Jour. Indian Association of Sedimentologists, Vol. 36, No. 2 (2019), pp.64-85
ISSN Online 2582 – 2020
ISSN Print 0970 – 3268

Heavy Mineral Distribution and Provenance Studies of Coastal Sediments of Visakhapatnam Coast – Statistical Approach

G. Appa Rao and T. Karuna Karudu
Delta Studies Institute, Andhra University, Visakhapatnam - 530 017
E-mail: apparao.gundabattula@gmail.com

Abstract: The present work aims to address the heavy mineral studies of coastal sediments. There are three different environments that are studied in the present investigation. They include beach sediments from VUDA Park to Bheemili, coastal red sediments at INS Kalinga area and sediments from Gosthani estuary sub-environments. The interpretation of heavy mineral data sets indicates that the nature and presence of similar heavy mineral assemblage in a beach sub-environments, coastal red sediments, and Gosthani estuary sub-environments suggests that the study area heavy minerals have been derived from the same source of lithologies. The heavy mineral assemblages and their concentrations of heavy minerals in different sub-environments of coastal sediments are derived mainly from metamorphic suite of rocks i.e., Eastern Ghats group of rocks of khondalites and charnockites etc.

The results of the cluster analysis have clearly brought about the importance of variations in the heavy mineral percentages in forming clusters. Application of cluster analysis on the heavy minerals variations resulted in two main clusters. Cluster-1 consists of nine sub-clusters and cluster-2 consists of eight sub-clusters. Beach environment and Gosthani estuary sediments fall under the cluster-1 category. The predominance of coastal red sediments is fall under the cluster-2 category. The clusters and sub-clusters have certain distinct characteristics which make them different from others and hence they have formed separate groups.

Keywords: Heavy minerals, Coastal red sediments, Beach Sands, Gosthani Estuary sediments, Cluster analysis.

INTRODUCTION

The coastline of Andhra Pradesh is situated on the Southeast coast of Indian Peninsula with waters of Bay of Bengal and length of the coastline is 974 kilometers. The coastline endowed with huge recent sediments. These have been attracting the attention of geologists for research in many aspects. The coastal region contains heavy minerals like ilmenite, magnetite, garnet, sillimanite, rutile, zircon, monazite and epidote etc. Each heavy mineral grain is a unique messenger of coded data, carrying the detail of its ancestry and the vicissitudes of its sedimentary history (Maria and David, 2007). The study area situated between the Latitudes 17° 72' and 17° 89' N, Longitudes 83° 34' and 83° 45' E, and covers beach sediments from VUDA park to Bheemili, coastal red sediments at INS Kalinga area and Gosthani estuary sub-environments. The location map of the study area is given in Fig. 1. The geological formations of the study area belong to Archean and Quaternary periods. The Archean rocks comprise mainly khondalites, charnockites, leptynites, pegmatites and quartz veins. Quaternary sediments include laterite and surficial soils and coastal sand deposits.

The coastal red sediments with bad land topography and an area comprising deeply gullied nature abundantly occur near to the INS Kalinga area. It is bounded by streams Chittigadda in the North-West and Peddagadda in the South-West. These sediments are in general loosely packed and are separated from the sea by the modern beach and dune sands. During the Holocene period the heavy winds blown particularly during the monsoon period lot of sediment blown to the interior of the present coast to the edge of Eastern Ghats. This activity promotes the accumulation of huge sands and later the sands became as coastal red sediments. Today, the coastal red sediments are one of the only three such existing formations in South East Asia, the other two being in Tamil Nadu (Teri Sands), India, and Sri Lanka. The rare natural wonder near INS Kalinga area, which took lot of time to produce these sediments, is about 10 km^2 from the backshore zone to 2.5 km inland and elevation is up to 90 m above Mean Sea Level (MSL). Nature, the great artist has gifted these sublimely beautiful formations. They are geologically important and are classified as "Heritage" since they hold prominent features of geological history of the late Quaternary period and carry the imprints of the fall of sea level and its subsequent rise, the impact of climate, and geological processes of the sediments. That is why it is even more important that these coastal red sediments must be preserved in its original form for future generations to understand the myths of nature. In July 2014, this unique natural heritage site was declared a "Scientifically significant Geo-heritage site" by the Geological Survey of India (GSI), following the efforts of the Geo-Heritage Cell of INTACH (Indian National Trust for Art and Cultural Heritage).

The Gosthani River is an East-flowing river which flows across the southern India state of Andhra Pradesh. This river originates from the Ananthagiri Hills at Borra caves region which is situated in the Eastern Ghats and eventually flows into the Bay of Bengal, forming an estuary at Bheemunipatnam. The river follows a dendritic pattern. This river basin is a tiny one which occupies an area measuring about 2000 km^2. A major portion of this basin is covered the Eastern Ghat rocks. Gosthani River is fed by rainfalls and it is said to enjoy about 110 cm of rainfall, which arrives from the Southwest monsoon. The Gosthani estuary situated 30 km North of Visakhapatnam city on the East coast of India. The estuary includes different sub-environments of swash bar, barrier bar, estuary bar and back barrier etc. has been included in the present study.

PREVIOUS WORK AND OBJECTIVE OF THE STUDY

Several workers have been made to their attempts to study the heavy minerals occurrences along the East Coast of India. The monazite and other black sand concentrations of heavy minerals at Bay of Bengal Coast have been described by Mahadevan and Sriramdas (1948), Mahadevan and Nateswararao (1950) and Sriramdas (1951). In the East Coast, heavy mineral variation in the delta and shelf sediments between Visakhapatnam and the Penner River was reported by Mallik (1968). Detailed studies of zircons in the beach sands along East Coast of India have been made (Venkataratnam and Rao, 1968). Concentration of garnet in the sands along Visakhapatnam-Bheemunipatnam Coast was reported by Sastry, et. al., (1981, 1987) have reported the energy conditions and heavy mineral concentration along Visakhapatnam-Bheemunipatnam Coast and Ramamohana Rao, et al., (1982) have reported the occurrence of thin layers of black sand in the inland stream channels along Visakhapatnam-Bheemunipatnam Coastal areas. In Kalingapatnam-Baruva Coast, cheralite was reported by Reddy and Prasad (1997) and heavy mineral distributions in different size fractions and variables were also explained by Reddy and Prasad, (1998). Rajasekhara Reddy, et al., (2009a & 2009b) studied the heavy mineral distribution in different distributaries of the Mahanadi delta of the East Coast of India. Murali Krishna, et al., (2016) studied heavy mineral distribution in Coastal red sediments of Bhimunipatnam. Rajasekhar Reddy (1990) applied cluster analysis to heavy mineral data of shelf sediments off cannanore-Calicut, West coast of India.

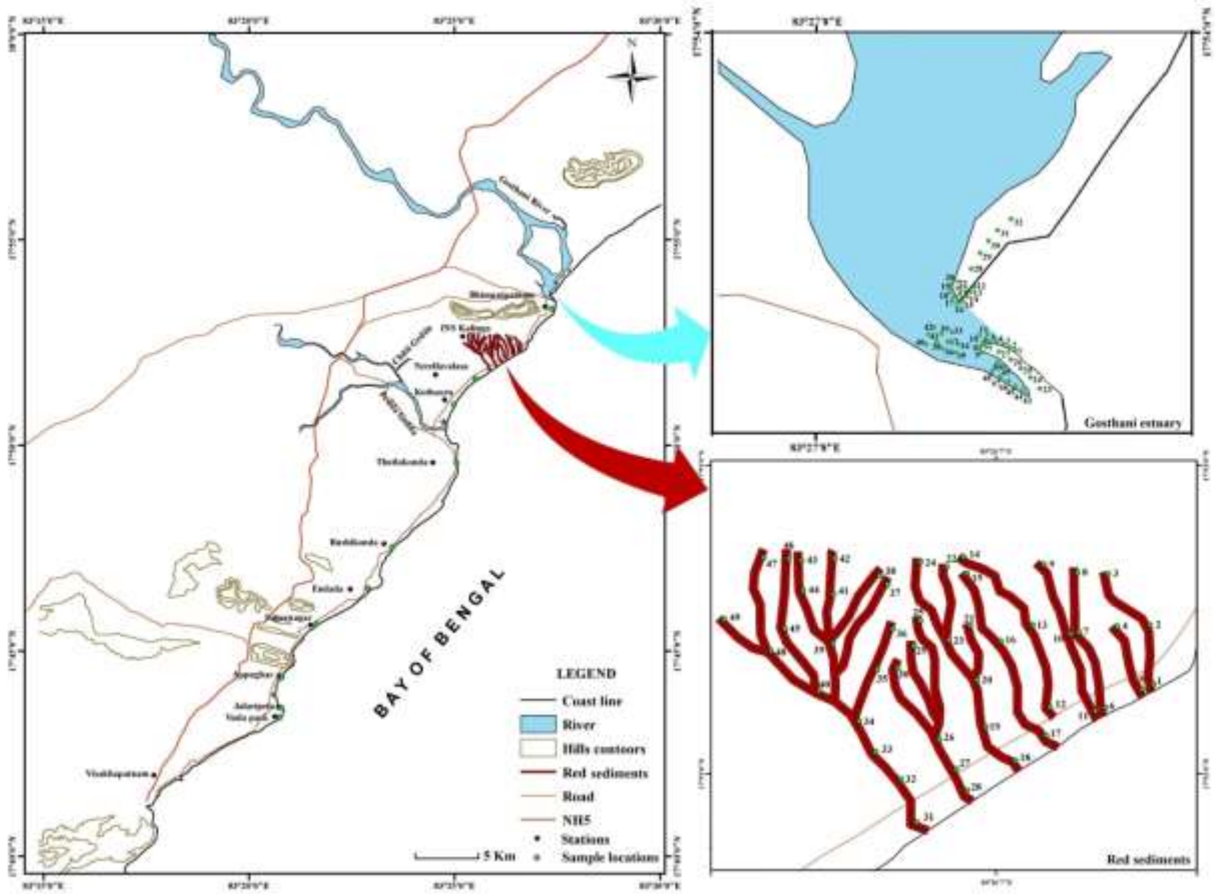

Figure 1: Sample location of the study area.

Karuna karudu (2012) applied cluster analysis to heavy mineral data of different sub-environments of Mahanadi delta, East Coast of India. The present paper is the continuation of this work and deals with the results of detailed studies, carried out on heavy mineral studies in order to throw light on the provenance.

METHODOLOGY

A total of ninety-six sediment samples were used for heavy mineral analysis, in which twenty-nine sediment samples from beach environments, forty-nine sediment samples from coastal red sediments and eighteen sediment samples from Gosthani estuary sub-environments. The following procedure has been adopted for heavy mineral analysis. The samples were thoroughly washed through 230 ASTM mesh sieve with water to remove clay and silt material. The washed samples were treated with a few ml of dilute hydrochloric acid to remove any carbonate shell. The addition of small amount of stannous chloride accelerates the removal of the iron coating. Then the samples were dried and sieved into three ASTM size fractions viz. +60 (+0.25 mm), -60 to +120 (-0.25 to +0.125 mm) and -120 to +230 (-

0.125 to +0.063 mm). Heavy minerals from the sand fractions have been separated using bromoform (sp. gr. 2.89). After separation, the heavy and light fractions were weighed and their weight percentages were calculated. The heavies were mounted on a glass slide with Canada balsam. About 300-400 grains in each slide were identified using by petrological microscope and counted for determination of individual number percentages and nature, origin, and distribution of heavy mineral of coastal sediments were interpreted. Cluster analysis is done using Statistica software.

RESULTS AND DISCUSSION

Range and average values of heavy mineral composition by weight percentage of different sub-environments of coastal sediments in +60, +120 and +230 fractions are present in table 1. Cluster analysis is carried out on the heavy mineral data of beach environment (foreshore, backshore, and dune), coastal red sediments and Gosthani estuary sediments (swash bar, barrier bar, estuary bar and back barrier) are presented in table 2 and Average heavy mineral percentages of different clusters are present in table 3.

+60 Fraction								
Environment	**Range**	**Sillimanite**	**Garnet**	**Epidote**	**Zircon**	**Monazite**	**Rutile**	**Opaques**
Foreshore	Min.	10.79	11.65	0.57	0.00	0.85	0.50	28.43
	Max.	44.49	38.63	1.32	1.84	10.82	13.31	55.67
	Av.	24.66	26.75	0.88	1.29	3.66	3.21	38.34
Backshore	Min.	10.60	20.87	1.13	1.58	0.78	0.00	14.35
	Max.	50.92	49.25	3.20	7.62	12.10	2.81	35.17
	Av.	32.01	29.16	1.76	3.64	4.67	1.70	25.38
Dune	Min.	8.13	24.62	0.45	1.20	0.00	0.00	15.08
	Max.	35.48	46.92	2.60	9.18	9.31	8.35	43.83
	Av.	22.56	34.09	1.52	4.37	3.40	4.01	27.98
Coastal red sediments	Min.	2.24	0.00	0.00	0.00	0.00	0.00	27.67
	Max.	70.26	2.97	0.00	4.97	8.58	3.03	88.34
	Av.	20.70	0.19	0.00	1.55	1.14	0.30	69.22
Swash bar	Min.	3.93	10.21	0.07	0.00	0.00	0.00	33.83
	Max.	36.08	31.26	1.55	2.01	2.99	2.45	74.64
	Av.	18.21	22.23	0.72	0.69	1.07	1.11	51.76
Barrier bar	Min.	8.22	13.12	0.49	0.13	1.34	0.80	55.05
	Max.	14.78	23.02	1.18	1.66	2.36	1.43	71.81
	Av.	10.78	16.75	0.72	0.97	1.81	1.11	65.97

Estuary bar	Min.	14.77	17.82	0.46	0.41	0.93	0.56	33.84
	Max.	25.80	26.94	1.29	1.24	1.56	0.98	62.16
	Av.	21.08	22.82	0.84	0.94	1.17	0.82	47.61
Back barrier	Min.	18.45	14.88	1.07	0.06	0.05	0.04	39.61
	Max.	23.81	25.30	1.32	1.61	1.40	1.13	48.94
	Av.	21.42	19.27	1.22	0.58	0.50	0.42	44.38
+120 Fraction								
Foreshore	Min.	9.84	7.19	0.63	0.85	0.83	0.54	29.99
	Max.	47.61	43.29	1.56	3.15	10.82	13.31	55.67
	Av.	25.17	22.18	1.13	1.62	3.51	3.11	42.45
Backshore	Min.	14.35	1.97	1.32	1.74	0.86	0.48	22.04
	Max.	35.51	34.09	2.17	7.62	11.08	8.35	62.28
	Av.	29.00	16.04	1.70	3.36	3.63	3.80	41.01
Dune	Min.	24.17	13.12	1.57	1.76	0.84	0.59	15.08
	Max.	43.83	38.77	2.35	9.18	9.31	2.81	44.93
	Av.	31.58	25.55	1.89	4.35	3.54	1.55	29.84
Coastal red sediments	Min.	0.00	0.00	0.00	0.00	0.00	0.00	37.63
	Max.	32.77	6.46	0.00	4.57	7.99	2.10	88.57
	Av.	15.65	0.24	0.00	1.85	1.88	0.64	74.73
Swash bar	Min.	4.57	10.62	0.37	0.36	0.12	0.77	30.24
	Max.	49.21	22.11	3.23	3.55	2.72	3.21	74.95
	Av.	19.97	16.85	0.89	1.46	1.33	1.80	54.97
Barrier bar	Min.	5.30	4.49	0.40	1.88	1.93	1.50	70.28
	Max.	8.49	11.71	1.11	3.03	4.31	2.10	80.02
	Av.	7.01	9.25	0.71	2.60	3.23	1.87	73.64
Estuary bar	Min.	4.99	7.49	0.20	1.31	1.88	1.97	52.28
	Max.	16.94	19.40	1.28	4.15	2.13	3.62	80.57
	Av.	12.74	13.86	0.71	2.46	2.00	2.65	64.02
Back barrier	Min.	23.99	16.44	0.41	0.22	0.19	0.42	40.09
	Max.	29.86	25.95	1.04	0.64	0.84	0.90	50.22
	Av.	27.57	20.27	0.76	0.41	0.43	0.73	45.94
+230 Fraction								
Foreshore	Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max.	14.72	7.44	1.37	5.05	0.52	0.68	99.13
	Av.	5.17	3.41	0.48	1.19	0.10	0.26	77.66
Backshore	Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max.	16.69	5.74	1.39	4.78	1.09	1.10	89.90
	Av.	5.48	1.71	0.55	1.44	0.30	0.33	55.88
Dune	Min.	0.39	0.35	0.00	0.56	0.00	0.00	84.23

	Max.	6.65	6.41	0.55	4.91	0.52	1.19	91.34
	Av.	2.97	2.88	0.09	2.54	0.13	0.64	88.94
Coastal red sediments	Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max.	21.19	3.21	0.00	5.60	4.51	1.36	90.48
	Av.	5.75	0.13	0.00	1.34	1.22	0.30	42.45
Swash bar	Min.	2.59	3.81	0.00	0.00	0.00	0.00	35.85
	Max.	25.17	41.86	2.71	9.20	5.71	3.52	79.68
	Av.	12.06	17.20	0.82	2.16	1.79	1.58	59.93
Barrier bar	Min.	2.00	4.10	0.12	1.56	5.22	0.81	76.89
	Max.	2.69	4.47	0.66	6.73	6.01	2.28	83.43
	Av.	2.44	4.26	0.33	4.99	5.53	1.76	79.43
Estuary bar	Min.	4.43	4.81	0.44	3.16	1.59	1.08	59.20
	Max.	7.09	8.00	0.91	5.96	3.41	2.30	77.51
	Av.	5.40	6.78	0.66	4.51	2.72	1.74	70.98
Back barrier	Min.	20.15	16.13	0.32	0.28	1.00	0.83	36.69
	Max.	25.58	18.35	2.16	1.56	1.75	1.67	54.64
	Av.	23.37	17.02	1.53	0.76	1.30	1.16	43.20

Table 1: Range and average values of heavy mineral composition by weight percentage of different sub-environments of coastal sediments in +60, +120 and +230 fractions.

Description and distribution pattern of individual heavy minerals of fraction wise variations of different sub-environments.

Sillimanite: The sillimanite grains in the present study area are found as prismatic and acicular in nature, and these grains are showing perfect cleavage, elongated, angular edges sometimes rounded at termination. They show moderate relief, non-pleochroic and straight extinction.

In **+60** fraction (Table 1), the concentration of sillimanite is higher in backshore with range 10.60 to 50.92 %, av. 32.01 % then in foreshore with range 10.79 to 44.49 %, av. 24.66 %, dune with range 8.13 to 35.48 %, av. 22.56 %, back barrier with range 18.45 to 23.81 %, av. 21.42 %, estuary bar with range 14.77 to 25.80 %, av. 21.08 %, coastal red sediments with range 2.24 to 70.26 %, av. 20.70 %, swash bar with range 3.93 to 36.0 %, av. 18.21 %, barrier bar with range 8.22 to 14.78 %, av.10.78 %.

In **+120** fraction (Table 1), the concentration of sillimanite are higher in dune with range 24.17 to 43.83 %, av. 31.58 % then in backshore with range 14.35 to 35.51 %, av. 29.00 %, back barrier with range 23.99 to 29.86 %, av. 27.57 %, foreshore with range 9.84 to 47.61 %, av.

25.17 %, swash bar with range 4.57 to 49.21 %, av. 19.97 %, coastal red sediments with range 0 to 32.77 %, av.15.65 %, estuary bar with range 4.99 to 16.94%, av.12.74%, barrier bar with range 5.30 to 8.49 %, av. 7.01 %.

In **+230** fraction (Table 1), the concentration of sillimanite are higher in back barrier with range 20.15 to 25.58 %, av. 23.37 % then in swash bar with range 2.59 to 25.17 %, av. 12.06 %, coastal red sediments with range 0 to 21.19 %, av.5.75 %, backshore with range 0 to 16.69 %, av.5.48 %, estuary bar with range 4.43 to 7.09 %, av.5.40 %, foreshore with range 0 to 14.72 %, av.5.17 %, dune with range 0.39 to 6.65 %, av.2.97 %, barrier bar with range 2 to 2.69 %, av.2.44 %.

Garnet: Garnet grains are generally pale pink in colour and the shape of the garnets is rounded or sub-rounded and occasionally sub-spherical. They are usually identified by their high relief, isotropic nature and inclusions of iron oxides are seen occasionally

In **+60** fraction (Table 1), the concentrations of garnet are higher in dune with range 24.2 to 46.92 %, av. 34.09 % then in backshore with range 20.87 to 49.25 %, av. 29.16 %, foreshore with range 11.65 to 38.63 %, av.26.75 %, estuary bar with range 17.82 to 26.94 %, av. 22.82 %, swash bar with range 10.21 to 32.26 %, av. 22.23 %, back barrier with range 14.88 to 25.30 %, av.19.27 %, barrier bar with range 13.12 to 23.02 %, av.16.75 %, coastal red sediments with range 0 to 2.97 %, av. 0.19 %.

In **+120** fraction (Table 1), the concentration of garnet are higher in dune with range 13.12 to 38.77 %, av. 25.55 % then in foreshore with range 7.19 to 43.29 %, av. 22.18 %, back barrier with range 16.44 to 25.95 %, av. 20.27 %, swash bar with range 10.62 to 22.11 %, av. 16.85 %, backshore with range 1.97 to 34.09 %, av.16.04 %, estuary bar with range 7.49 to 19.40 %, av. 13.86 %, barrier bar with range 4.49 to 11.71%, av. 9.25%, coastal red sediments with range 0 to 6.46 %, av. 0.24 %.

In **+230** fraction (Table 1) the concentration of garnet are higher in swash bar with range 3.81 to 41.86 %, av. 17.20 %, then in back barrier with range 16.13 to 18.35 %, av. 17.02 %, estuary bar with range 4.81 to 8.00 %, av. 6.78 %, barrier bar with range 4.10 to 4.47 %, av. 4.26 %, foreshore with range 0 to 7.7.44 %, av. 3.41 %, dune with range 0.35 to 6.41 %, av. 2.88 %, backshore with range 0 to 5.74 %, av. 1.71 %, coastal red sediments with range 0 to 3.21 %, av. 0.13%.

Epidote: Epidote is also one of the minor constituents of heavy minerals. Most of the grains are in colourless and some are yellow, greenish in colour with subrounded in shape and they show pleochroism.

In **+60** fraction (Table 1), the concentration of epidote are higher in backshore with range 1.13 to 3.20 %, av. 1.76 % then in dune with range 0.45 to 2.60 %, av. 1.52 %, back barrier with range 1.07 to 1.32 %, av. 1.22 %, foreshore with range 0.57 to 1.32 %, av. 0.88 %, estuary bar with range 0.46 to 1.29 %, av. 0.84 %, swash bar with range 0.07 to 1.55%, av. 0.72 %, barrier bar with range 0.49 to 1.88 % av. 0.72 %.

In **+120** fraction (Table 1), the concentration of epidote are higher in dune with range 1.57 to 2.35 %, av. 1.89 % then in backshore with range 1.32 to 2.17 %, av. 1.70 %, foreshore with range 0.63 to 1.56 %, av. 1.13 %, swash bar with range 0.37 to 3.23 %, av. 0.89 %, back barrier with range 0.41 to 1.04 %, av. 0.76 %, estuary bar with range 0.20 to 1.28 %, av. 0.71 %, barrier bar with range 0.40 to 1.11%, av. 0.71 % .

In **+230** fraction (Table 1), the concentration of epidote are higher in back barrier with range 0.32 to 2.16 %, av. 1.53 % then in swash bar with range 0 to 2.71 %, av. 0.82 %, estuary bar with range 0.44 to 0.91 %, av. 0.66 %, backshore with range 0 to 1.39 %, av. 0.55 %, foreshore with range 0 to 1.37 %, av. 0.48 %, barrier bar with range 0.12 to 0.66 %, av. 0.33 %, dune with range 0 to 0.55 %, av. 0.09 %.

Zircon: Morphologically zircon grains varies from sharp euhedral crystals through prismatic and anhedral fragments, grains with gently rounded terminations to well-rounded forms and complete spheres sometimes. In the present study, most of the zircon grains are rounded and subrounded with thick borders and colourless, but a few shows yellowish colour. The refractive index is fairly high, strong birefringence and uniaxial positive. Zoning is a characteristic feature of these grains.

In **+60** fraction (Table 1), the concentration of zircon are higher in dune with range 1.20 to 9.18 %, av. 4.37 % then in backshore with range 1.58 to 7.62 %, av. 3.64 %, coastal red sediments with range 0 to 4.97 %, av. 1.55 %, foreshore with range 0 to 1.84 %, av. 1.29 %, barrier bar with range 0.13 to 1.66 %, av. 0.97 %, estuary bar with range 0.41 to 1.24 %, av. 0.94 %, swash bar with range 0 to 2.01 %, av. 0.69 %, back barrier with range 0.06 to 1.61 %, av. 0.58 %.

In **+120** fraction (Table 1), the concentration of zircon are higher in dune with range 1.76 to 9.18 %, av. 4.35 % then in backshore with range 1.74 to 7.62 %, av. 3.36 %, barrier bar with range 1.88 to 3.03 %, av. 2.60 %, estuary bar with range 1.31 to 4.15 %, av. 2.46 %, coastal red sediments with range 0 to 4.57 %, av. 1.85 %, foreshore with range 0.85 to 3.15 %, av.

1.62 %, swash bar with range 0.36 to 3.55 %, av. 1.46 %, back barrier with range 0.22 to 0.64 %, av. 0.41 %.

In **+230** fraction (Table 1), the concentration of zircon are higher in barrier bar with range 1.56 to 6.76 %, av. 4.99 % then in estuary bar with range 3.16 to 5.96 %, av. 4.51 %, dune with range 0.56 to 4.91 %, av. 2.54 %, in swash bar with range 0 to 9.20 %, av. 2.16 %, backshore with range 0 to 4.78 %, av. 1.44 %, coastal red sediments with range 0 to 5.60 %, av. 1.34 %, foreshore with range 0 to 5.05%, av. 1.19 %, back barrier with range 0.28 to 1.56 %, av. 0.76 %.

Monazite: The most of the monazite grains are rounded. The light yellow colour is the characteristic property of this mineral. They show high relief with distinct borders. A few grains are faintly pleochroic with moderate birefringence.

In **+60** fraction (Table 1), the concentration of monazite are higher in backshore with range 0.78 to 12.10 %, av. 4.67 % then in foreshore with range 0.85 to 10.82 %, av. 3.66 %, dune with range 0 to 9.31 %, av. 3.40 %, in barrier bar with range 1.34 to 2.36 %, av. 1.81 %, estuary bar with range 0.93 to 1.56 %, av. 1.17 %, coastal red sediments with range 0 to 8.58 %, av. 1.14 %, swash bar with range 0 to 2.99 %, av. 1.07%, back barrier with range 0.05 to 1.40 %, av. 0.50 %.

In **+120** fraction (Table 1) the concentration of monazite are higher in backshore with range 0.86 to 11.08 %, av. 3.63 % then in dune with range 0.84 to 9.31 %, av. 3.54 %, foreshore with range 0.83 to 10.82 %, av. 3.51 %, barrier bar with range 1.93 to 4.31 %, av. 3.23 %, estuary bar with range 1.88 to 2.13 %, av. 2.00 %, coastal red sediments with range 0 to 7.99 %, av. 1.88 %, swash bar with range 0.12 to 2.72 %, av. 1.33 %, back barrier with range 0.19 to 0.84 %, av. 0.43 %.

In **+230** fraction (Table 1), the concentration of monazite are higher in barrier bar with range 5.22 to 6.01 %, av. 5.53 % then in estuary bar with range 1.59 to 3.41 %, av. 2.72 %, swash bar with range 0 to 5.71 %, av. 1.79 %, back barrier with range 1.00 to 1.75 %, av. 1.30 %, coastal red sediments with range 0 to 4.51 %, av. 1.22 %, back shore with range 0 to 1.09 %, av. 0.30 %, dune with range 0 to 0.52 %, av. 0.13 %, foreshore with range 0 to 0.52 %, av. 0.10 %.

Rutile: Most of the rutile grains are shades of red, such as deep blood red and brownish red in colour, showing prismatic and pyramidal terminations. In some samples grains showing irregular or conchoidal breakage patterns. 'Knee-shaped' twins and parallel crystal growths are encountered in some samples. They show high relief, deep colours, pleochroic and straight extinction.

In **+60** fraction (Table 1), the concentration of rutile are higher in dune with range 0 to 8.35 %, av. 4.01 % then in foreshore with range 0.50 to 13.31 %, av. 3.21 %, backshore with range 0 to 2.81 %, av. 1.70 %, swash bar with range 0 to 2.45 %, av. 1.11 %, barrier bar with range 0.80 to 1.43 %, av. 1.11 %, estuary bar with range 0.56 to 0.98 %, av. 0.82 %, back barrier with range 0.04 to 1.13 %, av. 0.42 %, coastal red sediments with range 0 to 3.03 %, av. 0.30 %.

In **+120** fraction (Table 1), the concentration of rutile are higher in backshore with range 0.48 to 8.35 %, av. 3.80 % then in foreshore with range 0.54 to 13.31 %, av. 3.11 %, estuary bar with range1.97 to 3.62 %, av.2.65 %, barrier bar with range 1.50 to 2.10 %, av. 1.87 %, swash bar with range 0.77 to 3.21 %, av. 1.80 %, dune with range 0.59 to 2.81 %, av. 1.55 %, back barrier with range 0.42 to 0.90 %, av. 0.73 %, coastal red sediments with range 0 to 2.10 %, av. 0.64 %.

In **+230** fraction (Table 1), the concentration of rutile are higher in barrier bar with range 0.81 to 2.28 %, av. 1.76 % then in estuary bar with range 1.08 to 2.30 %, av. 1.74 %, swash bar with range 0 to 3.52 %, av. 1.58 %, in back barrier with range 0.83 to 1.67 %, av. 1.16 %, dune with range 0 to 1.19 %, av. 0.64 %, back shore with range 0 to 1.10 %, av. 0.33 %, coastal red sediments with range 0 to 0.36 %, av. 0.30 %, foreshore with range 0 to 0.68 %, av. 0.26 %.

Opaques: The opaques consist of magnetite and ilmenite, the ilmenite being dominant. Opaques are present in a good proportion and are rounded, subrounded and sub-angular in the shape and black in colour. It has been observed that a few grains show a dull grey luster in patches, under the reflected light ilmenite will look like its altered product leucoxene.

In **+60** fraction (Table 1), the concentration of opaques are higher in coastal red sediments with range 27.67 to 88.34 %, av. 69.22 % then in barrier bar with range 55.05 to 71.81 %, av. 65.97 %, swash bar with range 33.83 to 74.64 %, av. 51.76 %, estuary bar with range 33.84 to 62.16 %, av. 47.61 %, back barrier with range 39.61 to 48.94 %, av. 44.38 %, foreshore with range 28.43 to 55.67 %, av. 38.34 %, dune with range 15.08 to 43.83 %, av. 27.98 %, backshore with range 14.35 to 35.17 %, av. 25.38 %.

In **+120** fraction (Table 1), the concentration of opaques are higher in coastal red sediments with range 37.63 to 88.57 %, av. 74.73 % compared to barrier bar with range 70.28 to 80.02 %, av. 73.64 %, in estuary bar with range 52.28 to 80.57 %, av. 64.02 %, in swash bar with range 30.24 to 74.95 %, av. 54.97 %, in back barrier with range 40.09 to 50.22 %, av. 45.94 %, in foreshore with range 29.99 to

55.67 %, av. 42.45 %, in backshore with range 22.04 to 62.28 %, av. 41.01 %, in dune with range 15.08 to 44.93 %, av. 29.84 %.

In **+230** fraction (Table 1), the concentration of opaques are higher in dune with range 84.23 to 91.34 %, av. 88.94 % then in barrier bar with range 76.89 to 83.43 %, av. 79.43 %, foreshore with range 0 to 99.13 %, av. 77.66 %, in estuary bar with range 59.20 to 77.51 %, av. 70.98 %, swash bar with range 35.85 to 79.68 %, av. 59.93 %, back shore with range 0 to 89.90 %, av. 55.88 %, back barrier with range 36.69 to 54.64 %, av. 43.20 %, coastal red sediments with range 0 to 90.48 %, av. 42.45 %.

Heavy mineral distribution in different sub-environments of Beach environment, Coastal red sediments and Gosthani estuary sub-environments:

Beach environment: Sillimanite, Monazite and Rutile are abundant in coarse (+60), medium (+120) size fractions and show decrease towards fine size (+230) in foreshore, backshore and dune. Opaques are concentrated more in finer fraction (+230) than in the coarser (+60), medium (+120) fractions and increasing gradually from <+60 to +230 in beach environments. Epidote and zircon are concentrated more in coarse size (+60) and medium size (+120) than in the finer fraction and decrease gradually from <+60 to +230 in backshore and dune whereas epidote and zircon are concentrated more in fine fraction (+230 ASTM) and increasing gradually from <+60 to +230 ASTM in foreshore sediments.

Coastal red sediments: Sillimanite, Monazite and Rutile are concentrated more in coarse fraction (+60), than in the finer fraction (+230) and decreases gradually from <+60 to +230. Opaques are concentrated more in finer fraction (+230) than in the coarser fraction and increases gradually from <+60 to +230.

The garnet concentrations are low in coastal red sediments compared to beach and Gosthani sub-environments and the grains of garnets are insignificant and found to be occurring in highly altered state and show leached and pitted surfaces, which indicates that garnets might have been undergone chemical decomposition under acidic conditions which led to produce iron oxides (Hematite) causes for red colorization of the sediment. The stability of members of the garnet group varies according to their chemistry. Dana, (1985) and Allen, (1948) observed that garnets with high ferrous iron content were particularly prone to disintegration in their investigation.

Gosthani estuary sub-environments: Garnets are concentrated more in coarse fraction (+60), than in the fine fraction (+230) in barrier bar, estuary bar and back barrier and in swash bar concentration more in (+230) fraction compared to coarse fraction (+60). Sillimanite concentration more in (+60) fraction than in the finer fraction (+230) in swash bar, barrier bar and estuary bar. Zircons are concentrated more in finer fractions (+230) than in the coarser fraction and increases gradually from <+60 to +230 in swash bar, barrier bar and estuary bar. Opaques are concentrated more in finer fraction (+230) than in coarse fraction and increases gradually from <+60 to +230 in swash bar, barrier bar and back barrier. Monazite and rutile are concentrated more in (+230) fraction compared to other fractions in swash bar, barrier bar and back barrier.

CLUSTER ANALYSIS OF HEAVY MINERAL DATA

'Cluster' is "a number of things of the same kind growing or joined together', or a group of homogeneous things. The term cluster analysis was first used by (Tryon, 1939) actually, encompasses a number of different classification algorithms. According to Kaufman and Rousseeuw (2005) objects in the same group are similar to each other and objects in different groups are as dissimilar as possible. The use of cluster methods has increased dramatically in the last 30 years, nowadays clustering methods are applied in many domains, including artificial intelligence and pattern recognition, ecology, economics, the geosciences, and much more. Clustering methods are useful whenever the researcher is interested in grouping together objects based on multivariate similarity.

The heavy minerals considered for the present study are sillimanite, garnet, epidote, zircon, monazite, rutile, opaques. The results of cluster analysis show that there are two major clusters. Cluster-1 contains nine sub-clusters and cluster-2 contains eight sub-clusters. The clusters and sub-clusters have certain distinct characteristics which make them different from others and hence they have formed separate groups.

Cluster-1: Beach environments (foreshore, backshore, and dune) and Gosthani estuary sediments (swash bar, barrier bar, estuary bar and back barrier) are falls under the cluster-1 category. The average heavy mineral percentages of different clusters are presented in table 3. The cluster-1 is characterized by high opaques, sillimanite, and garnet. Within the cluster-1 there are nine sub-clusters. Sillimanite percentage is low at sub cluster-1G and high at sub cluster-1A; garnet percentage is low at sub cluster-1H and high at sub cluster-1I; epidote percentage is low at sub cluster-1G and high at sub cluster-1C; zircon percentage is low at sub cluster-1D and high at sub cluster-1I;

monazite percentage is low at sub cluster-1A and high at sub cluster-1I; Rutile percentage is low at sub cluster-1A and high at sub cluster-1I; opaques percentage is low at sub cluster-1I and high at sub cluster-1F.

Cluster-2: The predominance of coastal red sediments is fall under the cluster-2 category. The cluster-2 is characterized by high opaques and sillimanite. Within the cluster-2 there are eight sub-clusters. Sillimanite percentage is low at sub cluster-2B and high at sub cluster-2G; garnet percentage is low at sub cluster-2E and high at sub cluster-2A; epidote percentage high at sub cluster-2A and remaining all sub-clusters are indicated low; zircon percentage is low at sub cluster-2B and high at sub cluster-2F; monazite percentage is low at sub cluster-2G and high at sub cluster-2D; rutile percentage is low at sub cluster-2D and high at sub cluster-2A; opaques percentage is low at sub cluster-2G and high at sub cluster-2B.

S. No.	Sillimanite	Garnet	Epidote	Zircon	Monazite	Rutile	Opaques
1-F/V	31.08	22.91	1.28	1.64	1.29	1.07	39.92
2-F/J	17.25	18.21	1.32	2.75	6.29	0.63	52.52
3-F/A	33.11	13.41	1.07	1.57	0.80	0.74	48.57
4-F/S	18.14	17.81	0.82	1.32	7.27	0.86	53.06
5-F/R	23.16	10.06	0.90	1.81	1.92	0.64	60.63
6-F/E	18.55	13.30	0.50	0.68	0.92	9.05	56.03
7-F/T	7.44	18.20	0.48	0.84	0.78	0.97	70.16
8-F/K	12.70	28.39	0.85	1.43	1.15	0.63	54.02
9-F/N	13.94	22.35	0.69	0.78	1.80	5.50	53.73
10-B/V	30.24	15.88	2.02	2.27	1.31	1.23	45.39
11-B/J	24.03	10.17	2.01	2.26	1.44	0.74	57.67
12-B/A	21.93	11.25	1.67	2.58	7.44	2.55	50.83
13-B/S	22.66	11.47	1.34	2.81	0.72	3.66	55.51
14-B/R	23.44	12.95	1.35	4.23	2.77	2.10	51.68
15-B/E	33.65	28.35	1.31	4.38	0.83	5.41	24.72
16-B/T	23.06	36.75	1.42	7.62	6.95	0.68	22.04
17-B/K	25.77	16.74	1.20	1.11	4.73	3.01	46.27
18-B/N	23.70	24.17	1.31	2.85	2.66	0.53	43.39
19-D/V	20.44	15.16	1.65	5.27	4.70	0.73	50.24
20-D/J	16.74	20.31	1.59	6.50	1.52	0.99	50.39
21-D/A	21.26	15.82	1.69	2.18	2.76	2.49	51.82
22-D/S	18.13	20.11	1.35	2.33	2.37	1.05	52.66
23-D/R	16.85	16.27	1.05	3.11	1.87	3.89	55.24

24-D/E	21.42	21.38	0.77	4.93	0.76	2.44	46.46
25-D/T	13.38	27.07	0.96	2.10	0.45	3.79	50.48
26-D/K	20.71	28.62	0.78	2.31	0.42	2.69	42.54
27-D/N	22.40	22.84	0.67	5.04	6.38	0.55	40.46
28-CR	12.35	0.69	0.00	2.50	2.04	0.39	78.43
29-CR	13.50	0.09	0.00	1.54	2.28	0.34	80.36
30-CR	14.82	0.04	0.00	0.79	1.95	0.52	80.61
31-CR	17.47	3.51	0.00	1.89	1.17	0.30	70.22
32-CR	32.29	0.82	0.00	1.37	0.00	0.36	61.81
33-CR	15.24	0.06	0.00	2.57	1.21	0.18	78.01
34-CR	15.31	0.09	0.00	1.46	0.66	0.25	78.67
35-CR	20.24	0.00	0.00	0.74	0.24	0.00	75.38
36-CR	23.88	1.06	0.00	1.41	0.80	0.53	61.11
37-CR	13.40	0.21	0.00	1.76	1.48	0.80	76.43
38-CR	16.71	0.06	0.00	1.75	0.33	0.51	76.05
39-CR	13.72	0.00	0.00	2.44	0.77	0.65	77.30
40-CR	24.03	0.00	0.00	1.06	0.41	0.33	62.77
41-CR	13.07	0.00	0.00	2.37	0.99	0.84	78.28
42-CR	19.70	0.00	0.00	1.68	0.85	1.05	73.14
43-CR	16.52	0.00	0.00	2.37	1.44	0.90	75.55
44-CR	18.83	0.00	0.00	2.72	0.78	0.63	70.30
45-CR	21.42	0.12	0.00	2.99	0.00	0.45	70.28
46-CR	17.94	0.00	0.00	3.71	1.14	0.75	71.70
47-CR	19.88	0.00	0.00	3.22	0.00	0.35	72.22
48-CR	30.83	0.00	0.00	2.49	0.00	0.66	57.62
49-CR	25.10	0.00	0.00	3.03	0.99	0.47	64.38
50-CR	17.81	0.22	0.00	2.22	1.06	0.56	71.62
51-CR	20.94	0.00	0.00	2.50	0.43	0.52	69.26
52-CR	14.30	0.00	0.00	1.39	0.00	0.70	81.31
53-CR	21.18	0.00	0.00	3.45	2.29	0.54	67.17
54-CR	19.73	0.00	0.00	1.94	0.59	0.39	72.74
55-CR	20.79	0.00	0.00	1.78	0.40	0.00	73.63
56-CR	18.75	0.00	0.00	2.79	2.24	1.01	73.70
57-CR	18.84	0.23	0.00	3.54	1.55	1.70	67.27
58-CR	10.32	0.33	0.00	0.94	5.82	0.89	79.24
59-CR	8.77	0.00	0.00	0.23	4.97	0.11	82.43
60-CR	13.78	0.00	0.00	1.07	4.85	0.00	76.46
61-CR	20.07	0.00	0.00	2.05	2.27	0.30	66.66
62-CR	17.56	0.00	0.00	0.65	1.41	0.24	74.20

63-CR	15.05	0.49	0.00	1.88	4.32	0.17	73.39
64-CR	18.36	0.00	0.00	1.06	2.22	0.19	74.77
65-CR	14.35	0.21	0.00	0.91	1.22	0.57	78.51
66-CR	5.05	0.00	0.00	1.15	0.60	0.84	72.08
67-CR	13.19	0.25	0.00	2.18	3.21	0.19	59.34
68-CR	8.58	0.99	0.00	0.76	1.45	0.00	83.32
69-CR	16.57	0.00	0.00	0.76	6.38	0.69	60.17
70-CR	3.42	0.24	0.00	2.43	1.18	1.08	78.83
71-CR	3.24	0.00	0.00	1.91	4.31	0.34	88.46
72-CR	2.06	0.00	0.00	1.85	2.72	0.56	82.22
73-CR	16.18	0.00	0.00	0.75	0.85	0.00	75.34
74-CR	13.85	0.00	0.00	1.72	2.95	0.54	74.65
75-CR	28.48	0.00	0.00	1.15	0.00	0.00	66.48
76-G/SB	31.86	27.25	0.49	0.25	0.16	0.40	34.20
77-G/SB	22.64	24.37	1.50	0.64	0.09	0.58	43.02
78-G/SB	23.89	17.07	1.61	0.30	0.40	0.62	41.88
79-G/SB	15.75	20.18	0.70	1.20	1.11	1.25	57.75
80-G/SB	17.09	14.96	1.13	2.50	1.44	2.27	57.95
81-G/SB	17.91	20.18	0.90	0.93	0.79	1.82	53.46
82-G/SB	15.39	20.43	0.51	1.28	1.64	2.34	56.01
83-G/SB	13.37	20.53	0.76	1.26	2.80	1.68	58.05
84-G/SB	18.59	26.10	0.54	0.87	0.70	0.93	49.69
85-G/SB	3.70	8.43	0.41	4.70	3.67	2.48	74.45
86-G/SB	13.14	14.33	0.67	1.13	1.37	1.83	66.04
87-G/SB	16.48	19.67	0.56	0.76	1.17	1.46	57.96
88-G/SB	7.93	10.36	0.72	2.81	2.82	1.76	71.74
89-G/BB	8.21	13.01	0.82	1.57	3.96	1.25	69.59
90-G/BB	5.77	7.27	0.37	3.56	3.73	1.67	76.24
91-G/BB	6.24	9.97	0.57	3.42	2.88	1.83	73.21
92-G/EB	8.06	10.04	0.37	3.04	2.28	1.34	73.41
93-G/EB	15.60	18.11	0.69	2.99	2.11	2.16	48.44
94-G/EB	15.56	15.31	1.16	1.88	1.50	1.70	60.76
95-G/BB	22.48	23.20	0.81	1.27	1.33	1.22	47.89
96-G/BB	25.41	15.96	1.26	0.19	0.49	0.48	43.46
97-G/BB	24.46	17.39	1.43	0.29	0.41	0.61	42.17

Table 2: Percentages of heavy mineral data of the study area.

(S. No. 1-27: Beach sediments (Foreshore, Backshore and Dune); S. No. 28-75: Coastal red sediments; S. No. 76-97: Gosthani estuary sediments (swash bar, barrier bar, estuary bar and back barrier)

Cluster-1	**Sillimanite**	**Garnet**	**Epidote**	**Zircon**	**Monazite**	**Rutile**	**Opaques**	**Others**
1A	31.47	25.08	0.88	0.94	0.73	0.74	37.06	3.11
1B	22.22	24.10	0.97	2.84	1.94	1.33	43.96	2.63
1C	29.71	15.34	1.43	1.65	2.28	1.66	46.74	1.19
1D	22.34	17.13	1.25	0.94	0.85	0.97	43.99	12.53
1E	17.63	19.32	1.20	2.76	3.65	1.07	52.42	1.95
1F	15.55	18.71	0.82	1.60	1.67	2.51	57.18	1.96
1G	14.89	27.19	0.78	1.47	0.76	1.79	51.40	1.73
1H	21.94	12.52	1.39	2.73	2.83	2.74	54.30	1.54
1I	28.35	32.55	1.37	6.00	3.89	3.04	23.38	1.43
1(A+B+C+D+E+F +G+H+I)	22.68	21.33	1.12	2.33	2.07	1.76	45.60	3.12
Cluster-2	**Sillimanite**	**Garnet**	**Epidote**	**Zircon**	**Monazite**	**Rutile**	**Opaques**	**Others**
2A	7.56	11.45	0.55	2.63	2.69	1.64	71.85	1.62
2B	6.06	0.26	0.00	1.35	3.41	0.50	82.42	6.00
2C	14.01	0.14	0.00	1.77	1.26	0.52	78.79	3.50
2D	14.22	0.16	0.00	1.56	4.04	0.24	74.83	4.95
2E	18.58	0.01	0.00	1.70	0.96	0.42	74.25	4.22
2F	19.39	0.45	0.00	2.79	1.19	0.64	69.39	6.16
2G	27.44	0.31	0.00	1.75	0.37	0.39	62.36	7.38
2H	11.60	0.08	0.00	1.36	3.40	0.57	63.86	19.11
2(A+B+C+D+E+F +G+H)	14.86	1.61	0.07	1.86	2.17	0.62	72.22	6.62

Table 3: Average heavy mineral percentages of different clusters

Provenance

INS Kalinga area (coastal red sediments) is bounded by small streams Chittigadda in the North-West and Peddagadda in the South-West. An ephemeral river Gosthani flows on the Northern side of the INS Kalinga area and further north of this study area ephemeral rivers like Nagavali, Vamsadhara (originates in the Eastern Ghats Mobile Belt). In the Southern side of the study area, ephemeral rivers like Sarada, Varaha and Tandava originated in the Eastern

Ghats and rocks consisting mainly khondalite and charnockites.

Above stated all the rivers predominantly traversed by the Eastern Ghats Mobile Belt (EGMB). The Eastern Ghats are made up of khondalites and charnockites. Khondalites well foliated with garnet-sillimanite-biotite-feldspathic gneisses. They are mainly derived from metamorphosed products or pelitic sediments and occur in various shades of brown, buff, red, pink and grey. Mineral assemblages in khondalites are garnet ± sillimanite ± potash feldspar +quartz, garnet + biotite + sillimanite + potash feldspar + plagioclase + quartz, garnet + biotite + cordierite + sillimanite + plagioclase + quartz and garnet + biotite + cordierite + plagioclase + quartz (Murthy and Divakara Rao, (1999)). Khondalites are relatively less competent as compared to charnockites, medium to coarse grained and are highly weathered (Chetty, 1999). Excessive leaching of garnets in the rock imparts a dark reddish colour to the rock. The Charnockitic group of rocks includes basic charnockites, acid to intermediate charnockites and hypersthene-gneisses. Basic charnockites (pyroxene granulites) consists of hypersthene, augite/diopside and calcic plagioclase. Acid to intermediate charnockites are consists of potash and sodic feldspar, hypersthene, quartz and garnet are the main constituent minerals. Opaques, apatite, zircon and sphene occur as accessories.

The interpretation of heavy mineral data sets indicates that the nature and presence of similar heavy mineral assemblage in a beach sub-environments, coastal red sediments, and Gosthani estuary sub-environments suggests that the study area heavy minerals have been derived from the same source of lithologies.

From the above, it is clear that the sillimanite comes from khondalite series of Eastern Ghats. The prismatic character of the sillimanite minerals also suggests their derivation from khondalitic rocks. The provenance of garnets is related to Khondalite suite (Garnet – sillimanite – graphite gneisses and schist) of Eastern Ghats, occasionally dark pink garnets are derived from charnockitic rocks (Mallik, 1968). Particularly the grains of garnets in coastal red sediments are highly altered and show leached and pitted surfaces, which indicates that these garnets might have been giving rise to the red colour to the sediments. The Eastern Ghats are considered to be the “home” of well-rounded monazite. This is based on the occurrence of monazite in pegmatites (Mahadevan and Sathapathi, 1948) and charnockites (Murty, 1958) of the Eastern Ghats. The sub-angular grains of magnetite and ilmenite indicates that they might have been derived from nearby sources, i.e.

mainly Eastern Group of rocks (Venkat Ram Reddy, 2015). Zircons are mostly rounded and sometimes euhedral in shape. These euhedral grains are mostly from granitic rocks and to a less extent from charnockites whereas the rounded ones are mainly from khondalites (Rajasekhara Reddy, et. al., 2009a). Epidote is derived from low-grade metamorphic rocks like khondalites (Mallik, 1968) and pyroxene granulites.

Weighted pair-group average Euclidean distances

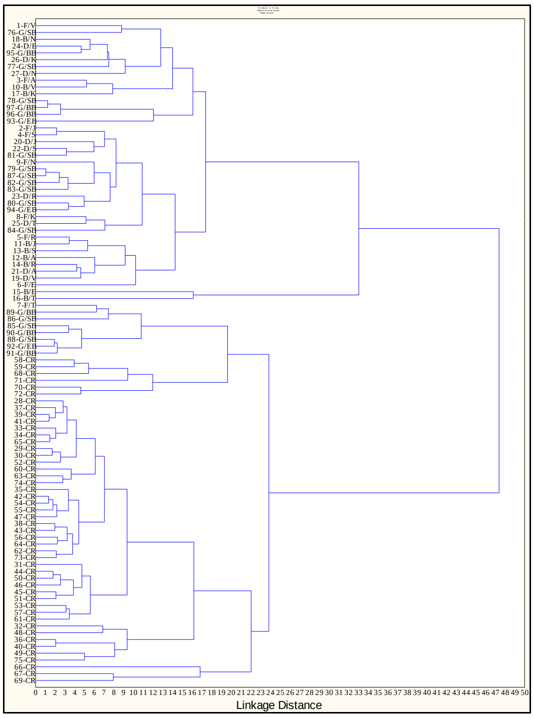

Figure 2: Dendogram

Conclusions

The heavy mineral suite predominantly consists of opaque minerals, sillimanite and garnet followed by minor amounts of zircon, monazite, rutile, and epidote etc.

Heavies are concentrated more in medium fractions (+120) than in coarser and finer fractions in the Gosthani estuary sub-environments, coastal red and dune sediments, whereas heavies are concentrated more in finer fraction (+230) than in the coarser fraction in foreshore and backshore sediments.

Garnets are concentrated more in coarser (+60) than in the finer fraction and decreases gradually from <+60 to +230 ASTM in all sub-environments, except coastal red sediments and swash bar. Opaques are concentrated more in finer fraction (+230) compared to other fractions in all sub-environments, except estuary bar. Sillimanite are concentrated more in medium fraction (+120) fraction compared to other fractions in foreshore, dune, swash bar and back barrier environments whereas sillimanite increases gradually from <+60 to +230 ASTM in back shore, coastal red sediments, barrier bar, and estuary bar.

The garnet concentrations are low in coastal red sediments compared to beach and Gosthani sub-environments and the grains of garnets are insignificant and found to be occurring in highly altered state and show leached and pitted surfaces, which indicates that garnets might have been undergone chemical decomposition under acidic conditions which led to produce iron oxides causes for red colorization of the sediment. The stability of members of the garnet group varies according to their chemistry. Dana, (1985) and Allen, (1948) observed that garnets with high ferrous iron content were particularly prone to disintegration in their investigation.

The interpretation of heavy mineral data sets indicates that the nature and presence of similar heavy mineral assemblage in a beach sub-environments, coastal red sediments, and Gosthani estuary sub-environments suggests that the study area heavy minerals have been derived from the same source of lithologies. The heavy mineral assemblages and their concentrations of heavy minerals in different sub-environments of coastal sediments are derived mainly from metamorphic suite of rocks i.e., Eastern Ghats group of rocks of khondalites and charnockites.

The results of the cluster analysis have clearly brought about the importance of variations in the heavy mineral percentages in forming clusters. Application of cluster analysis on the heavy minerals variations resulted in two main clusters. Cluster-1 consists of nine sub-clusters and cluster-2 consists of eight sub-clusters. Beach environment (foreshore, backshore, and dune) and Gosthani estuary sediments (swash bar, barrier bar, estuary bar and back barrier) fall under the cluster-1 category. The predominance of coastal red sediments is fall under the cluster-2 category. The cluster-1 is characterized by high opaques, sillimanite, and garnet whereas cluster-2 is characterized by high opaques and sillimanite. The sub-clusters that formed within the major clusters represent the small variations in their characteristics minerals.

Acknowledgement

Authors are thankful to Prof. C.V. Raman, former Director, Delta Studies Institute and former principal, College of Science and Technology, Andhra University for valuable guidance and extending the lab facilities to carry out this research work.

References

Allen, V.T., (1948). Weathering and heavy minerals. Jour. Sedim. Petrol., 18, 38-42.

Chetty, T.R.K., (1999). Evolution of the Eastern Ghats granulite belt (Phase I), Terminal Report, NGRI, Hyderabad.

Dana, E.S., (1985). The system of mineralogy of James Dwight Dana, 6th edn. New York: Wiley, 1134.

Karuna Karudu, T., (2012). Textural and heavy mineral characteristics of different sub-environments of Mahanadi delta, East coast of India. Ph.D. Thesis submitted to Andhra University.

Kaufman. L. and Rousseeuw, P.J (2005). Finding groups in data. An introduction to cluster analysis. Wiley, Hoboken, NY.

Mahadevan. C. and Nateswararao, B. (1950). Black sand concentrates in Vizagpatnam coast. Curr. Sci., 19, 48-49.

Mahadevan, C. and Sathapati, N. (1948). The home of Monozites in the Vizagapatnam area. Curr. Sci., 17, 297.

Mahadevan, C. and Sriramdas, A. (1948). Monazites in the beach sands of Vizagapatam District. Proc. Ind. Acad. Sci., 27, 275-27.

Mallik, T.K., (1968). Heavy minerals of shelf sediments between Vishakhapatnam and the Penner delta, eastern coast of India. Bull. Nat. Inst. Sci. India., 38, 502-512.

Mange, Maria A. and Wright, David T. (2008). Heavy Mineral in Use, Development in Sedimentology, Elsevier, New York. 58, XXVII.

Murali Krishna, K.N., Reddy, K.S.N., Ravi Sekhar, Ch., Bangaku Naidu, K., Ganapathi Rao, P. and Reddy, G.V.R. (2016). Heavy Mineral Studies on Late Quaternary Red Sediments of Bhimunipatnam, Andhra Pradesh, East Coast of India. Jour. of the Geol. Soc. of Ind., 90, 111-117.

Murty, M.S., (1958). Occurrence of monazite in the charnockites of Visakhapatnam. Current Science., 27, 347-348

Murthy, N.N. and Divakara Rao, V. (1999). Geochemistry, Provenance and Depositional Environment of the Khondalites from the Eastern Ghats Mobile Belt. Gondwana Research Group Memoir No.5. Eastern Ghats Granulites. 15-30.

Rajasekhar Reddy, D., (1990). Sedimentology and geochemistry of shelf sediments off cannanore-Calicut, West coast of India. Ph.D. Thesis submitted to Andhra University.

Rajasekhara Reddy. D., Karuna Karudu, T., and Deva Varma, D. (2009a). Textural Characteristics and Heavy Mineral Distribution in the Sediments of Kathjodi-Debi River, Mahanadi Delta, East Coast of India. Jour. of Indi. Ass. of Sedi., 28(1), 17-30.

Rajasekhara Reddy. D., Karuna Karudu, T., and Deva Varma D. (2009b). Heavy mineral distribution in different distributaries of Mahanadi Delta, Abstracts volume: XXVI Annual convention of Ind. Ass. of Sed. & National Seminar on Deltas and Other Sedimentary Basins of India: Their Resource Potential, 16 -18th Dec.09, 23.

Ramamohana Rao, T., Shanmukha Rao, CH. and Sanyasi Rao, K. (1982). Textural analysis and mineralogy of the black sand deposits of Visakhapatnam-Bhimunipatnam coast, A.P., India. Jour. Geol. Soc. of India, 23, 284-289.

Reddy, R.D. and Prasad, V.S.S. (1997). Thorium-rich monazites from the beach sands of Kalingapatnam-Baruva coast, Andhra Pradesh, East coast of India. Curr. Sci., 73, 880-882.

Sastry, A.V.R., Swamy, A.S.R. and Prasada Rao. (1981). Distribution of sands along Visakhapatnam-Bheemunipatnam beach. Ind. Jour. Mar. Sci., 10, 369-370.

Sastry, A.V.R., Swamy, A.S.R. and Vasudev, K. (1987). Heavy minerals of beach sands along Visakhapatnam-Bhimunipatnam, East coast of India. Ind. Jour. Mar. Sci., 16, 39-42.

Sri Ramdas A., (1951). The black sand concentrations of Vizagapatam Beach. The Quarterly Jour. of the Geol, Min. and Metall. Soc. of India. 23, 169-180.

Tryon R. C. (1939). Cluster Analysis. Ann Arbor, MI: Edwards Brothers.

Venkata Ram Reddy. G., (2015). Textural and heavy mineral studies of late Quaternary Red Sediments of Bhimunipatnam, Andhra Pradesh, East coast of India. Ph.D. Thesis submitted to Andhra University.

Venkataratnam. K., and Rao A.T. (1968). Zircons from beach sands along East Coast of India. Ind. Mine., 20-29.