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Grain size variation in sand column along Chhatrapur coast, Ganjam district, Odisha – A clue to the depositional environment

Indrajit Patra[1], William Prasad[1] and A. Y. Rao[2]
1: BSOI, AMD, Visakhapatnam; 2: Since retired
E-mail: indrajitpatra.amd@gov.in

Abstract

The concentration of heavy mineral placer deposits along the coastal tracts are function of various favourable factors i.e. hinterland geological formations, prevalence of favourable climatic condition, their transportation through intricate drainage systems and various coastal processes, which operated during the geological past. Textural analysis of the available unconsolidated sediments from the present deposits is of vital importance to decode the prevailing depositional environment while grain size analysis is the major parameter used. Present study highlights the grain size analysis of the identified sand column from Chhatrapur Mineral Sand Deposit along the coastal tract of Odisha to infer the environment of deposition of heavy mineral bearing sand and their heavy mineral content variation. Standard procedure of sampling, data analysis and interpretation techniques were adopted. Result shows that, sands from frontal and rear dune are characterized by distinct bi-modal distribution, medium to fine, moderately to well sorted with good positive skewness, whereas, sand from Inter-dunal region shows dominant unimodal, medium to coarse grain, moderately poorly sorted nature and slightly positive skewness. The better heavy mineral concentration (10 to 25 % grade) in frontal and rear dunes is attributed to prevalence of aeolian dune deposition accompanied by good sorting. In contrast, the low concentration of heavy mineral (3 to 6 %) in inter dune region is due to occasional fluvial regime and poor sorting of sediments. Thus, grain size analysis can be an effective tool to decipher local prevailing depositional environment, which has a bearing on heavy mineral concentration as well.

Key Words: Grain size, depositional environment, texture, heavy mineral concentration.

Introduction

India, endowed with a coastline of over 6000 km, hosts some of the largest and richest shoreline placers comprising of ilmenite, rutile, leucoxene, garnet, zircon, monazite and sillimanite (Ali et al., 2001). The coastline of Odisha has got a special place in heavy mineral inventory of India with mostly uniform composition dominantly in beach & dune complex and minor inland (Rao et al., 2001). The concentration of heavy minerals (HM) suite is a function of hydro-dynamic conditions like sediment influx from hinterland, wave energy and its velocity, long-shore current and wind speed, which control the littoral transport, sorting and deposition of placer minerals in suitable locale (Rao et al., 2001). Therefore, textural studies from grain size analysis have been a key factor to decode these events and have been applied worldwide and in Indian coast (Mason and Folk, 1958, Elshahat, 2018, Sundararajan et al., 2009, Pradhan et al., 2020).

Grain‑size analysis can be used to distinguish among sedimentary environments as well as to identify water or wind conditions that shaped the deposition environment and are widely used to determine and compare aeolian, marine, lacustrine, and fluvial environments. Grain size distribution is affected by other factors such as distance from the shoreline, distance from the source (river), source material, topography and transport mechanisms (Zhu et al., 2014, Abuodha, 2003). The mode of transportation and the energy conditions of the transporting medium are the two most important factors interpreted from grain size study and hence is applied with ease (Friedman, 1961, 1962, 1967). Moreover, the methodology to interpret the depositional environment from granulometric analysis is well established in the field of sedimentology by standard procedures (Folk and Ward, 1957, Folk, 1968 and Friedman, 1967).

The present area of investigations forms a part of well-known high grade Beach Sand Minerals (BSM)deposit i.e. Chhatrapur Mineral Sand Deposit, Ganjam district, Odisha. This is located along the southern sector of coastal Odisha and is under active exploration by Odisha Sand Complex (OSCOM), IRE (India)Ltd. (Rao et al., 2001).Moreover, Atomic Minerals Directorate for Exploration & Research (AMD)carried out HM investigations from time to time, along this coastal tract. Earlier (Rao et al, 1993) carried out textural studies along three geomorphic domains i.e. frontal-inter-rear and interpreted an increase ingrain size from top to bottom based on limited number of samples. In the present case, very detailed studies have been attempted in a small area, depending on the variation in lithology of sand column with an objective to interpret the grain size variation to depositional environment and its bearing on HM content as well. The work includes, drilling, sampling of sand column, sieving of selected samples, estimating univariate statistics, plotting of grain size data and bi-variate plot etc.

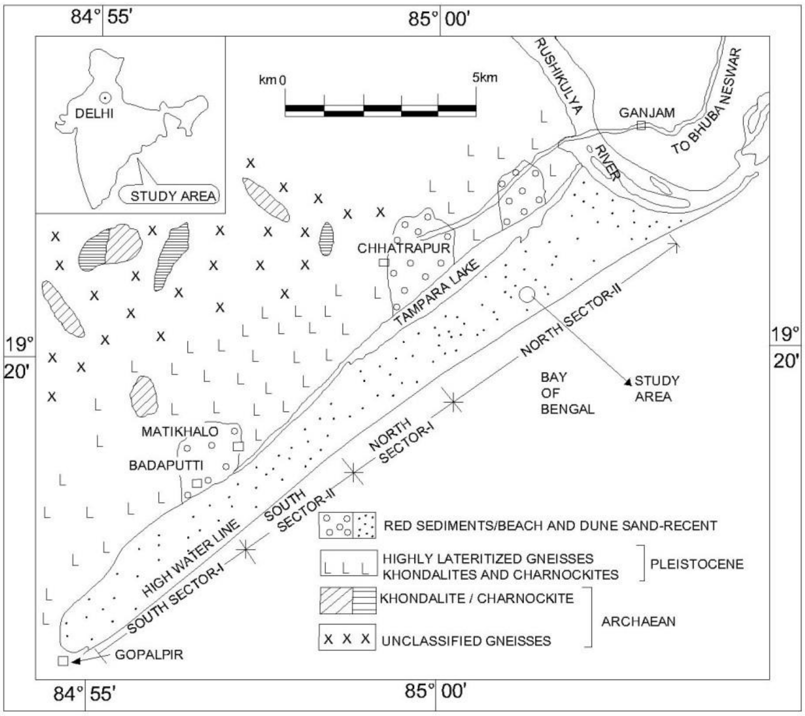

Figure 1: Generalized geological map aroundChhatrapur deposit showing study area

Geology / Geomorphology

Geologically, Chhatrapur deposit, is a well known beach-dune and ridge complex oriented along $N50^0$ - 55^0 E direction, almost parallel to the coastal trend in this part. This area forms part of the well known Central Migmatic Zone (Ramakrishna et al., 1998) of EGMB (Eastern Ghat Mobile Belt). The central migmatitic zone contains rock types subjected to extensive anatexis and migmatisation i.e. migmatitic hornblende ortho-gneisses and leptinites associated with charrnockites, garrnetiferous granite gneisses occur as domes) and khondalites as enclaves within granitic rocks, besides presence of younger phases of alkaline rocks, anorthosites etc. The weathered derivatives are invariably present, and the above rock types with soil cover are present all along the major Rushikulya drainage basin, which is the feeder to the HM suite to Chhatrapur Mineral Sand Deposit. The Quaternary Formations in the area are represented by laterites, red sediments, alluvium and dune sands. According to Devdas and Meshram (1990), the Quaternary deposits (coastal/river valley) is divided into four Formations namely Lower Naira Fm. (sand, gravel and ash bed), followed by Balgarh Fm. (laterite), Kaimundi Fm. (sandy), Bankigarh Fm. (deltaic deposits) overlain by Recent alluvium. The present deposit belongs to Kaimundi Fm. and is represented by sand dunes (yellowish brown), well sorted, medium to fine grained, disposed parallel to the coast. In regard to geomorphology, the Rushikulya River with its narrow coastal plain, form estuarine type of Delta. The dune belt has been divided into i) frontal dune (close to the shore), ii) rear dune (the landward side) and iii) inter dune, the intervening area between frontal and rear dune (Rao, 1989). The Tampara Lake is the major geomorphic feature at the landward boundary of the deposit. The simplified geological map with location of study area is furnished in figure 1.

Methodology

The basic objective is to study the grain size parameters to infer the depositional environment and theirbearing on heavy mineral concentration. In the study area, there are development of different geo-morphic domains i.e. Frontal - Inter - Rear dunes with varying widths. Manual drilling (Dormer) indigenously developed by AMD was employed for sampling in the area. Samples were drawn at every 1.5 m interval lalong the run of the boreholes. Auger sampling was done up to the water table and Dormer drilling below water table. Detailed litho-logging in the area was carried out to understand the lithological variation depth wise and domain wise, which can be related to prevailing depositional conditions. The area in general shows the dominance of fine to medium sand (yellowish to brownish) all along the three domains.

In the frontal dune area, fine to medium sand is dominant with variation in colour from yellowish brown to brownish black due to variation in heavy mineral content. In the interdunal zone, although the lithology is mostly same i.e. yellowish brown fine to medium sand, but a distinct zone of medium to coarse sand (whitish to light yellow colour) is observed at 7.0m depth with angular fragments. This may be due to changing depositional environment. In the rear dune part in the top part, there is dominance of fine size, but the overall lithology is fine to medium sand. Sticky clay was intercepted around 9.0 to 10.0 m depth in Rear dune part. Therefore, representative samples (50-70 gm approx.) was collected from 1 borehole in frontal dune (FD) and rear dune (RD) area and 3 boreholes in Interdunal (ID) areas. From the borehole in FD region, systematic close sampling (0.5 m interval; 16 samples) was done to record minor variation.

From rear dune area, samples at 1.5m interval was collected. In the inter-dune area, only one sample each was collected from coarse sand unit from three boreholes in interdunal region, as such unit was absent from Frontal and Rear dune areas. The detailed map showing these four boreholes is given in figure 2 and the lithological section across the area is given in figure 3. The samples were dried and sieved using ASTM sieve (10 minute shaking time) with sieves of 425, 250, 177, 150, 125,106, 75 micron sizes to get a total of 08 fractions. The initial weight of the samples and the weight in the respective sieves was recorded. The sieving data is shown in table 1. Weight % of material in each sieve were converted into %retention in each sieve. In the

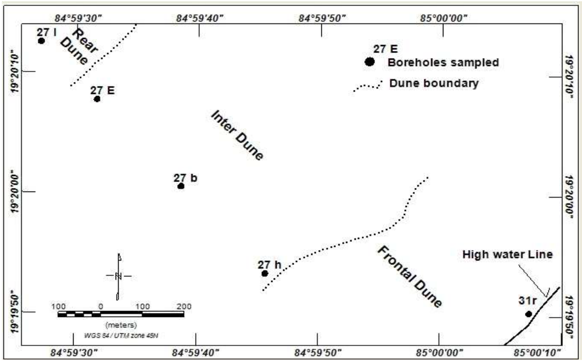

Figure 2: Area in parts of Chhatrapur Deposit showing the locations of boreholes.

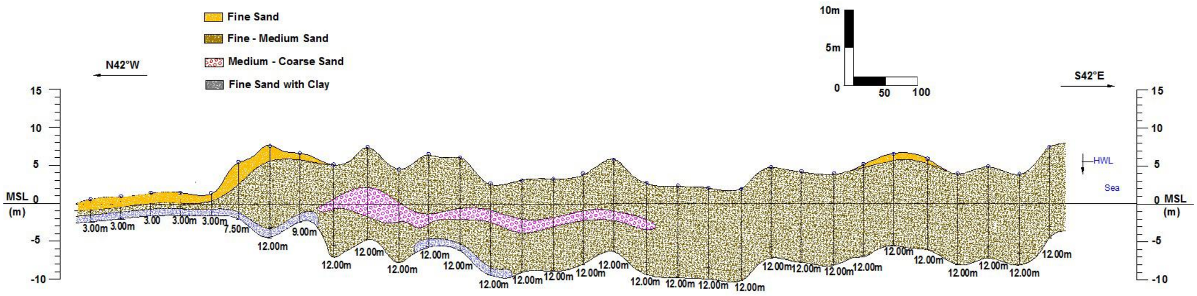

Figure 3: Detailed litholog in the study area

present study, cumulative frequency curves (also, smooth curves) were drawn manually from cumulative weight of sediment and phi units using graph paper. Phi units (ϕ5, ϕ 16,ϕ 25, ϕ 50, ϕ 75, ϕ 84 and ϕ 95) were determined manually from smooth curves. Then the Mean, Standard Deviation and Skewness of each sediment sample were calculated by Graphic Method using standard formulas. This method is widely accepted owing to its ease and easy interpretation methodology (Folk and Ward, 1957, Krumbein, 1934). Simple plots of grain size (μ) versus % retention was attempted to decipher the modal distribution. Bivariate plot was also attempted to distinguish between depositional environments.

Table 1: Grain size data by sieving (n=26; 16 from FD, 03 from ID & 07 from RD

Size (micron)	425+	250+	177+	150+	125+	106+	75+	75	Total Wt (gm)
Seive (Mesh)	40	60	80	100	120	140	200	200	
FRONTAL DUNE (n=16; BH No. 31 r)									
RD/31r/1	15.871	31.586	3.648	3.769	1.157	0.221	0.285	0.071	56.607
RD/31r/3	14.462	25.228	4.383	5.521	1.686	0.732	0.577	0.170	52.759
RD/31r/5	19.933	30.948	4.726	6.410	1.790	0.931	0.451	0.161	65.350
RD/31r/7	20.303	20.127	3.646	4.794	1.858	1.104	0.806	0.249	52.886
RD/31r/9	29.082	19.711	2.597	3.541	1.019	0.476	0.249	0.420	57.094
RD/31r/11	13.594	22.523	3.333	4.621	2.137	0.360	0.475	0.230	47.272
RD/31r/13	9.623	28.485	4.366	7.432	2.267	1.204	0.634	0.204	54.214
RD/31r/15	13.687	30.938	5.107	6.852	1.956	1.251	0.534	0.232	60.555
RD/31r/17	10.313	31.851	6.889	10.307	2.439	1.549	1.081	0.180	64.608
RD/31r/19	14.698	34.370	4.894	6.475	1.760	0.813	0.266	0.311	63.587
RD/31r/21	14.565	24.386	4.052	5.961	1.754	1.197	0.575	0.216	52.706
RD/31r/23	19.795	29.856	4.627	7.461	2.820	0.687	0.722	0.447	66.414
RD/31r/25	10.433	30.921	6.839	10.712	3.037	1.095	0.688	0.661	64.385
RD/31r/27	17.703	33.569	3.446	3.477	1.028	0.733	0.491	1.178	61.625
RD/31r/29	10.372	29.628	6.776	2.412	9.686	1.659	1.209	1.990	63.732
RD/31r/31	14.176	29.988	5.599	6.369	1.659	1.110	0.783	0.985	60.668
INTER DUNE (n=03; BH No.27 b, h & E)									
27b/3	64.10	10.80	0.81	0.81	0.16	0.10	0.01	0.12	76.91
27E/5	31.54	17.44	1.44	1.43	0.27	0.12	0.08	0.31	52.63
27h/3	49.80	17.50	2.00	2.31	0.45	0.25	0.05	0.75	73.11
REAR DUNE (n=07; BH No.27 l)									
27 l/1	11.40	26.46	3.50	7.45	2.93	2.37	1.75	0.56	56.42
28 l/2	10.32	23.76	3.49	8.49	3.60	2.80	1.13	0.17	53.76
28 l/3	14.03	21.79	4.83	6.22	1.36	0.71	0.70	0.12	49.75
29 l/4	15.50	22.26	4.96	8.08	1.23	1.80	1.17	0.75	55.74
29 l/5	16.39	23.01	2.30	5.75	2.15	0.79	0.51	0.31	51.22
30 l/6	20.71	22.93	1.85	6.36	1.27	0.60	0.49	0.11	54.31
30 l/7	15.06	18.74	3.90	5.35	1.31	0.81	0.55	0.24	45.96

Results & Discussions

Based on the results of the above methodology, following relevant points are highlighted: .Modal Distribution: The grain size data (Table 1) was utilized to prepare plots (Figure 4, 5 and 6) of modal distribution FD, ID and RD areas. Besides, percentage of coarse, medium, fine and very fine population is given in pie-diagrams (Figure 7, 8, & 9).

The three modes of transport (suspension, saltation and surface creep) are developed as separate population in a grain size distribution and the distribution pattern is strongly dependent on provenance, sedimentary processes and dynamics. Hence, analysis of these parameters is the basis for determining the process response characteristics of individual sand units (Visher, 1969 and Sahu, 1964). Modality of a distribution reflects the dominance of a particular size class/classes within the mixture and bi-modal distribution and is characteristics of many depositional environments (Taira and Scholle, 1979).Figure 4 (for FD) exhibits a distinct bi-modal (at 250 μ and 150 μ) pattern suggesting dominance of saltation process over suspension, during their transportation. The variation in grain size indicates their deposition under varying energy condition. Wentworth (1922), classified sands into five categories i.e.very coarse (2000-1000 μ), coarse (1000-500 μ), medium (500 -250 μ), fine (250 -125

μ) and very fine (125-63 μ), based on sizes. Pie diagram (figure 6) also suggests that, more than 90 % of sediments are within medium to fine sand range. The dominance of medium to fine sand also indicates dunal environment (Reddy et al., 2013). The grain size plot for RD exhibits similar characteristics to that of Frontal Dune. However, in the bi-modal pattern, the secondary mode is clearer than Frontal Dune. In comparison to Frontal Dune, the quantum of fine to very fine sand is marginally higher in Rear Dune (Fig. 9).

Figure 5 (for ID) exhibits two modes, but the prime mode is 450+ μ which is coarse sand, and the secondary mode is poorly developed at 150 μ. Unlike FD, here more than 90 % is contributed by coarse to medium sand (Fig. 8). The grains are mostly angular in nature and the relatively coarser size indicating their deposition under higher energy condition. The dominance of traction process over saltation during transportation is inferred from the data. This energy condition is typical of fluvial origin (Friedman, 1967).

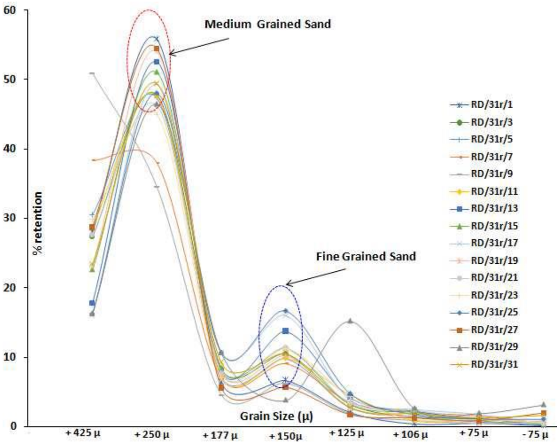

Figure 4: Grain size plot of sand samples (n=16) from BHNo.31r, Frontal Dune, showing distinct bi-modal pattern

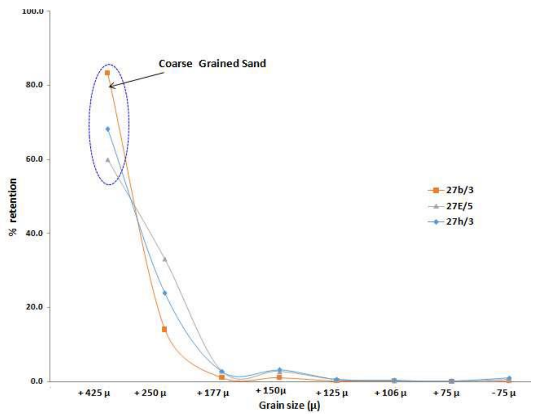

Figure 5: Grain size plot of sand samples (n=03) from

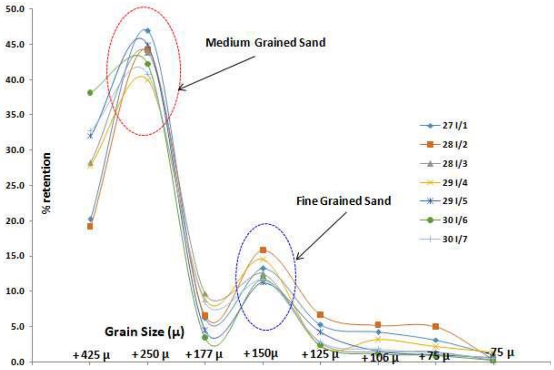

Figure 6: Grain size plot of sand samples (n=07) fromBH 27 I, Rear Dune

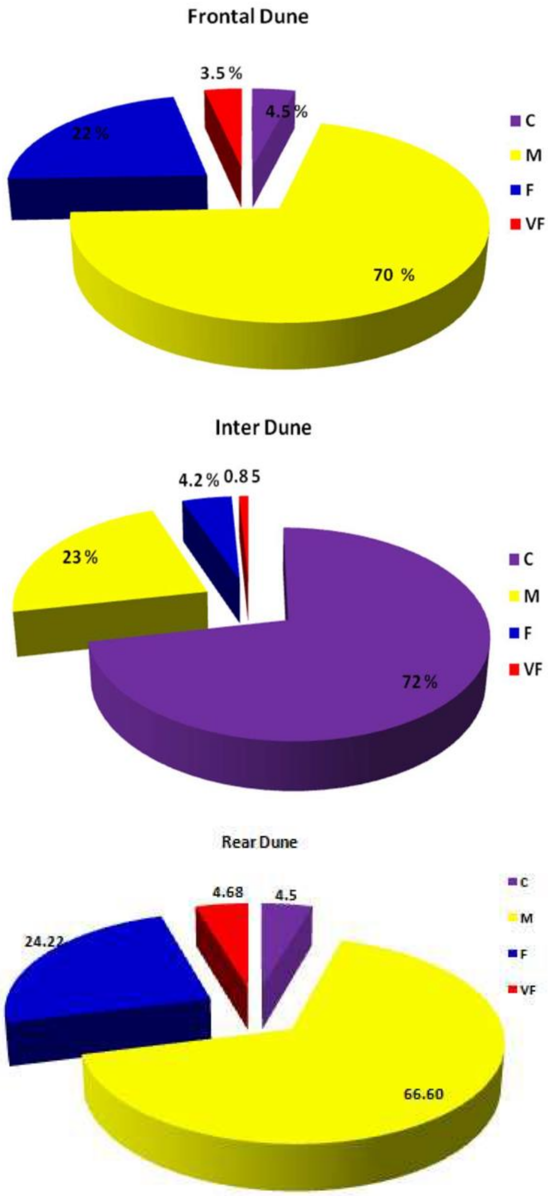

Figure 7, 8 & 9: Pei diagrams showing % of coarse, medium, fine and very fine sand in Frontal-Inter-Rear Dunes.

Univariate statistics

Textural attributes of sediments like, Mean, standard deviation and skewness are widely used to reconstruct the depositional environment of sediments and sedimentary rocks (Komar, 1998), as they have correlation between size parameters and transport processes/depositional mechanism of sediments(Folk and Ward, 1957, Friedman, 1967 , Visher, 1969). The mean size of the sediments indicates average size of the sediments which is influenced by the source of supply, environment and the average kinetic energy (velocity) of the depositing agent (Sahu, 1964). Standard deviation is a useful measure of dispersion of a distribution around the mean. It indicates the difference in energy associated with two modes of deposition. Sorting is inversely proportional to standard deviation. Skewness is a measure of frequency distribution that indicates the position of the mean with respect to the median and, is geometrically independent of sorting nature of the sample.

In the FD, the sediments are well to moderately well sorted (S.D. range from 0.48 to 0.70; n=16) and show strongly positive to positive skewness (Range: 0.29 to 0.40). The characteristic grain size (medium to fine), sorting (well to moderately well sorted) and positive skewness indicates their deposition in aeolian environment. No systematic variation of grain size with respect to depth is observed. In the Rear Dune, similar characteristics is observed except marginal higher sorting (S.D. ranging from 0.38 to 0.60).In the ID, the grain size for this unit vary from 0.30 to 0.72 ϕ (n=3) and are moderately to poorly sorted(S.D.: ranging from 0.72 to 1.20) with slightly positive (Range: 0.05 to 0.1) skewness. The coarser grain size, poorly sorting and slightly positive skewness nature of sand indicate their deposition under fluvial environment.

Wind and river transportation results from unidirectional flow and may be responsible for the generally positive skewness of dune and river sands (Friedman, 1961). As more and more fine sands are added to the dunes due to wind activity, the resulting skewness is slightly positive as compared to river.

Bivariate plot

The mean and standard deviation are the prime variables to differentiate dune - beach -River depositional environment, although overlaps are observed at various occasions (Friedman, 1967). The simple Mean - SD plot for present study is shown to distinguish between dune and river environment (Figure 10) , where these occur as two separate clusters. The sorting in case of dune is better as compared to river and the mean size also is more in case of river.

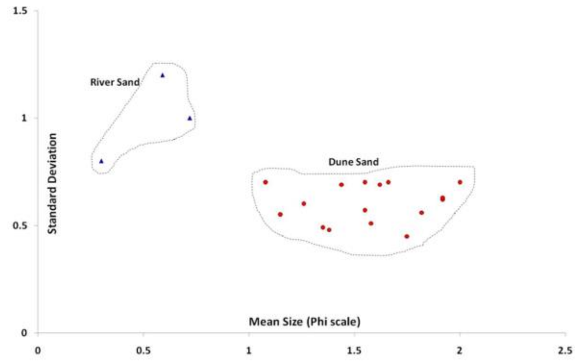

Figure 10: Bi-variate plot of mean vis-à-vis standard deviation todistinguish between dune and river sand from Chhatrapur area

Conclusion

Detailed grain size analysis of sands collected from frontal, inter and rear -dune regions of parts of Chhatrapur deposit, clearly reflects contrasting depositional environment. Sands from frontal/rear dune are characterized by medium to fine grained, moderately well sorted and strong positive skewness suggesting a typical case of dunal deposition. These conditions are very essential for heavy mineral deposition, which is corroborated by good grades of heavy minerals in this zone (i.e. 10 to 25 % grade).The heavy mineral suite essentially comprise of ilmenite, garnet, sillimanite, monazite, zircon and rutile as economic minerals and EGMB is the provenance for these heavy minerals. This unit at top is exposed to aeolian action, which is an effective sorting agent for which higher heavy mineral grade is observed in this unit. In contrast, sands at depth from Inter-dunal region are medium to coarse grained, poorly sorted with slightly positive skewness. This suggests, local prevalence of fluvial environment, and hence is reflected by less heavy mineral content (3 to 6 %), due to less sorting. Hence, study of grain size data is helpful to infer the deposition history as first-hand information on relative heavy mineral distribution in aparticular area.

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