currents, sea level oscillations, shoreline structure, winds, and other factors, as well as distance from the shoreline, distance from the source material, nature of the source material, and topography of the area. The objective of the grain size data was to better understand the micro level variations in depositional environments

Between Ennore and Kovalam, Chandrasekaran et al., (1996) attempted a textural analysis of beach sands. The study found that the sands range in grain size from coarse to fine and are widely distributed with fineness rising toward Kovalam and concluded that fluvial deposition in the coastal area is possible. Chandrasekar & Rajamanickam, (2002) looked into the grain size distribution in central Tamil Nadu and found that the median is the most important textural parameter for distinguishing between different depositional environments.

Anbarasu et al., (1994) has stated that grain size distribution analysis of the sedimentary particles formed by various soil types may be used to research the current coastal configuration and the paleo-coastal configuration in depth. The distribution of grains in the beaches is limited according to their grain size.

The nature of the protolith was discovered using trace elements found in river sediments from the Bistrita River in Romania (Maftei et al., 2018). The presence of REE in the crystal structure of muscovite indicates that the source is primarily mica schist, which is exposed by the supergene process in the provenance area. XRF, XRD, NIR, and Micro-Raman spectroscopy were used to determine the elemental composition of minerals. Maftei et al., (2019) assessed the ecological risk and spatial distribution of heavy metals in surface sediments of Tazlau River.

Maftei et al., (2020) employed micro-Raman spectroscopy to successfully distinguish polymorphic triplets such as kyanite-sillimanite-andalusite and anatase-rutile-brookite and to identify heavy minerals from Romania's Pianu valley.

The majority of heavy mineral studies were conducted to ascertain sediment provenience, since the origin of many heavy minerals is restricted to particular rock types. Heavy mineral suites can reveal a lot about the mineralogical makeup of a source area. Within a sedimentary basin regional and stratigraphic variations in heavy mineral suites can be used to infer sediment provenance differences.

As a result, heavy minerals can be used in sediment transport and weathering research as well as paleo-geographic studies. It is worthwhile to use them in paleogeographic reconstructions particularly in elucidating sediment transport pathways. Heavy minerals serve as an index for stratigraphic correlation of unfossiliferous strata. Angusamy & Rajamanickam, (2000) published on beach morphology and inferences from heavy mineral assemblages from Mandapam to Kanyakumari coasts on India's south east coast.

The current study area is in the estuarine environment, which is located on Tamil Nadu's south west coast, and the river that forms that estuary is the river Thamirabarani. Granulometric analysis and heavy minerals present in the sediments were used as a proxy to establish the depositional environment, tidal variations, and the source of sediments in the Thengapattanam estuary.

2. STUDY AREA

The proposed research took place in the Thengapattanam Estuary in Tamil Nadu's south west region. The Thamirabarani River, which flows through the Thoothukudi, Tirunelveli and Kanyakumari districts of Tamil Nadu, originates from the Western Ghats and then confluences in the Laccadive Sea near Thengapattanam, where it forms an estuary. For this study, a sedimentary Core was obtained at the latitude and longitude of 8014′ 16.6″N and 77010′ 11.4″E (Fig. 1). A 1m length core was collected using a 3-inch diameter PVC coring tube for grain size analysis. Following that, the core is sub-sampled every 4 cm for a total of 25 samples. The sub-samples were then sun dried.

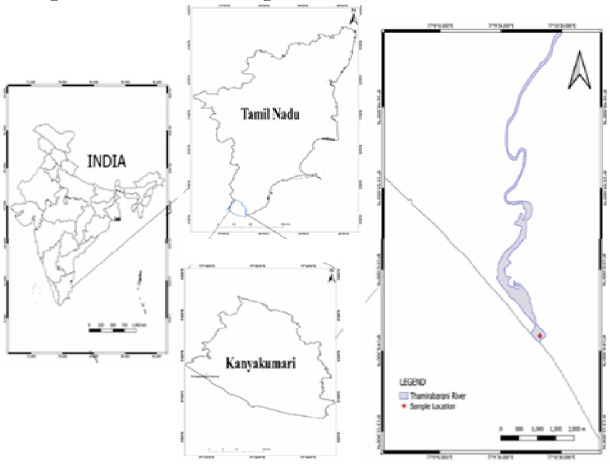


Figure 1. Thengapattanam estuary Sampling Site.

2. METHODOLOGY

2.1. Granulometric analysis

The dried sub-samples were coned and quartered for the granulometric analysis, and approximately 30g of samples were taken. The 30g samples were then treated with hydrogen peroxide to extract organic matter before being washed with distilled water and dried in a 65°C hot air oven. The sieve sets were shaken continuously for about 20 minutes in descending order of size using a Ro-tap sieve shaker (18, 25, 35, 45, 60, 80, 120, 170, 230, and Bottom). The sieved samples were weighed to an accuracy of 0.1g on a single pan electrified scale. Weight percentages and total weight were computed. (Folk & Ward 1957) suggested a method for calculating statistical parameters such as Inclusive Standard Deviation (I), Graphic Mean (Mz), Inclusive Graphic Kurtosis (KG), and Inclusive Graphic Skewness (SkI). The depositional environment and transportation mechanisms were deciphered using the statistical parameters obtained.

2.2. Heavy mineral processing

The samples must be coned and quartered before sieving with ASTM sieve meshes 120. Heavy mineral separation is done with the samples obtained in the 120 mesh. Bromoform ($CHBr_3$) is a chemical liquid that had been used in laboratory filtration process to separate low density minerals from high density minerals (heavy minerals). Heavy minerals collected through filtration are dried on a heated plate before being placed in glass with Canada balsam for microscopic examination.

3. RESULTS AND DISCUSSION

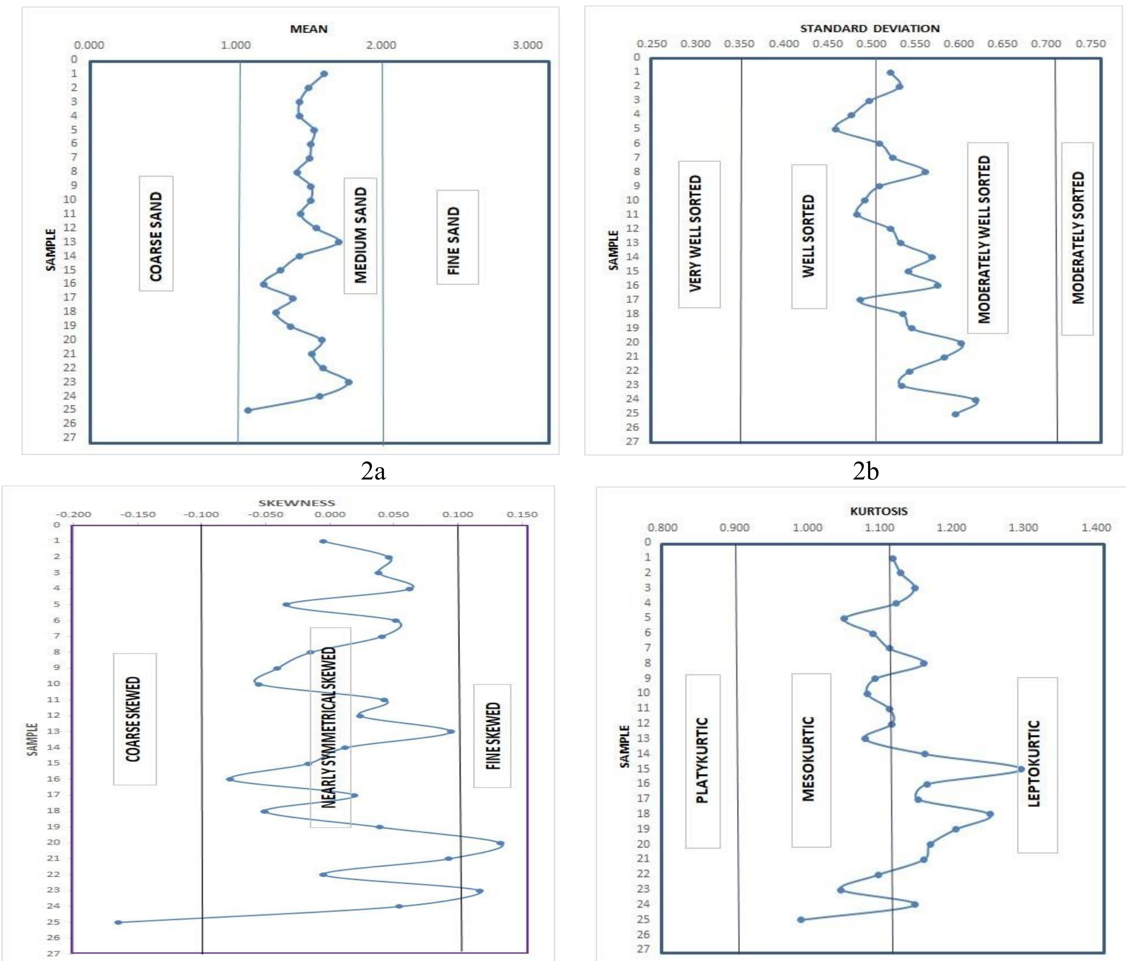
The cumulative frequency distribution is calculated for several parameters, including mean size, sorting, skewness, and kurtosis. Using the formulae proposed by (Folk & Ward 1957), the values of the textural parameters and grain size distribution of the samples were measured. The findings of the grain size study are summarized in the table below (Table 1).

3.1. Mean

The mean reflects the average size of the sediment as influenced by the source of supply and depositional environment. The total amount of available sediment, the amount of energy imparted to it, and the transporting agent all play a role in determining it. The amount of turbulence, as well as the direction of currents and waves, influences the energy of the transporting agent. The mean value of the sediments in the study region ranges from 1.085 to 1.771, suggesting that the medium size sand is widespread (Fig. 2a) in Thengapattanam estuary**.**

3.2. Standard Deviation

The standard deviation is a calculation of the sorting or uniformity of the particle size distribution. The size of the sediments has a significant impact on the sorting process. Sorting sediments is a good way to determine how energetic the depositional environment was and whether the sediments are coarse or fine-grained. Sediment sorting is influenced by factors such as scale, shape, basic gravity, sediment durability, degree of turbulence, transporting agent velocity, hydrodynamic properties such as wave height, wave length, current velocity, and the form and rate of sediment supply to the depositional region. Sorting is used to classify



2c **2d**

Figure 2. Plots showing the variations in Mean, Standard Deviation, Skewness, Kurtosis.

Table 1 Granulometric analysis data

SI. No	Mean	Range	SD	Sorting (SD)	Skewness	Sk1	Kurtosis	KG
1	1.605	Medium sand	0.522	Moderately Well Sorted	-0.005	Symmetrical	1.119	Leptokurtic
2	1.497	Medium sand	0.532	Moderately Well Sorted	0.0046	Symmetrical	1.129	Leptokurtic
3	1.437	Medium sand	0.498	Well Sorted	0.0038	Symmetrical	1.149	Leptokurtic
4	1.44	Medium sand	0.478	Well Sorted	0.063	Symmetrical	1.123	Leptokurtic
5	1.538	Medium sand	0.459	Well Sorted	-0.034	Symmetrical	1.052	Mesokurtic
6	1.516	Medium sand	0.509	Moderately Well Sorted	0.052	Symmetrical	1.091	Mesokurtic
7	1.504	Medium Sand	0.525	Moderately Well Sorted	0.04	Symmetrical	1.114	Leptokurtic
8	1.419	Medium Sand	0.561	Moderately Well Sorted	-0.015	Symmetrical	1.162	Leptokurtic
9	1.516	Medium Sand	0.509	Moderately Well Sorted	-0.041	Symmetrical	1.095	Mesokurtic
10	1.513	Medium Sand	0.492	Well Sorted	-0.055	Symmetrical	1.083	Mesokurtic
11	1.44	Medium Sand	0.484	Well Sorted	0.043	Symmetrical	1.114	Leptokurtic
12	1.55	Medium Sand	0.522	Moderately Well Sorted	0.024	Symmetrical	1.117	Leptokurtic
13	1.705	Medium Sand	0.534	Moderately Well Sorted	0.095	Symmetrical	1.08	Mesokurtic
14	1.436	Medium Sand	0.568	Moderately Well Sorted	0.012	Symmetrical	1.163	Leptokurtic
15	1.306	Medium Sand	0.542	Moderately Well Sorted	-0.017	Symmetrical	1.297	Leptokurtic
16	1.19	Medium Sand	0.576	Moderately Well Sorted	-0.078	Symmetrical	1.165	Leptokurtic
17	1.388	Medium Sand	0.487	Well Sorted	0.019	Symmetrical	1.153	Leptokurtic
18	1.274	Medium Sand	0.535	Moderately Well Sorted	-0.051	Symmetrical	1.253	Leptokurtic
19	1.379	Medium Sand	0.546	Moderately Well Sorted	0.039	Symmetrical	1.205	Leptokurtic
20	1.588	Medium Sand	0.603	Moderately Well Sorted	0.133	Symmetrical	1.17	Leptokurtic
21	1.525	Medium Sand	0.584	Moderately Well Sorted	0.093	Symmetrical	1.161	Leptokurtic
22	1.596	Medium Sand	0.543	Moderately Well Sorted	-0.005	Symmetrical	1.099	Mesokurtic
23	1.771	Medium Sand	0.535	Moderately Well Sorted	0.117	Symmetrical	1.047	Mesokurtic
24	1.572	Medium Sand	0.618	Moderately Well Sorted	0.054	Symmetrical	1.15	Leptokurtic
25	1.085	Medium Sand	0.596	Moderately Well Sorted	-0.165	Symmetrical	0.992	Mesokurtic

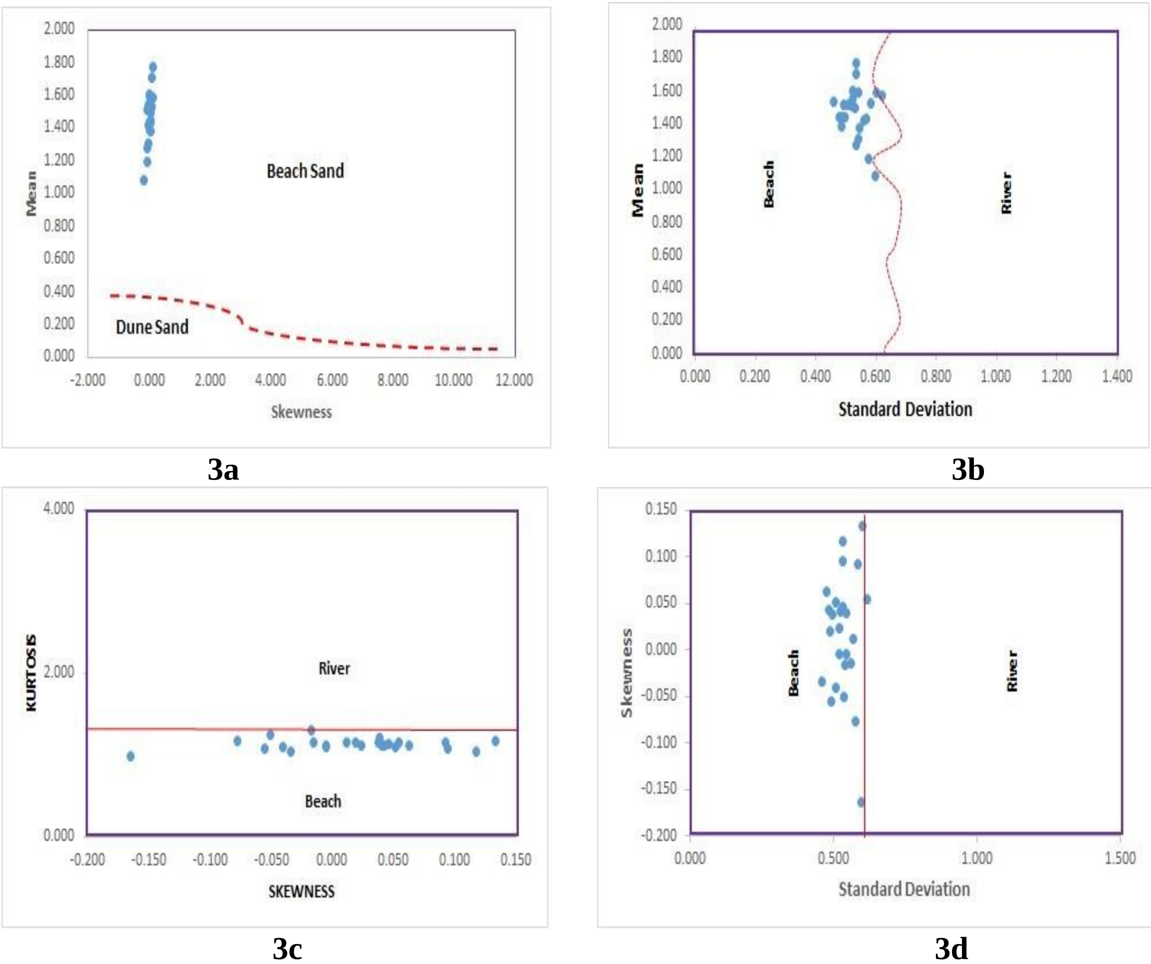


Figure 3. The Bivariate plots shows the depositional environment of sediments in Thengapattanam estuary.

sedimentary environments in the study field. The sorting values for the study area range from 0.459 to 0.618, indicating that the study area contains well-sorted to moderately well-sorted sediments (Fig. 2b).

3.3. Skewness

Skewness is a pure number that calculates the asymmetry of a distribution and is typically represented by a positive or negative sign. Data that is perfectly symmetrical has a skewness value of 0. A negative skewness value indicates that the tail of a distribution is on the left side of the distribution, whereas a positive skewness value indicates that the tail is on the right side of the distribution. The graphic skewness of the samples ranges from - 0.165 to 0.133. (Skewed from nearly symmetrical to finely skewed). The lower variance in skewness values suggests that erosion, transportation, and sedimentation conditions were consistent throughout the deposition of the study area sediments (Fig. 2c).

3.4. Kurtosis

Folk & Ward (1957) described graphic kurtosis as a qualitative measure of sediments that have been sorted in a high environment and then transported and modified by a specific form of environment, whereas moment kurtosis is a geological index of mixing between two end populations. The graphic kurtosis in the study area ranges from 0.992 to 1.297. The convergence of these two communities is most likely due to the passage of long-shore currents and the fluvial discharge of sediments. This is due to the wide range of sediment compositions and variations in coastline gradients (Fig. 2d).

3.5. Bivariate plot

Folk & Ward (1957), as well as Friedman (1961, 1967), were among the first to show that bivariate plots of one sediment size against another can distinguish the environment of deposition. Historic beach, coastal dune, inland dunes, and river sands can all be distinguished using scatter plots and graphic techniques. The mean vs. standard deviation plot is the most effective.

The skewness vs. kurtosis plot was useful in describing the boundaries of beach, dune, and river sand fields. The use of bivariate plots on India's western coast to identify dune and river zonation from a standard deviation vs. skewness plot. As a result, the plots of skewness vs. mean (Fig. 3a) and mean vs. standard deviation (Fig. 3b) show that the beach setting has a dominant influence in this area. The maximum concentration of samples in the coastal dune region has once again indicated the presence of a dominant marine environment in the (Fig.3c) drawn using kurtosis and skewness. The standard deviation and skewness plots (Fig. 3d) also revealed a smaller number of samples needed to distinguish another area from the river. Similarly, the samples from the estuary in the riverine setting show a clear distribution.

4. DISTRIBUTION OF HEAVY MINERALS

Heavy minerals from selected samples were mounted with Canada balsam and examined under a petrographic microscope for their individual optical properties. Heavy minerals classified based on optical properties includes garnet, tourmaline, kyanite, rutile, sillimanite, zircon, augite, and opaques. The weight fractions of sediments and heavy minerals were listed in (Table 2). In the (Table 3), the average, maximum, and minimum values of heavies and opaques are tabulated. (Table 4) depicts the possible source of heavy minerals found in the core sediments of the Thengapattanam estuary.

4.1. Sillimanite and Kyanite

Sillimanite and kyanite (AlSi03) are chemically aluminum-dominated polymorphic minerals that crystallize in an orthorhombic and triclinic system and are found in high-grade (amphibolite and eclogite grade) metamorphic rocks like metapelites. The sillimanites from the research area have a straight extinction with a slight blunt edge, and the prismatic

Table: 2 Heavy minerals weight percentages in core.

SI. N0	Sample No	Depth From	Depth To	Weight Fractions in 120 mesh	Heavy fractions in 120mesh	Weight % of Heavies	Initial Weight
1	-	0	0.04	1.39	0.98	3.58	27.34
2	3	0.09	0.12	0.74	0.39	1.44	26.93
3	5	0.17	0.2	0.56	0.32	1.12	28.5
4	7	0.25	0.28	1.05	0.74	2.9	25.46
5	9	0.33	0.36	0.82	0.53	1.9	27.78
6	11	0.41	0.44	0.52	0.34	1.18	28.59
7	13	0.49	0.52	2.06	1.38	4.86	28.39
8	15	0.57	0.6	0.55	0.41	1.42	28.79
9	17	0.65	0.68	0.41	0.3	1.05	28.45
10	19	0.73	0.76	0.85	0.78	2.71	28.71
11	21	0.81	0.84	1.41	1.19	4.31	27.59
12	23	0.89	0.92	2.71	2.03	7.01	28.93
13	25	0.97	1	0.19	0.13	0.46	28.26

Table: 3 Average, Maximum and Minimum values of Heavy minerals.

Parameter	Sillimanite	Garnet	Augite	Kyanite	Tourmaline	Zircon	Rutile	Monazite
Maximum	17.62	9.602	6.81	6.34	3.414	3.9	1.46	0.97
Minimum	9.03	4.405	2.92	1.44	1.69	1.76	0.423	0.331
Average	13.61	6.12	4.21	3.98	2.614	2.61	0.577	0.206

Table: 4 Possible source rocks for the heavy minerals from the core sediments of Thengapattanam estuary

Mineral assemblage	Source rock	Reference
Sillimanite, Garnet, Tourmaline, kyanite, Rutile	Metapelites Amphibolite Genesis Eclogite grade	Chandrasekar (1992)
Monazite, Zircons	Sediments, Granites	Mohan (1995)

	Green Schist grade	

character is more or less preserved, indicating that the sediments were carried at a sub-critical to critical flow velocity. The kyanites from the study area are blue in color and have a tabular shape. Sillimanite percentage varies from 17.6 to 9.03 with an average of 13.61 in Thengapattanam. Kyanite percentage varies from 6.4 to 1.4% with an average of 3.9% in Thengapattanam.

4.2. Monazite

Monazite crystallizes in a monoclinic system and can be found in a variety of solid solution series. It contains phosphate as well as a number of rare earth elements (REEs). The percentage of monazite in the sediments from the study area varies from 0.9 to 0.3 % with an average of 0.2% in Thengapattanam.

4.3. Augite

Augite is a calcium-rich pyroxene mineral that crystallizes in a monoclinic system and has acicular and prismatic properties. It is most common in high-temperature metamorphic rocks, and the primacy of calcium composition indicates the source rock's basic composition. The augite in the study area exhibited nearly perpendicular cleavage under plane polarized light. The percentage of augite varies from 6.8 to 2.9% with an average of 4.2% in Thengapattanam.

4.4. Tourmaline

Tourmaline is a mineral that crystallizes in a trigonal system and has three distinct side faces. Changes in the nature of the elemental makeup result in a variety of colors. The bluish-green tints of tourmaline, which have a strong dichroic under optically, have been noticed in the study area. The majority of the grains have retained their prismatic structure, indicating that transit is minimal and that the protolith is primarily of igneous origin. The percentage of tourmaline ranges from 3.41 to 1.69% with an average of 2.68% in Thengapattanam.

4.5. Zircon

Zircon is an igneous mineral with secondary crystallization in metamorphic rocks crystallizes in tetragonal system. Zircon grains in the research area are typically rounded to sub-rounded in shape, and oval to elongated in shape. As a result, the grain shape of the zircon grains in the study area implies that the protolith is sedimentary in origin. The percentage of the zircon grains ranges between 3.9 to 1.76% with an average of 2.61%.

4.6. Garnet

Garnets are metamorphic minerals with a wide range of colors due to their chemical composition. In the study area, which ranges in color from red to pale brown, euhedral to subrounded forms were observed. The color of iron dominated garnets is usually red, indicating that the source rock is iron dominated. It exhibits isotropism under cross nicols. Garnet percentage varies from 9.6 to 4.4 with an average of 6.1 in Thengapattanam.

4.7. Rutile

Rutile is titanium bearing mineral which is a common accessory in both metamorphic and igneous origins. Found primarily in coarse-grained high-pressure metamorphic rocks (e.g., eclogites, or kyanite-bearing). The rutile identified in the study showed extreme relief and dichroic pleochroism when examined optically. The grain boundaries are sub–angular to sub–round, indicating that transportation was moderate. The percentage of rutile varies from 1.4 to 0.4% with an average of 0.57% in Thengapattanam.

5. CONCLUSION

The process of retro-gradation occurs when seawater reaches marginal land ecosystems such as deltas and estuaries mainly because of tidal fluctuations and less sediment transport by the river. Retrograde sediment piling is characterized by fine grain sediments such as silt and clay deposits, which are one of the distinguishing characteristics of estuarine sediments and can be seen in the estuaries of India's west coast.

The current study area is in the estuarine environment, which is located on Tamil Nadu's south west coast, and the river that forms that estuary is the river Thamirabarani. Granulometric analysis and heavy minerals present in the sediments are the proxies to establish the depositional environment, tidal variations, and the source of sediments in the Thengapattanam estuary. For the granulometric analysis the statistical parameters are assessed (i.e., mean scale, mode, standard deviation, skewness, and kurtosis). The sediments were medium to coarse grained, with moderately well sorted to well sorted textural parameters. The skewness values show that the sediments are mesokurtic to leptokurtic in nature. The sediments had a relatively well-sorted character, suggesting that the effect of stronger energy conditions in the estuary was constant. The bivariate plots, which are plotted using data from the studies, clearly indicate that the estuary includes beach sands.

The Thamirabarani River originates in the Pothigai Hills of the Western Ghats, an escarpment which contains highly metamorphosed rocks. Minerals with higher average percentages in the study areas, such as sillimanite, garnet, and kyanite, suggest that metamorphic rocks were the source. Sillimanite, kyanite, are the minerals richer in aluminum percentage sources in Meta-pelites, schist, and genesis under high pressure and temperature conditions.

Heavy minerals such as sillimanite, rutile, and zircon retained their prismatic shapes with blunt heads, indicating that water flow varies from sub-critical to critical flow with little transit. The presence of rounded zircon and garnets in the sediments indicates that the sediments' protolith was sedimentary origin. The presence of beach-type sediments indicates that the estuary is current-dominated, with constant sediment reworking of sediments under a micro-tidal regime.

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