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Textural and Heavy Mineral Characteristics of Sediments from Chaliyar River and Adjoining Beypur Beach, Kerala: Implications to Sediment Dynamics and Provenance

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Abstract

The texture of sediment provides information about the environment of deposition, distance and mode of transportation. Heavy minerals are generally deposited by mechanical concentration as placer deposits. Heavy minerals can occur in a source rock as primary and accessory compounds. The continued action of weathering removes the detrital mineral grains and transports them along a stream channel. Detailed petrographic and mineralogic analyses of sediments will help in understanding the provenance, paleoenvironment and diagenetic processes. The river sediments from Chaliyar are polymodal to unimodal with well sorted to moderately sorted nature. The CM pattern indicates that samples were transported by rolling and bottom suspension. The beach sediments are unimodal in nature and well sorted. The linear discriminative function suggests that beach sediments are shallow marine deposits and suggestive of marine regression. The major heavy minerals found were hornblende, hypersthene, garnet, chlorite, biotite, sillimanite, kyanite, rutile and epidote. The provenance of the sediments includes hornblende-biotite gneisses, charnockites, khondalites and chlorite-biotite schists.

Keywords: Textural Analysis, Heavy Minerals, Chaliyar, Charnockites, Khondalites, Provenance.

Introduction

Rivers are one among the most important geological agents. They form connectivity between land and the sea. Through the denudation, sediments are generated and transported through river system and get deposited in different energy environmental conditions. Study of sediments deposited along the course of river and beach environments givers direct implications of mode of transport, energy conditions during transport and depositional environments (Blott, 2001; Steffano and Ferro, 2002; Surian, 2002; Mychielska-Dowgiallo and Ludwikowsky, 2011). The textural characteristics of the sediments from all the environments have their own signatures imprinted about the different stages of the denudational activities. The grain size analysis is the one among the most commonly used parameters in this regards (Riyaz and Jeelani, 2015).

Many studies document the sedimentological (Datta and Subrahmanian, 1997), petrological (Chowdhary, 1989; Garzanti *et al.*, 2004; Jasy *et al.*, 2010), mineralogical (Heroy, 2003; Zaman *et al.*, 2012; Abedin *et al.*, 2018; Rahman *et al.*, 2020; Hossain *et al.*, 2021) and geochemical aspects of the river sediments. The heavy mineral assemblage such as ilmenite, rutile, leucoxene, zircon, monazite and sillimanite are the represented minerals from Kerala State (Ramasamy *et al.*, 2013, 2014; Nayak *et al.*, 2012; Malik *et al.*, 1987; Babu *et al.*, 2013).

Many studies have been carried out to find out the heavy mineral assemblages and textural diversity of the Indian Rivers (Datta and Subrahmanian, 1996; Rajmohan *et al.*, 2012) and coast- lines (Rajganapathi *et al.*, 2013; Gayathri *et al.*, 2021). Bhattacharyya *et al.* (2005) have carried out investigation on the heavy mineral deposits of the Kerala coast and interpreted that the Neendakara-Kayankulam belt has feasible amount of deposits. Further, Ravindra Kumar and Sreejith (2010) have established the relationship between heavy mineral placer deposits and hinterland rocks of south coast of Kerala. They tried to establish a source to sink relation from the chemistry of garnets. Anooja *et al.* (2013) have studied the heavy mineral content and provenance of late quaternary deposits of southern Kerala. They identified the provenance of garnet and pyribole- free heavy mineral suite in beaches of the Kollam Coast as weathering of the Neogene sedimentary deposits in the coastal lands. Sundararajan *et al.*

(2009) have done the detailed study on characterisation of ilmenite deposits in the coastline of Kerala. Moreover, Babu *et al.* (2007) have studied the effects of December 24, 2004 tsunami on the ilmenite population of the Kerala Coast. The Chavakkad-Ponnani belt of the Kerala Coast has the evidences of the presence of the heavy minerals and characters of ilmenite in beach placer sands along with gold in association with pyriboles (Nayak, 2011; Nayak *et al.*, 2012).

The present study documents the characterization of sediments in terms of its textural characteristics and distribution of heavy minerals in the Chaliyar River Basin (CRB) and the adjoining Beypur-Chaliyar Beach. The CRB is one among the least explored basins in the Kerala State in terms of the energy conditions prevailing along the basin along with its heavy mineral distribution pattern and same has been discussed in the present work.

Area of Study

The area of present study is the channel of the CRB and the Beypore-Chaliyar Beach (BCB) in the Calicut district of Kerala (Fig.1). The state of Kerala in south India is predominantly comprised of Precambrian terrain. The major rock types include granites, granulites, gneiss and greenstones with the younger Meso-Cenozoic dykes intruded into the older Precambrians. The Kerala state is also occupied by the sediments of the Neogene Period (Soman,2002). The major part of the Western Ghats and midland region are composed of gneiss, charnokitic gneiss and pyroxene bearing granulites. Khondalites are major rock formations of the southern Kerala. They are associated with garnet biotite gneiss and quartzo feldspathic gneiss. The dykes of the lower-middle Proterozoic age, pegmatites of the middle Proterozoic age and later dolerite dykes, contemporaneous with Deccan basalt magmatism, are the common intrusive elements seen in the granulitic terrain of this state. The western part of the state consists of the sedimentary rocks of the Neogene and Quaternary Periods mainly at the four distinct regions such as Aleppey, Vaikom, Quilon and Warkali. The extensive lateritic cover is seen along the midland region which is formed due to the weathering of the crystalline rocks. The Holocene alluvial deposits are present along the Kerala coast. The major portion of the river flows through the charnockitic terrain of the Kerala state. Similarly, the most of the river tributaries have originated from area comprised of the biotite gneiss. The origin of the Chaliyar River mainly takes place from the regions with abundant hornblende biotite gneiss whereas, amphibolite and lateritic terrains are present in the mid region of the river. The river crosses few dolerite dykes and pebble beds further downstream.

Methodology

The present study is carried out on sediments collected from the channel of CRB and the BCB. Three sediment samples were collected from both northern and southern side of the Chaliyar Estuary with an approximate interval of one km. The geographic locations of the sampling points were taken using GPS (Table 1). Nine sediment samples were collected from the CRB. Each sample was subjected to onsite coning and quartering. They were weighed using highly accurate weighing machine and ensured that all of them are of the same weight. All the samples were washed in water 2-3 times to remove the silt content. After washing with water, samples were treated with

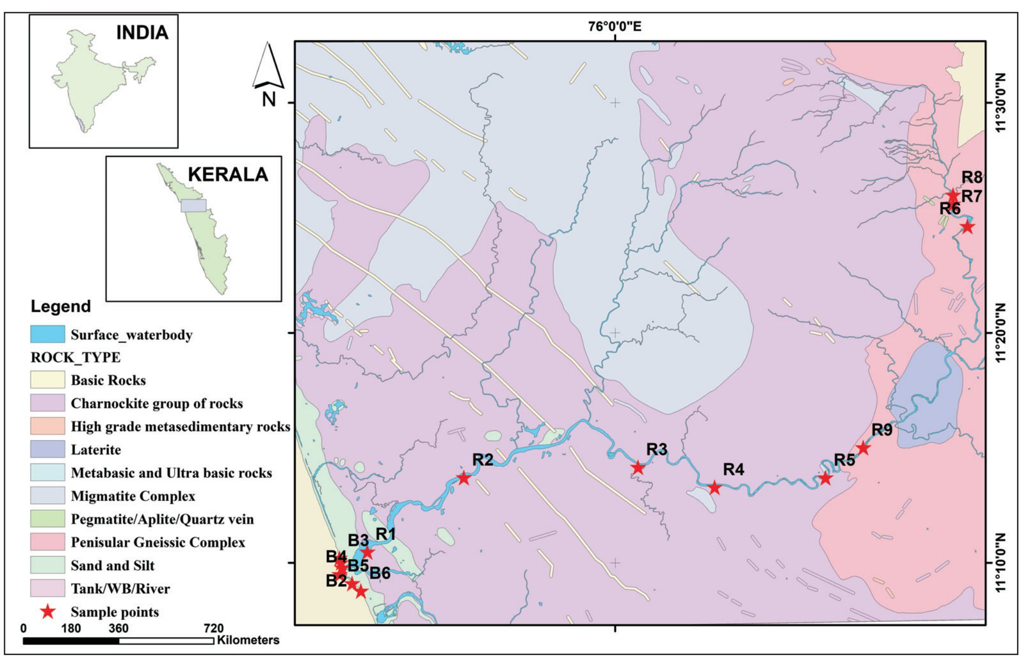

Fig. 1. Location map of the study area. Red stars represent the sampling stations.

Table 1: Coordinates of the Sample site from the study area (B1, B2…*etc* represent beach samples and R1, R2…*etc* represent river samples)

Sl No	Sample Name	Latitude	Longitude
1	B1	11.162967 N	75.802263 E
2	B2	11.166609 N	75.801527 E
3	B3	11.169958 N	75.800419 E
4	B4	11.1581191 N	75.800607 E
5	B5	11.151553 N	75.809587 E
6	B6	11.146170 N	75.815966 E
7	R1	11.174525 N	75.820560 E
8	R2	11.228289 N	75.890466 E
9	R3	11.235862 N	76.016580 E
10	R4	11.221384 N	76.072063 E
11	R5	11.228195 N	76.152310 E
12	R6	11.41037 N	76.255051 E
13	R7	11.426565 N	76.244557 E
14	R8	11.433003 N	76.244739 E
15	R9	11.250110 N	76.179593 E

Hydrogen Peroxide (16%), to remove organic matter. The samples were again treated with Hydrochloric acid (20%) to remove the carbonate content. The samples were dried in oven at mild temperature for 2 days. These sediment samples were subjected to particle size analysis using dry sieving methods (Ingram, 1971). The sieves with 7,10,14,18,25,35,45,60,80, 120,170 and 230ASTM mesh numbers were used. The sieves were arranged in such a way that meshes size number increases (7 at top and 230 at bottom). A lid was kept above ASTM 7 mesh and a pan was kept under ASTM 230 mesh. They were weighed to find out weight percentage and cumulative weight percentage of each fraction. The statistical parameters of textural characteristics were determined and were used in plotting, association and interpretation. The heavy minerals were separated from the light minerals by the gravity separation in a liquid having high density. The bromoform is the common heavy liquid used for the heavy mineral separation. The representative heavy mineral fraction needed for identification was taken by coning and quartering. The samples were observed under optical microscope and the minerals were identified by their optical properties. The counting of each mineral grain was carried with great care. The total number of each grains present were noted down.

Results

Textural Analysis of Beach and River Sediments

The mean size of surface sediments of the BCB ranges from 0.746 ϕ to 1.884 ϕ. Four out of the six beach sediments are in the category of medium sand, while rest two comes under coarse sand. One of the coarse sand fractions is moderately well sorted, while all others are well sorted. One among the six beach samples is symmetrically skewed. It is having a positive skewness value of 0.074 ϕ. The finely skewed sediments are two in number and three sand fractions are coarsely skewed. The kurtosis distribution for the beach sediments ranges from 0.808ϕ to 1.247 ϕ. The three samples show platykurtic nature, while two are leptokurtic and one is mesokurtic in character. The higher percentage of platykurtic samples represents a high-energy environment. The presence of high energy environment is inferred in case of extreme low or high values of kurtosis, which might have resulted in the sorting characteristics of that part of the sediment (Malvarez, 2001). All five samples are unimodal and one is bimodal type. The mean size of surface sediments of the CRB, varies from 0.600 ϕ to 1.267 ϕ. Three samples from the head region come under coarse sand category. As the energy of stream reduces downstream, it will start depositing grains which it cannot carry further down. Hence, the coarser grains will be seen in the head region. The sand fractions collected from the mid region of river come under medium sand. The sands collected from the end region of river are finer. Only one among the nine river samples is well sorted. It is taken from the mid region of the river. Four sand fractions are moderately well sorted, while the rest four samples are moderately sorted. Two samples are symmetrically skewed especially one from the head region and another from the mid region. All the other seven samples are coarsely skewed. The kurtosis value ranges from 0.731 to 1.576 ϕ. Two among the nine samples are platykurtic in nature. Four samples are leptokurtic and one is very leptokurtic. Two sand fractions are mesokurtic. Only one river sample shows polymodal nature. It is taken from the high upstream region of the river. Three samples are unimodal and five are bimodal. The textural parameter values, range of grain size parameters of beach- and river-sediments and the percentage distribution of grain size parameters are represented in the tabular form (Table 2-4).

Table 2: Statistical data on textural parameters of sediments

Sample	Mz	SD	SK	KU	Mz	SD	SK	KU
B1	1.818	0.376	0.074	1.247	MSa	WS	S	LK
B2	0.746	0.697	-0.225	1.244	CSa	MWS	CS	LK
B3	1.008	0.378	0.196	0.877	MSa	WS	FS	PK
B4	1.443	0.411	-0.113	0.878	MSa	WS	CS	PK
B5	1.884	0.434	-0.274	0.808	MSa	WS	CS	PK
B6	0.983	0.397	0.287	0.902	CSa	WS	FS	MK
R1	0.958	0.601	-0.299	1.302	CSa	MWS	CS	LK
R2	0.854	0.794	-0.237	1.135	CSa	MS	CS	LK
R3	0.678	0.760	-0.162	1.001	CSa	MS	CS	MK
R4	1.167	0.606	-0.282	1.576	MSa	MWS	CS	VLK
R5	1.008	0.448	0.046	1.017	MSa	WS	S	MK
R6	0.998	0.734	-0.164	1.394	MSa	MWS	S	PK
R7	0.982	0.597	-0.237	1.318	CSa	MS	CS	PK
R8	0.600	0.885	-0.183	0.764	CSa	MWS	CS	LK
R9	1.267	0.502	-0.065	0.731	CSa	MS	CS	LK

Mean Size (Mz) ; Standard Deviation (SD); Skewness (SK); Kurtosis (KU); Moderate sand (MSa);Coarse sand (CSa); well sorted (WS);Moderately well sorted (MWS); Moderately sorted (MS);Symmetrical skewness (S); Coarsely skewed (CS);Finely Skewed (FS);Leptokurtic (LK);Platykurtic (PK);Mesokurtic (MK);Very leptokurtic (VLK)

Table 3: Nomenclature and range of grain size parameters of beach and river sediments

Parameters of grain size distribution	Beach sediments	River sediments
Mean ϕ	.746-1.884	.600-1.267
Standard deviation	.376-.697	.448-.885
Skewness	-.274-.287	-.299 -.046
Kurtosis	.808-1.247	.731 -1.576

Table 4: Percentage distribution of grain size parameters

Parameters	Beach sediments (%)	River sediments (%)
Mean		
Medium sand	66	33.33
Coarse sand	34	66.67
Standard Deviation		
Very well sorted (<.35)		
Well sorted (.35-.50)	84.4	11.2
Moderately well sorted(.50-.71)	16.6	44.44
Moderately sorted (.71 -1.0)		44.44
Poorly sorted (1.0-2.0)		
Skewness		
Strongly fine skewed (1-.3)		
Fine skewed (.03-.1)	34	
Near symmetrical (.1 - -.1)	16	77.78
Coarsely skewed (-.1 - -.3)	50	22.22
Strongly coarsely skewed (-.3 - -1)		
Kurtosis		
Very platykurtic (<.67)		
Platykurtic (.67-.91)	50	22.22
Mesokurtic (.91-1.11)	16	22.22
Leptokurtic (1.11 -1.50)	34	44.44
Very leptokurtic (>1.50)		11.11

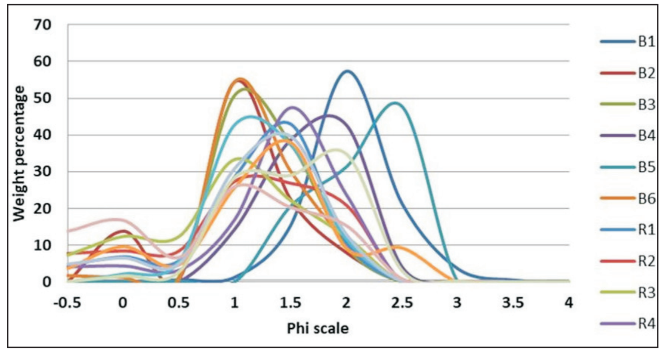

Fig. 2. Graphical Representation of frequency distribution

The frequency curves of majority of Beach samples show unimodal distribution with modes ranging from 0.5 to 2.5 ϕ (Fig. 2). Only one beach sample show bimodal distribution. Its mode ranges from -0.5 to 0.5 ϕ and 0.5 to 2.5 ϕ. The majority of sands fall under medium sand category, which is well sorted. The sample B2 has bimodal distribution with the moderately well sorting. Five out of nine sand fractions of the river show bimodal distribution. Their modes range from 0.5 to 2.5 ϕ and -0.5 to 0.5 ϕ, respectively (Table 5). It is interesting to note that, samples collected from the end stages of river show bimodal distribution. The sand fractions collected from the mature stage of the river shows unimodal distribution. Their mode ranges from 0.5 to 2.5 ϕ if we observe the head region of the river, two out of three samples show bimodal nature with mode ranging from 0.5 to 2.5 ϕ. Remarkably, the sands collected from the most headward region shows polymodal distribution. Their mode ranges from -0.5 to 0.5ϕ; 0.5 to 2ϕ and 2 to 2.5ϕ. This indicates the energy differentials during sediment deposition. The cumulative curves of the sediments were plotted using Visher (1969) procedure (Fig. 3; Table 6). The curve indicates the dominance of saltation type of transportation (90%) followed by traction load (5%) and suspension load (5%).The truncation points of traction – saltation occurs at 0.5 ϕ for most of the samples, but truncation occurs at 1 ϕ for B1 and B5. The truncation between saltation and suspension occurs at 2ϕ for majority of the samples and for R9, B1 and B5, truncation occurs at 2.5 ϕ.

Bivariant Plots

Information on the environment of deposition of the sediments can be inferred from an association of two statistical parameters. This is also helpful in delineating the overlap in the closely related depositional environments. Many researchers have attempted to unravel the depositional history

Table 5: Frequency distribution from the study area

Phi scale	B1	B2	B3	B4	B5	B6	R1	R2	R3	R4	R5	R6	R7	R8	R9
-0.5	0.00	0.00	0.00	0.00	0.00	1.74	4.56	7.78	7.29	4.13	0.04	3.66	4.85	13.81	0.10
0	0.00	13.84	0.20	0.10	0.08	1.22	6.85	8.46	12.40	4.38	2.19	9.63	6.54	16.76	1.62
0.5	0.62	0.81	1.49	0.12	0.21	0.86	5.84	8.46	12.40	3.23	5.63	4.67	4.99	6.70	2.80
1	1.32	54.48	50.86	14.41	0.08	54.56	28.66	27.43	33.37	17.05	42.84	25.72	30.95	25.97	28.48
1.5	15.38	22.48	37.71	38.62	20.61	30.12	42.98	26.87	22.16	47.39	37.30	37.97	39.62	20.30	29.02
2	57.33	7.97	9.61	42.68	31.32	11.25	10.76	20.88	12.30	23.71	11.75	9.10	12.90	15.32	34.81
	21.25	0.39	0.04	4.03	47.7	0.25	0.25	0.12	0.08	0.10	0.24	9.25	0.15	0.84	3.01
3	3.59	0.04	0.09	0.04	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.16
3.5	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6: Cumulative weight percentage of the study area

Phi scale	B1	B2	B3	B4	B5	B6	R1	R2	R3	R4	R5	R6	R7	R8	R9
-0.5	0.00	0.00	0.00	0.00	0.00	1.74	4.56	7.78	7.29	4.13	0.04	3.66	4.85	13.81	0.10
0	0.00	13.84	0.20	0.10	0.08	2.96	11.41	16.24	19.69	8.51	2.24	13.29	11.40	30.57	1.71
0.5	0.62	14.65	1.69	0.22	0.29	3.83	17.25	24.70	32.09	11.74	7.87	17.96	16.39	37.26	4.51
1	1.94	69.13	52.55	14.63	0.37	58.38	45.91	52.13	65.46	28.79	50.70	43.68	47.33	63.23	32.99
1.5	17.32	91.60	90.26	53.25	20.98	88.50	88.89	79.00	87.62	76.19	88.01	81.65	86.95	83.53	62.01
2	74.65	99.57	99.87	95.93	52.30	99.75	99.65	99.88	99.92	99.90	99.76	90.75	99.85	98.85	96.83
2.5	95.90	99.96	99.91	99.96	100.00	100.00	99.90	100.00	100.00	100.00	100.00	100.00	100.00	99.69	99.84
3	99.49	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.93	100.00
3.5	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
4	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

of the sedimentary deposits through bivariant plots (Folk and Ward 1957; Friedman 1961, 1967; Moiola and Weiser, 1968). The scatter plot between two parameters gives an idea about the maturity, sorting, source behind the distribution of sands and wave turbulence nature.

Size vs. Standard Deviation

Mean size *vs* standard deviation plot of the beach sediments shows that majority of the samples are well sorted and only one among the beach samples is moderately well sorted (Fig. 4). The better sorting of beach sands can be ascribed to constant wave action. Waves are the better sorting agents than the river currents. The river sediments show moderately well sorted to moderately sorted region. Some of the river sediment fractions are well sorted. Thus, it can be inferred from the plot that the beach sands are better sorted than the river sands. Similarly, the mean sediment size increases with respect to the enhanced sorting trend.

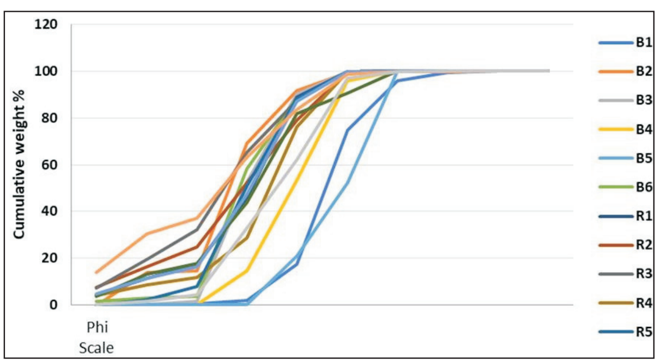

Fig. 3. Graphical representation of cumulative weight percentage

Mean vs. Skewness

All the studied samples fall within the inland and beach categories as per the standard classifications (Friedman, 1967; Moiola and Weiser, 1968; Fig. 5).

Standard Deviation vs. Kurtosis

Standard deviation *vs.* Kurtosis plot suggests that majority of the beach samples are platykurtic and well sorted (Fig. 6). A single beach sample is moderately well sorted and comes under leptokurtic category. The river samples are mostly moderately well sorted to moderately sorted. The two out of nine river samples are platykurtic in nature, while the other two are mesokurtic along with the five leptokurtic samples.

Kurtosis vs. Skewness

It can be inferred from the Kurtosis *vs*. Skewness plot that majority of the river samples are showing negative

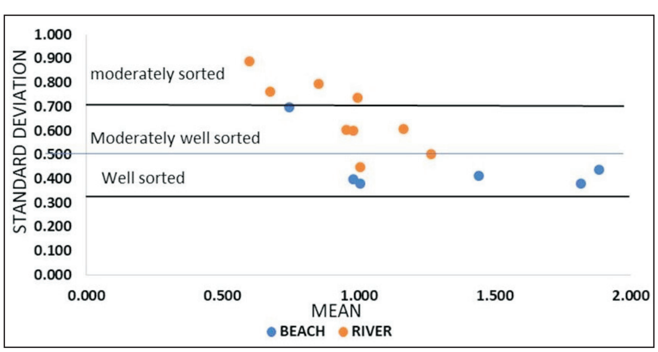

Fig. 4. Bivariant plot forMean vs Standard deviation (*after,* Folk and Ward, 1957)

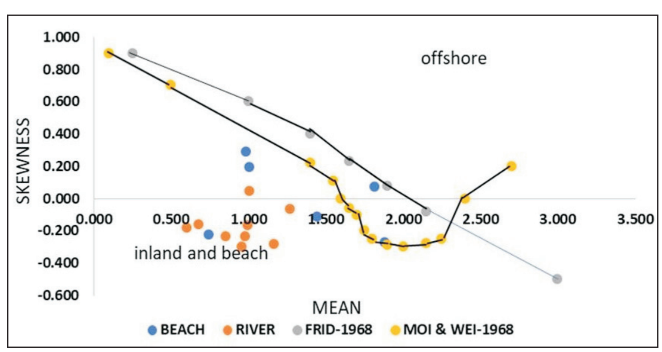

Fig. 5. Bivariant plot for Mean versus Skewness (*after,* Folk and Ward, 1957)

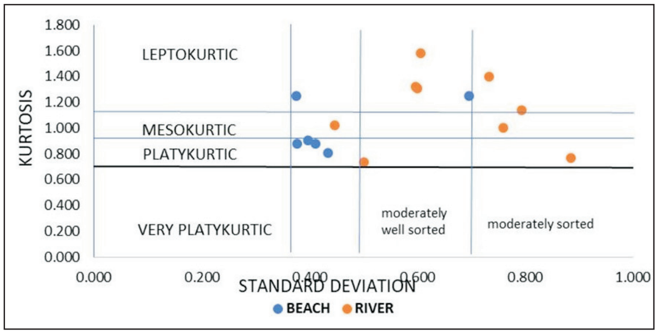

Fig. 6. Bivariant plot for Standard deviation versus Kurtosis (*after,* Folk and Ward, 1957)

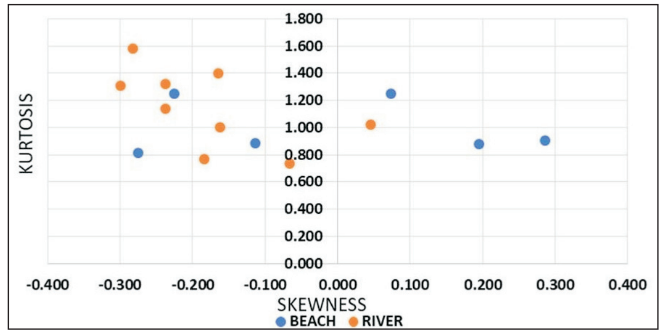

Fig. 7. Bivariant plot for Skewness versus Kurtosis (*after,* Folk and Ward, 1957)

skewness (Fig. 7). The least skewness value is 0.30.Only one river sample shows positive skewness (around 0.50). The beach samples show both positive and negative skewness. The highest kurtosis value is represented by 1.60, while no sediment samples have kurtosis value below 0.60.

Linear Discriminative Function (LDF)

The LDF helps us in knowing about the depositional environment (Table 7). Using the discriminant function analysis, we could find out the different depositional environments such as Y1(Aeolian beach), Y2 (Beach, shallow agitated water), Y3 (shallow marine and fluvial), Y4 (Turbidity, Fluvial). The LDF analysis of sediment samples was done using the following equation. The results were applied to determine the relation between grain and depositional environment (Sahu 1964; Gul Murat *et al.*, 2009). The following formulae were derived using the LDF method.

Y1 Aeolian; Beach =

$$-3.5688Mz + 3.7016r^2 - 2.0766SK + 3.1135KU \quad (I)$$

Y2 Beach; Shallow Marine =

$$156534Mz + 65.7091r^2 - 18.5043U; \quad (II)$$

Y3 Shallow marine; Fluvial =

$$0.2852MZ - 8.7604r^2 - 4.8932SK + 0.0482KU \quad (III)$$

The aeolian and beach environments are represented by values ranging from -2.944 to 3.474. In shallow marine region, aeolian beach environment is identified at B5. Y2 is associated with beach environment with values ranging from 44.94 to 62.51. Y3 of the sediments ranges from -2.87 to 0.269. It indicates that all of the sediments were shallow marine deposits. Thus, it can be inferred from the results that almost all the sediments were deposited under beach as the shallow marine deposits.

C-M Pattern

The *CM* plot was constructed with the help of grain size parameters, where, 'C' is coarser with one percentile value and 'M' is the median value in micron plotted on a log-probability scale (Passega, 1957; Passega and Byramjee,1969; Fig. 8).The general pattern of this diagram consists of segments NO, OP, PQ, QR and RS. Each segment defines a particular deposition agent and a sedimentation process. The clustering of sediments near segment 1 was observed. Therefore, it is inferred that majority of the samples were transported by rolling. Rest of the samples are present near to segment 2, which indicates that they were transported by rolling and bottom suspension.

Heavy Mineral Assemblages and Distribution

Heavy minerals have been used to derive the source from which they were derived. The mineral abundance was studied by counting individual grains and then the number percentage was calculated. Hornblende, hypersthene, garnet, chlorite, biotite, kyanite, sillimanite, epidote and rutile constitute the heavy mineral population (Fig. 9-10; Table 8). Population of the heavy minerals has been considered under medium fraction and fine fraction of the sediments (Fig. 11-12). Among medium fraction of the river sediments,

Table 7: Linear Discrimination Function Analysis of the samples from the study area

Sample	Mean	Std.Dev.	Skewness (Sk)	Kurtosis (Ku)	Y1	Remarks-Y1	Y2	Remarks-Y2	Y3	Remarks-Y3	Y4	Remarks-Y4
B1	1.818	0.376	0.074	1.247	-2.24	Beach	62.19	Beach	-1.03	ShallowMarine	8.35	turbidity
B2	0.746	0.697	-0.225	1.244	3.474	Beach	62.52	Beach	-2.88	ShallowMarine	5.41	turbidity
B3	1.008	0.378	0.196	0.877	-0.74	Beach	44.94	Beach	-1.88	ShallowMarine	6.63	turbidity
B4	1.443	0.411	-0.113	0.878	-1.55	Beach	47.91	Beach	-0.48	ShallowMarine	4.86	turbidity
B5	1.884	0.434	-0.274	0.808	-2.94	Aeolian	51.85	Beach	0.269	ShallowMarine	3.71	turbidity
B6	0.983	0.397	0.287	0.902	-0.71	Beach	47.66	Beach	-2.46	ShallowMarine	7.35	turbidity

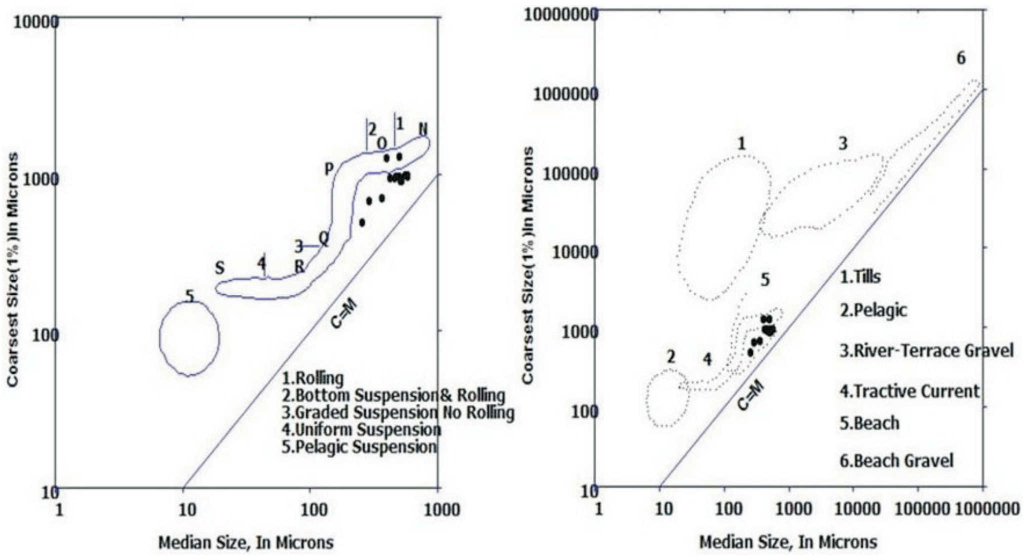

Fig. 8. C-M pattern model for mode of transportation and deposition (*after,* Passega, 1957; Passega and Byramjee, 1969)

hornblende is found to be ranging from 6.95% to 40.94%, hypersthene from 15.28% to 18.43%, biotite from 2.79% to 13%, chlorite from 3.95% to 7.53%, garnet from 7.35 to 23.99 and opaque from 6.19 to 48.29%. Kyanite and sillimanite were not detected from the river sediments and epidote and rutile were not detected in the medium fraction of the river sediments. Only one river sample has shown fine fraction representation, location R7. Among the beach sediments, medium fraction of the sediments has shown hornblende presence of 14.18% to 19.73%, hypersthene from 28.90% to 33.41%, biotite from 0.00% to 7.27%, chlorite from 7.01% to 13.30%, kyanite from 0.00% to 2.27%, sillimanite from 0.00% to 5.08%, garnet at location B1 with 21.89%, epidote from 1.66% to 2.81%, rutile from 2.16% to 2.23% and opaque from 0.00% to 33.47%. In the fine fraction of beach sediments, hornblende was found to be ranging from 15.96% to 35.82%. The range of other minerals include hypersthene from 23.57% to 27.68%, biotite from 5.03% to 11.38%, chlorite from 6.48%

Table 8: Heavy mineral assemblages (Weight %) from the study area

Sample No.	Hornblende %	Hypersthene %	Biotite %	Chlorite %	Kyanite %	Sillimanite %	Garnet %	Epidote %	Rutile %	Opaque %	Total %
B1HMM	19.65	30.12	7.27	11.18	0.00	5.08	21.89	2.58	2.23	0.00	100
B1HMF	35.82	27.68	5.22	6.48	0.00	2.74	0.00	0.00	2.40	19.65	100
B3HMM	14.18	28.90	7.25	7.01	2.27	1.38	0.00	2.81	2.73	33.47	100
B3HMF	15.96	23.57	11.38	11.44	5.08	3.31	4.28	2.69	0.87	21.41	100
B4HMM	19.73	33.41	0.00	13.30	0.00	3.28	0.00	1.66	2.16	26.46	100
B4HMF	22.87	24.45	5.03	6.89	2.48	3.02	8.93	0.00	1.99	24.35	100
R7HMM	6.95	15.28	13.00	3.95	-	-	19.92	-	-	40.89	100
R7HMF	27.21	18.99	-	-	-	-	13.03	6.33	3.72	30.72	100
R8HMM	40.94	18.43	2.91	7.53	-	-	23.99	-	-	6.19	100
R5 HMM	18.27	18.36	2.79	4.95	-	-	7.35	-	-	48.29	100

Table 9: Correlation matrix for the heavy minerals from the study area (N=10)

	Hornblende	Hypersthene	Biotite	Chlorite	Kyanite	Sillimanite	Garnet	Epidote	Rutile	Opaque
Hornblende	1									
Hypersthene	0	1								
Biotite	-0.57	-0.19	1							
Chlorite	-0.09	0.71	0.12	1						
Kyanite	-0.3	0.11	0.48	0.32	1					
Sillimanite	-0.08	0.8	0.15	0.76	0.31	1				
Garnet	0.13	-0.53	0.15	-0.22	-0.37	-0.22	1			
Epidote	-0.09	0.12	-0.23	-0.21	0.13	0.03	-0.05	1		
Rutile	0.13	0.55	-0.39	-0.11	-0.01	0.34	-0.37	0.69	1	
Opaque	-0.54	-0.39	0.03	-0.49	-0.01	-0.58	-0.38	-0.05	-0.16	1

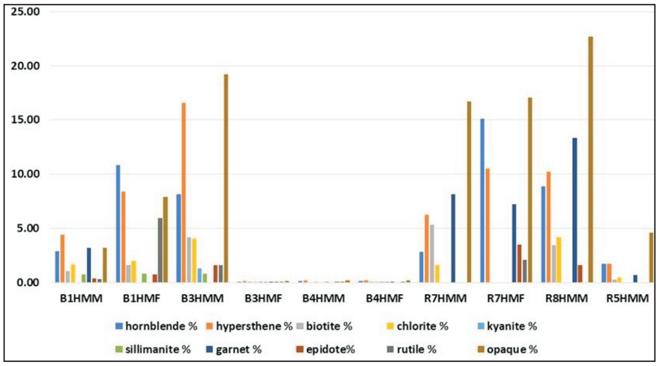

Fig. 9. Heavy mineral percentage variation from the study area at different locations

to 11.44%, kyanite from 0.00% to 5.08%, sillimanite from 2.74% to 3.31%, garnet from 0.00 to 8.93%, epidote from 0.00% to 2.69%, rutile from 0.87% to 2.40% and opaque from 19.65% to 24.35%.

Correlation Matrix

The study of correlation matrix has been carried out to know the relation between mineral assemblages of a study area. The correlation matrix of heavy mineral grains of the Chaliyar River and adjoining beach is done (Table 9). Hornblende is shows negative correlation with biotite and opaques. Hypersthene shows positive correlation with chlorite, sillimanite and rutile and negative correlation with garnet. Chlorite shows positive correlation with sillimanite, while sillimanite shows negative correlation with the opaques. Epidote has the positive correlation with rutile.

Discussion

Modality of sediment distribution is the number of peaks in it, *viz*. unimodal has one peak, bimodal has two and polymodal has three and more peaks. All of the unimodal sands are well sorted and the bimodal sand is moderately well sorted. This reveals that only one source of energy prevailed during the deposition of the sediments. A sediment sample which shows polymodal nature is only moderately sorted. This clearly indicates that multiple types of energy conditions prevailed during the deposition of the sediments. The bimodal and polymodal type of deposits were formed by the mixing of differently sorted sediments under the mixed environments. If there are no mixed environments, the distance travelled by the sediments is the prime variable which determines the sorting of grains. Finkelstein (1982) has linked the sorting of sediments to the constructive wave activity and beach slope. Among beach sediments, well sorted, fine grained unimodal nature (without any silt and clay) implies single source generally as fine grained, well sorted unimodal nature of beach sediments without any silt and clay. It indicates that the sediments are derived from a single source, which has undergone frequent phases of modification by strong waves and currents (Babu *et al.*, 2015). The sorting action of strong waves along with tough sediments might have limited the sediments to fine size and well sorted character. The constant wave energy and the sustained contact of beaches to waves for extensive duration further enhanced the sorting of the sediments. The sediments collected from the upstream regions of the river are coarse and not well sorted. The grains show poor sorting with the coarser size under the higher energy conditions which are generally observed in the source regions signifying the contribution of sediments from the different tributaries. The progressive size based sorting is generally displayed by river sands from their source (poorly sorted) to mouth (well sorted). In contrast to this pattern, a multifaceted distribution pattern is observed in the present case. This pattern can be attributed to the sudden reduction in the competency of the river, mixing of sediments at the river mouth and rise in the thickness of water column. The coarser

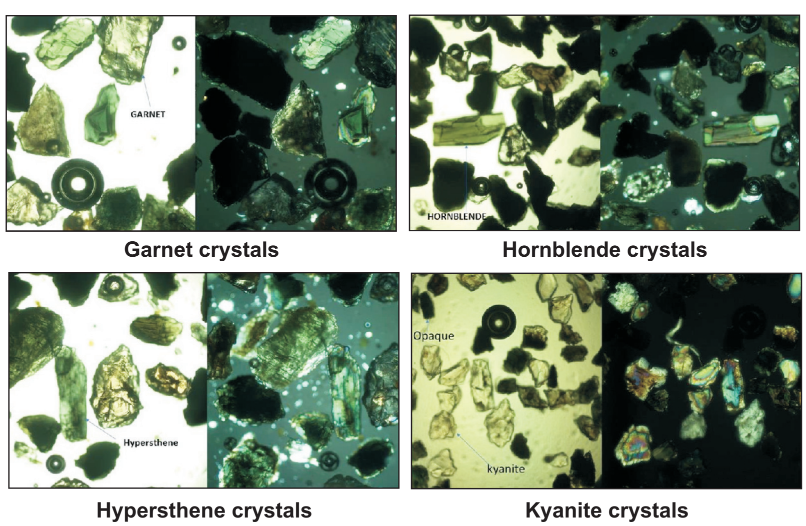

Fig. 10. Photomicrographs of the heavy minerals in open and crossed Nichols (left and right, respectively; 5X magnification).

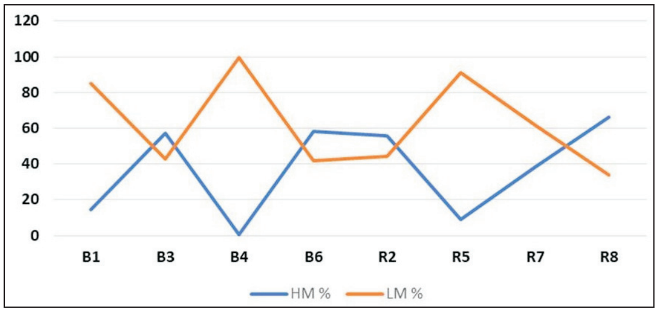

Fig. 11. Variation of heavy and light minerals of medium sized sediments

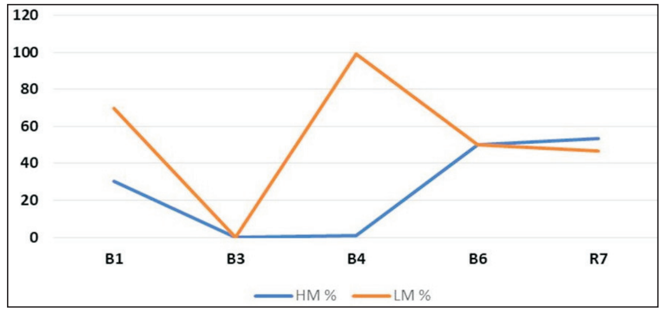

Fig. 12. Variation of heavy and light minerals in fine sized sediments

sediments are seen towards the mouth region of the river. The finer sediments are taken away by the turbulent action of waves and currents leaving coarser particles as lag deposits.

Sediments can show a positively skewed pattern (finer admixtures are greater than the coarser ones) or a negatively skewed pattern (addition of coarser material or removal of finer material from the population). Alsharhan and El-Sammak (2004) suggested that the sediments of high energy wave conditions are medium grained and negatively skewed. Under fluctuating energy conditions, local oscillations in the form of skewness are exhibited by the bottom sediments (Duane, 1964). The skewness of beach sediments varies from positive to negative. Addition of subsidiary amounts of silt, clay fractions to the original fragments might have resulted in the wide variations in the textural parameters of the beach sediments. Sediments will show positive skewness in areas where wave base surge or bottom currents do not disturb the bottom sediments and in the quite water environments (Duane, 1964). The deposits of the environments such as beaches, littoral and tidal inlets show negative skewness. Almost all of the river sediments exhibit negative skewness. This may be due to the presence of subordinate coarser sand or gravel. Most of the beach sediments are platykurtic in nature. The platykurtic distribution of sediments might be the result of deposition of considerable proportion of silt and clay which gives to two sub-equal modes of fine and coarse particles. Rest of the beach sediments are meso and leptokurtic in nature. They indicate the occurrence of uneven subpopulations of sediment sizes. Majority of the river samples are leptokurtic in nature. The reason for the increased kurtosis at some locations may be due to the mixing of the different inflow of sediments at the depositional environments having different competency levels. As shown by Folk and ward (1957), sorting in tails may vary due to the addition of minor levels of different mode depositions to a unimodal assemblage. The sorting in the central part remains good and thus makes the deposit leptokurtic. The platykurtic samples are lesser than leptokurtic ones. They might have been deposited by the intermixing of silt and clay particles. Generally, well to moderately sorted deposits are mesokurtic. Nearly unimodal, well sorted sands will usually have very poor sorting and the alternate rise and fall in the values of kurtosis with worsening of sorting may be due to the progressive addition of finer particles gradually giving rise to the sediments of different degrees of bimodality.

The Phi mean size versus skewness implies that the bulk of the sediments are skewed negatively (Fig. 5). This further indicates that skewness is controlled by the phi mean size. The negative skewness is produced in a two-mode mixing environment where finer mode is abundant and results positive skewness if the coarser mode is dominant. It can be stated from the studies that sudden variations on the energy of transporting agent might have resulted in the bimodality. The Phi mean size versus standard deviation plot indicates that sorting increases with the rise in the mean grain size (Fig. 4). The factors such as currents and tides (especially in the river mouth), fluctuations in the river competency and depth of the river might have influenced to have a sharp escalation in the polymodality of the sediments and decrease in the sorting value. Standard deviation versus kurtosis plot suggests that all the beach samples are meso-platykurtic in nature and well sorted (Fig. 6). It is observed that as the kurtosis decreases, sorting increases. Skewness versus Kurtosis plot shows that kurtosis value increases with decline in skewness (Fig. 7).The *CM* pattern indicates that majority of the samples were transported by rolling (Fig. 8). Some of the samples were transported by rolling and bottom suspension. The *CM* pattern also shows beach environment for the studied sediments. It can be inferred from the linear discrimination function that almost all the sediments were deposited under beach and shallow marine environment.

Heavy mineral assemblages can be used for demarcating the probable sources from which they have been derived. The enrichment of the heavy mineral along the beaches are mainly influenced by various factors such as host rocks, climatic conditions, agents, hydraulic conditions while transport and deposition *etc* (Hubert, 1971; Folk and Ward, 1957). Interestingly, the study area consists of charnockite group of rocks, migmatitic complex, peninsular gneissic complex and Khondalite rocks. Hornblende and hypersthene are the most abundant minerals found in the beach and river sediments. Hornblende is indicative of metamorphic provenance. Mallik *et al*. (1987) postulated that charnockite and retrograde charnockites are the important source rocks for the minerals hypersthene and hornblende.

The charnockites and khondalites are the main source rocks for the ilmenite (opaques), sillimanite and igneous rocks for the rutile and pyroxene (Soman, 2002). Hota and Wataru (2009) also expressed that igneous parentage is the source for pyroxene and rutile minerals and postulated that minerals such as biotite and chlorite belong to the low-rank metamorphic rocks and the minerals like, garnet, sillimanite, hornblende have the source of high-grade metamorphic sources. The enrichment of the heavy mineral along with beaches owes to the strong convergence of wave orthogonals and the scavenging of the lighter minerals other than the source rocks during the monsoon seasons (Chandrasekar *et al.*, 2010).

Conclusions

The river sediments are polymodal to unimodal and have well sorted to moderately sorted nature. The *CM* pattern indicates that samples were transported by rolling and bottom suspension of beach environments. The beach sediments are unimodal in nature and well sorted. The linear discriminative function suggests that beach sediments were formed under shallow marine depositional conditions. The major heavy minerals found were hornblende, hypersthene, garnet, chlorite, biotite, sillimanite, kyanite, rutile and epidote. The provenance of the sediments includes hornblende-biotite gneiss, charnockites, khondalites and chlorite-biotite schists.

Authors' Contributions

Sharath Raj B.: Supervision, Conceptualization, Writing-Original Draft. **Sujith M. S.:** Investigation and Formal Analysis, Writing-Original Draft. **Babu Nallusamy:** Supervision, Conceptualization, Writing-Original Draft, Editing. **Mohammed Aslam M A:** Reviewing. **T. K. Lakkundi**: Reviewing and Editing.

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