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A COMPARATIVE STUDY OF TEXTURE, MINERALOGY AND SEDIMENTATION OF SELECTED BEACH SEDIMENTS OF GOA COAST, INDIA

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ABSTRACT

Present work on beach sediments of Goa Coast has been attempted in order to understand the variations in textural and mineralogical parameters of sands for the interpretation of depositional and transportational mechanisms. The grain-size parameters of beach sands suggest that (i) the sands are fine-to-coarse-grained, very well-sorted to well-sorted, positively skewed to negatively skewed, platykurtic to leptokurtic in Tiracol-Chapora beach of north Goa and (ii) fine-grained, moderate to well sorted, negatively skewed, platykurtic to leptokurtic sands in Colva beach of south Goa. The shape parameters suggest that the sands in both areas are subspherical, subangular to subrounded in nature indicating probably a short distance of transportation. The heavy mineral assemblage consisting of unstable to ultrastable opaque and non-opaque minerals suggest a nearby mixed igneous and metamorphic source of the sediments. The discriminant analysis using all the samples and seven variables clearly separates the sediments of Tiracol-Chapora and Colva sands. In general, the grain size data of these sands along the Goa Coast indicate a fluctuating energy condition of the depositional site contributing a mixed nature of sediments with variable amounts of sand, silt and clay in northern part as compared to that of the southern part of the area where sands show unimodal distributions indicating uniform depositional conditions.

INTRODUCTION

The Goa coast trending NNW-SSE forms a part of the central west coast of India, bounded in the east by western ghats and on the west by Arabian sea. The coast line consists of beautiful sandy beaches separated from one another by rocky headlands and river mouths. The important rivers which carry sediment material to these beaches include the Tiracol, Chapora, Mandovi and Zuari.

The area has been investigated in the past for its geology, geomorphology and structure by Oertel (1958), Gokul *et al.* (1985) and the textural and mineralogical study of beach sediments by Veerayya (1972), Veerayya and Varadachari (1975), Veerayya *et.al.* (1981), Kidwai and Wagle (1975) and Murthy *et al.* (1986) and others.

The area is essentially covered by the Goa group of rocks (Dharwar Super Group) belonging to Archaean-Proterozoic age except for a narrow strip of the area in the northeastern border of Goa, which is overlain by the Deccan Traps of Late Cretaceous to Early Eocene age. The general stratigraphic succession of Goa is presented in Table 1.

Present study include the Tiracol-Chapora beach in the north Goa and the Colva beach in the South (Fig. 1) for a comparative study of the textural and mineralogical variations. The Tiracol coast has alternate rocky cliffs with small accumulations of sands in the form of pocket deposits. The foreshore is flat to steep in parts with broad low level berm. A series of sand dunes exist along the

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TABLE 1 : GENERALIZED STRATIGRAPHIC SUCCESSION OF GOA (Gokul *et al.*, 1985)

Age	*Formation*	*Lithology*
Sub Recent to Recent	——	Beach sands, laterite
Upper Cretaceous to Lower Eocene	Deccan Traps	Basalt
	Basic Intrusives	Dolerite, gabbro
Proterozoic	Acid Instrusives	Pegmatite, vein quartz, porphyritic granite, Hornblende granite, feldspathic gneiss, granite gneiss
	Vageri Formation	Metabasalt, Metagreywackes
ARCHEAN to PROTEROZOIC; DHARWAR SUPER GROUP; GOA GROUP	Bicholim Formation	Banded ferruginous quartz Manganiferous chert breccia with pink ferruginous limestone, pink ferruginous phyllite quartz-chlorite-amphibolite schist.
	Sanvordem Formation	Argillite, quartzite, metagraywackes
		Meta-gabbro, peridotite, talc-chlorite schist, variegated phyllite, quartz-chlorite schist, quartzite, quartz-sericite schist.
	Barcem Formation	Red phyllite, quartz porphyry, massive schistose and vesicular metabasalt

entire backshore wherever sandy beaches are present. The accumulation of sediments is seen to be much thicker towards the southern part as compared to the northern part of Tiracol coast. The Colva beach is considered as the longest beach along the Goa coast with a wide, gentle foreshore at extreme ends and is backed by well-developed sand dunes.

METHODOLOGY

In all thirty sediment samples were collected uniformly from the mid-foreshore portion of beaches, using a plastic tube from 5 cm below the surface. The samples were treated in the laboratory to remove organic material and salts. The dried, coned and quartered samples of 40 gms each were sieved using 1/4 ϕ interval and the size parameters were calculated following the Folk and Ward (1957) formulae. About 200 random grains from each sample have been projected using a camera lucida and the grain boundaries have been traced to measure the largest inscribing and smallest circumscribing diameters for the calculation of sphericity and roundness measures using Riley's (1941) sphericity and Wadell's (1933) roundness formulae. The heavy mineral fraction has been separated from the samples by gravity method (Carver, 1971) and the identification of different heavy minerals have been made using a low power binocular microscope.

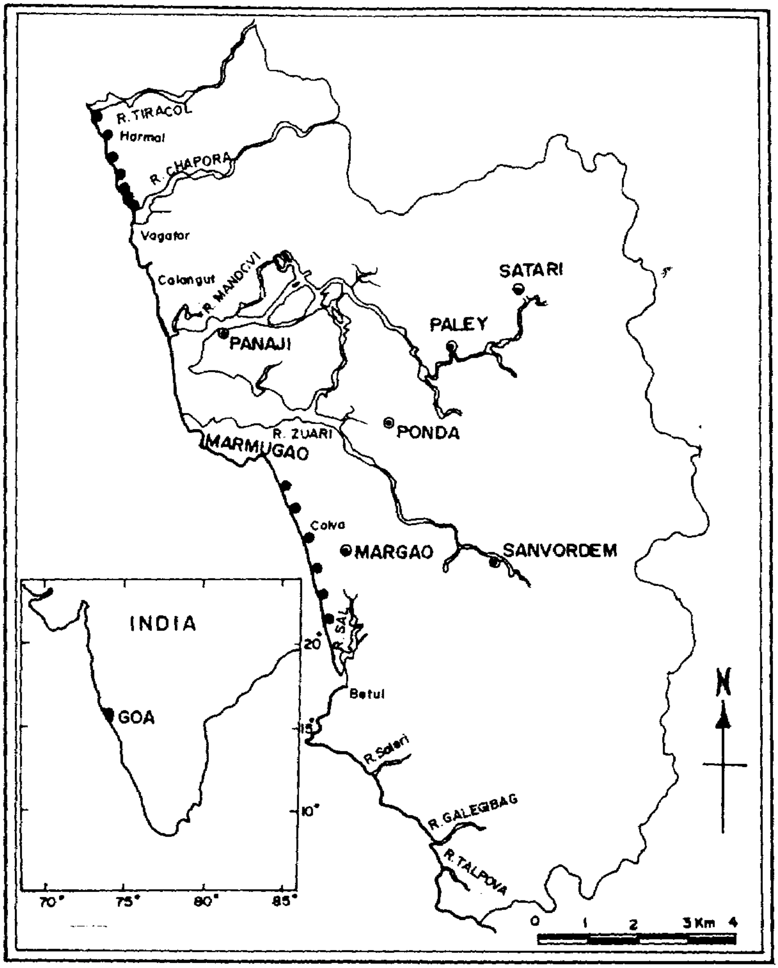

Fig. 1. Location map of the area

RESULTS AND DISCUSSION

Grain-size textural parameters are sample statistics used to describe particle size distribution within sediments and are calculated according to the equations of Folk and Ward (1957). Although their underlying assumption of log-normal grain size distribution in sediments has been questioned recently (Christiansen *et al.*, 1984) and the log-hyperbolic function favoured (Flenley *et al.*, 1987), the Folk and Ward (1957) parameters of mean grain size, sorting (standard deviation), skewness and kurtosis have been employed in this study. This may be justified by their common usage (cf. Folk, 1966, 1968) and by the fact that Wyrowoll and Smyth (1985) found no apparent advantage in using the parameters of the log-hyperbolic as opposed to log-normal distributions. Table-2 shows the data on size parameters, shape and heavy mineral concentrations of Tiracol-Chapora and Colva beach sediment samples. The interrelationships between various parameters (calculated as correlation coefficients) are shown in Table 3.

TABLE 2 : TEXTURAL AND HEAVY MINERAL DATA OF BEACH SEDIMENTS OF GOA COAST

S. No.	*Mz* (ϕ)	$\sigma_{\phi i}$	*Sk*	*KG*	ψ	ρ	*HM%*
			Tiracol - Chapora Beach Sediments				
1	2.5536	.3342	-.1012	.1215	.5713	.3121	1.8220
2	2.1315	.4814	.1604	.8853	.6428	.3520	2.4230
3	2.0417	.5721	.2982	.9344	.6213	.2921	2.4830
4	3.0417	.3254	.2352	1.2588	.5564	.3845	2.3830
5	2.6500	.4021	-.1484	1.5027	.6413	.3282	2.3100
6	2.6670	.3042	-.1815	1.3871	.5500	.3421	3.2840
7	2.5583	.4358	-.3964	.7904	.5687	.3090	2.4250
8	2.4917	.3428	-.2764	.7306	.6196	.3426	2.4000
9	2.8500	.3093	.1459	1.2841	.6272	.3568	2.1600
10	2.5830	.3140	-.2538	.9643	.5812	.3624	1.8690
11	3.0667	.2915	.4570	1.3320	.5711	.3622	2.4240
12	2.6250	.3454	-.4032	1.3173	.6391	.3433	1.8900
13	2.5157	.3542	-.3031	.7514	.5891	.3034	1.6900
14	2.4250	.4723	-.4168	.8197	.6337	.2293	2.1200
15	1.8333	.4911	.2553	1.1048	.5932	.3052	2.5600
			Colva Beach Sediments (South Goa)				
1	2.5833	.4019	-.3859	1.2807	.5975	.2750	.0500
2	2.3667	.7034	-.5931	1.0246	.6250	.2430	.7500
3	2.5500	.4121	-.4018	.9563	.5825	.2510	.1800
4	2.4833	.4598	-.5197	1.0587	.5830	.2960	1.7210
5	2.4833	.5830	-.5774	.9989	.6400	.2664	1.3840
6	2.0167	.6780	-.1083	.6557	.6060	.2450	1.4230
7	2.5000	.5075	-.3559	.9953	.5975	.2705	.8700
8	2.5333	.3564	-.3725	.7566	.6100	.2643	.5700
9	2.4500	.3341	-.3809	.9568	.6271	.3075	.3280
10	2.5166	.4470	-.4330	.8197	.6097	.2340	.2200
11	2.5000	.5026	-.5285	1.1953	.5828	.2855	.1910
12	2.5120	.4496	-.4511	.7172	.6475	.3325	.2100
13	2.6333	.4322	-.4645	1.4856	.5853	.2749	.1000
14	2.6166	.5254	-.6052	1.9467	.6005	.2620	.1800
15	2.4000	.6004	-.3905	.8197	.6256	.2713	.2400

SIZE

The size parametres discussed here include mean grain size, standard deviation, skewness and kurtosis.

Mean size. The Tiracol-Chapora beach sediments are in the medium-to-fine-grained sand range with local accumulations of coarse sand, whereas the Colva sands are essentially fine-grained. The grain-size for the Tiracol-Chapora and Colva beach sediments range between 1.8333 to 3.0667 ϕ and

TABLE 3 : CORRELATION MATRIX OF TEXTURAL DATA OF BEACH SEDIMENTS OF GOA

	Mz ϕ	σ_ϕ	*Sk*	*KG*	ψ	ρ	*HM%*
Mz ϕ	1.0000	−.6322	−.0043	.3635	−.3392	.4148	−.0009
$\sigma_{\phi I}$	−.6322	1.0000	−.2798	−.0806	.3508	−.6576	−.3029
Sk	−.0043	−.2798	1.0000	−.0090	−.1727	.5783	.6512
KG	.3635	−.0806	−.0090	1.0000	−.0812	.1453	−.0359
ψ	−.3392	.3508	−.1727	−.0812	1.0000	−.1743	−.1730
ρ	.4148	−.6576	.5783	.1453	−.1743	1.0000	.5964
HM%	−.0009	−.3029	.6512	−.0359	−.1730	.5964	1.0000

2.0167 to 2.6333 ϕ respectively. The occurrence of a mixture of coarse, medium and fine sands in the Tiracol-Chapora area and uniform fine sands in Colva area may perhaps indicate a fluctuating energy state of deposition for Tiracol-Chapora sediments and constant energy conditions during the deposition of Colva sediments.

Standard deviation. The Tiracol-Chapora beach sediments are well-sorted to very well-sorted with their standard deviation values in the range of 0.3042 to 0.5721 and the Colva beach sediments are moderate to well sorted with the standard deviation values varying between 0.3341 and 0.6001 (Friedman, 1967). In general, the sorting of beach sediments increase with decrease in grain size (Mckinny and Friedman, 1970). The various size parameters are somewhat independent and relationship does exist between mean size and sorting values of most water laid sediments. The similar relation between Mz and ρ_ϕ ($r = -0.6322$, Table 3) was recorded in the present study. Sediments in both areas show dominance of wave induced currents over the tidal currents because of the presence of negative correlation between Mz and ρ_ϕ and better sorting in sediments (Channon and Hamilton , 1971).

Skewness. The Tiracol-Chapora samples show a mixture of negatively skewed to positively skewed nature of sands whereas those of Colva are exclusively negatively skewed (Table 2). Duane (1964) considers negative skewness to be a product of erosion of fine particles from the sediment material of sheltered environments. He also suggests that negative skewness is a product of winnowing action, produced due to two unequal forces acting in opposite direction, one incoming swash and the other outgoing back wash (Friedman, 1961). Martins (1965) explains positive skewness as a result of the unidirectional sediment transport. The positive skewness is due to removal of the finer materials leaving behind coarser mode with fine tails by long shore current circulation. The sediments deposited at the river mouth are probably carried along the small elongated beaches of opposing nature of long shore current. The beach sediments near the river mouth therefore, show the positive skewness as observed in some locations in the Tiracol-Chapora area. The mixture of positive and negative skewness may indicate regions of flux (Purandara *et al.*, 1987). The positive to nearly symmetrical nature of samples would result from the incorporation of fines by onshore winds from the exposed parts of the foreshore and berm. The Colva beach sediments, however, show a characteristic negative skewness values all along the area. The results of skewness when compared with the study of winnowing caused by waves and tides, the Tiracol-Chapora samples indicate moderate winnowing because of mixed skewness values whereas the Colva samples suggest a strong winnowing action resulting to predominant negative skewness.

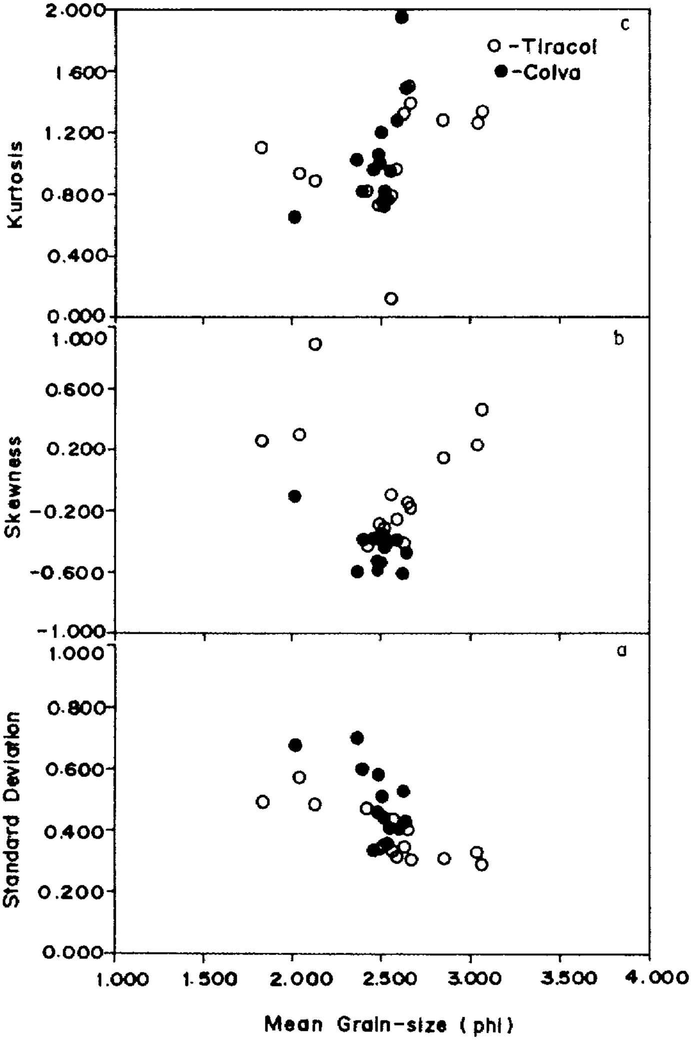

Fig. 2. Bivariate plots of : (a) standard deviation, (b) skewness and (c) kurtosis against mean grain size.

Kurtosis. The kurtosis values in the present area fluctuate around one in almost all the localities in south and north, and are placed in the very platykurtic to leptokurtic category. The kurtosis values around unity indicates better sorted nature of sediments due to greater velocities over long time. The kurtosis values around unity may be attributed to a limited admixture of materials or minimum changes in energy. Folk and Ward (1957) attributed high and low values of kurtosis to a mixed population.

Nordstrom (1977) has related the variation in kurtosis to the variation in energy. Such variations observed in the present area may be due to the difference in the mode of wave energy in causing variations in redistribution of the sediments.

Bivariate Plots. Bivariate plots of different combinations of grain size parameters have been advocated by number of authors as a method suitable to distinguish between modern sediments deposited by different processes (Friedman, 1961; Martins, 1965; Moiola and Weiser, 1968). This method is based on the assumption that different proceses of transportation result in variations in grain size distributions. These are reflected in the statistical parameters which, when plotted as scattergrams, produce bivariate clusters of samples affected by the same process, and separation of those samples influenced by different processes. Figure 2a, b and c show plots of some combinations of parameters which have attributed an ability to distinguish sands from different environments.

SHAPE

Particle shape is very significant when investigating transport processes (Pettijohn *et al.*, 1972). But despite this, there have been relatively few studies which consider grain roundness and sphericity. The variations in grain sphericity and roundness yield information imparted by depositional processes. The degree of particle sphericity is important in the selective transportation of particles (Krumbein, 1941). Sphericity is independent of the degree of rounding of the grains. The mutual independence of particle roundness and sphericity is attested by the lack of statistically significant correlation between the two shape parameters (Table 3). The mean sphericity and mean roundness values in Tiracol-Chapora and Colva samples occupy a narrow range of 0.5500 to 0.6428, 0.2293 to 0.3845 and 0.5825 to 0.6271, 0.2340 to 0.3328 respectively, indicating subspherical, sub-angular to subrounded nature of sands characteristic of transportation probably by rivers from a nearby source. Figure 3 shows the relationship between mean size with sphericity and roundness. The roundness increases with the grain size whereas no relation is seen between mean size and sphericity. This is also confirmed from the correlation coefficients between them (Table 3).

HEAVY MINERALS

Heavy mineral analysis of the samples were undertaken following standard procedures. The heavy mineral assemblages in sands can provide useful information about the character of the source rocks and have also been used to differentiate sands deposited in different environments. Although the detailed quantitative study of heavy minerals is beyond the scope of this paper, the present work attempted to provide a qualitative information on the abundance of heavy minerals in the samples. In general the Tiracol-Chapora samples show relatively high concentration of heavies than those of Colva (Table 1). The heavy mineral assemblage in the present samples include opaques and non-opaques. The opaques are abundant with subangular to subrounded magnetite and ilmenite. The non-opaques include rutile, andalusite, kyanite, staurolite, tourmaline, epidote, augite, diopside, spinel, garnet, zircon and few pyroxenes. The light mineral composition show predominant quartz (more than 80%) associated with significant amounts of carbonate and minor feldspars, mica and clay minerals. Monocrystalline subangular to subrounded quartz grains are common and often contain inclusions of opaques, tourmaline etc. Because of the dominant monomineralic composition, the absence of rock fragments, low clay content and subrounded and well sorted nature of the dominant grains, the sands can be considered as submature to mature (Folk, 1966). The ultimate source of these minerals in the present area can be traced back to the drainage basins of the river systems rising on on the western ghats in the east flowing over a vastmetamorphic terrain composed of dominant Algongian schists, bearing epidote, chlorite, staurolite with associated amphibolites and pyroxenites, quartzites with associated iron and manganese ore deposits and igneous terrain composed of granites and basalts (Oertel, 1958). A minor amount of the assemblage could be attributed to the weathering and erosion of headlands facing the sea.

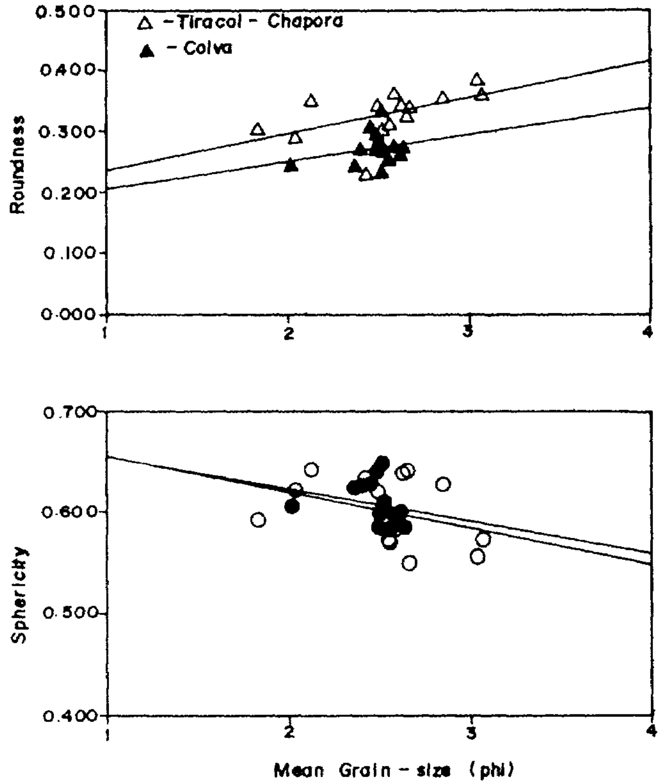

Fig. 3. Variations in mean particle roundness and sphericity with grain size.

DISCRIMINANT ANALYSIS

Discriminant analysis has been successfully used to differentiate modern sands (Moiola *et al.*, 1973, 1974; Moiola and Spencer, 1979; Sahu, 1982a, 1982b and 1983). It may therefore be an appropriate method of differentiating sands deposited in varied environments on the basis of their textural and shape characteristics (Pettijohn *et al.*, 1972). In the present study the linear discriminant analysis is used as only two groups are considered. Accounts of the mathematical working of the technique are available in Klecka (1975). The data set used for discriminant analysis consisted of all the samples collected. The seven variables used to provide the discriminatory information were the four grain size parameters (mean size, standard deviation, skewness and kurtosis), mean sphericity, mean roundness and the total percentage of heavy minerals in individual samples. The discriminant function was produced for all the variance in the data set. The results of classification stage of the analysis clearly show that all the samples have been correctly classified into respective groups (Fig. 4). This clearly suggests that the Tiracol-Chapora and Colva sediments though belonging to one environment, actually differ in terms of their depositional conditions. From the grain size data it is apparent that the Tiracol-Chapora samples show somewhat oscillating energy conditions and those of Colva show constant energy conditions of the depositional environment.

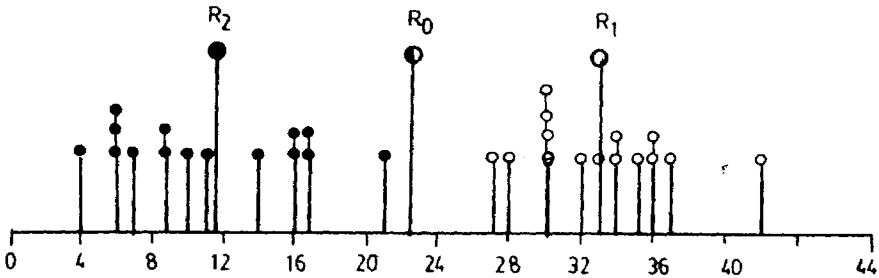

Fig. 4. Discriminant frequency plot.
(Not to scale)

CONCLUSIONS

The grain size and shape parameters suggest that the Tiracol-Chapora sands are fine-to-coarse-grained, well-sorted, positive to negatively skewed and those of Colva beach are fine-grained, negatively skewed sands. The variations in the size parameters can be correlated with the variations in the energy conditions of the depositional media. The shape parameters suggest that the sands are subspherical, subangular to subrounded grains deposited from a nearby source. The heavy mineral assemblage consisting of unstable to ultrastable minerals indicate a nearby mixed igneous and metamorphic provenance and a product of catchment area geology. The discriminant analysis of grain size, shape and heavy mineral percentage data clearly separates the Tiracol-Chapora and Colva sediments and can be related to varying energy conditions of depositional sites.

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