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Grain Size Characterization of Lagoonestuarine System: Eastern Coast, Sri Lanka

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Abstract: ***Grain size distribution and textural parameters are spectacles to interpret the sediment movements and depositional processes of lagoonestuarine systems that are intermittently open in flood control measurements. A spatial grain size distribution study was carried out to investigate the morphologically controlled sediment movement and deposition of the lagoonestuarine system of the Eastern coast, Batticaloa, Sri Lankawith a specific emphasis on inlet management. A total of 51 surface sediment samples of the lagoonestuarine system of Batticaloa were collected and analyzed for grain size distribution and textural parameters. The results revealed that a marked relationship between lagoonestuarine morphology and the mode of the particle size distribution with respect to the sediment deposition and inlet flows. Statistical parameters are further confirmed from the grain size distribution curves which indicate that the sediments of beach and inlet associated areas have medium to coarse size positively skewed platykurticnature. However, barrier deposits and shaded areas have medium size negatively skewed leptokurtic nature. The prominent sediment components of barrier deposits and shaded areas as well as beach and inlet associated areas reflect the morphological transition of lagoon environment to estuarine environment. The subordinate components of sediments show two different depositional environments indicating inlet changes. The inlet opening and the closure depends on the intensity of river flux and marine processes. The grain size distribution and morphology parameters of studies samples show a clear relationship which indicate both anthropogenic and natural processes control the changes of inlet of the lagoon estuarine systems.***

Keywords: Grain size distribution, statistical parameters of sediments, intermittently open estuary, eastern coast of Sri Lanka

1. Introduction

Sedimentological studies are one of the tools to interpret the evolution of sedimentary environments. The particle size and the morphology of sediments are the major tools to interpret the source or provenance of sediments, transportation modes and depositional environments (Greenwood, 1961;Friedman, 1967;Pettijohn, 1984).The parent lithology and the climatic conditions influence characteristics of sediments in the provenance stage and further modified it during the transportation stage (Weltje and von Eynattern, 2004). The particle size distribution is characterized during the period of transportation by sorting, abrasion or chemical alterations (Pettijohn, 1984). In addition, during depositional process the particle size is characterizing with the energy conditions of the environment and flow regimes (Pettijohn, 1984; Cheetham et al, 2008; Amireh et al. 2014). Therefore, studying on particle size distribution is a basic tool on studying depositional environment, transportation modes and provenance of sedimentary beds.

The sediment pathways are complex in coastal systems since the transport agents are processes having their own spatial and temporal characteristics such as river discharges, near shore waves, coastal tides, local winds and episodic storms (Venkatramanan et al., 2011).Especially in lagoon environments the sediments supply is from both marine and terrestrial, and the particle size distribution is characterized in each cases (Ergin et al., 2007; Cheetham et al., 2008). Development of bar built estuaries in associated with lagoons is common feature and grain size analysis reflects the coastal configuration (Watson et al., 2013). The sediment composition of barrier bars also affects from the wave/tidal actions, littoral currents and the petrographical compositions of the shore (Abdulkarim et al., 2011).

Sri Lanka is commonly having sandy beaches. Sedimentological studies of those beaches are limited to the West-, Northwest- and South-coastal regions(Katupotha and Wijayananda, 1989; Morton, et al., 2008;Jayawardhana et al., 2012;Jayasinngha et al., 2014).Few studies have been carried out recently on paleo tsunami events occurred in Southeastern areas (Matsumoto et al, 2008; Ranasingha et al., 2013). However, there are no studies carried out on the interpretation of the formation of lagoons and estuaries in the Eastern coast of Sri Lanka. The Eastern coast of Sri Lanka is directly exposed to the Bay of Bengal of the Indian Ocean and Northeast monsoon winds are basic current generators for the ocean deposits. The coastal area is having lagoonestuarine system that the inlet management is needed for the annual flood control measures as the closure of inlet is done by the natural prolong events of sedimentation per annum.

The purpose of this study was to investigate the sediment movement and deposition patterns of lagoon estuarine system that having an inlet with anthropogenic management and natural closure events of part of Eastern coastal segment of Sri Lanka by analyzing the grain size parameters. Hence, this study is important for the coastal management of estuaries during flood events.

2. Study Area and Physical Setting

The study area along coast extends from Kalmunei to Kalawanchikudi, a distance of about 11km and the inland extend is about 9km (Fig. 1).

2.1 General geology

Coastal morphology of the study area has being identified as quaternary deposits with barrier bars and beach rocks (Katupotha, 2007).The underlined rocks of the area are Precambrian metamorphic rocks such as biotite gneiss and granitic gneiss with quartz of eldspathicpegmatite lenses. Basement rocks extend North South direction (N40°W) and the dip direction is towards Northeast. Most of the inland lagoon boundary consists of highly weathered or lateritic capped residual profiles with thin sediment depositions. The average local elevation of the area is about 4m and almost the area is flat.

2.2 Climate

The Northeast monsoon rainfall occurs from November to February and it makes heavy rainfalls with flood inundation in lowlands. The annual rainfall and the average temperature of the area are 1500-2000mm and 22.5-32.5°C respectively (Department of Meteorology, Sri Lanka). There are two main river outputs directly flow to the lagoon estuarine system. One river (Karawahu channel) flows parallel to the strike of the basement and other one runs along the major fracture direction (see Fig. 1).The Rivers are currently used for cultivations and therefore the discharge into the lagoon is comparatively low.

3. Material and Methods

Field studies were carried out in September 2014 and fifty one (51) surface sediment samples were collected (Fig. 1).Five morphologically different areas were selected to represent the mainland area namely Navithanveli, Annamalei and Mandurand barrier deposits namely Thuraineelavanai, Pandirippu, Periyakallar, Koddakallar and Mahiloor. The samples were taken from 50cmbelow the surfaces by cutting a trench to avoid the vegetation interference. Specific physical, mineralogical and stratigraphical characteristics of sediments were observed in prior to the sample collection. Composite samples were prepared for detail laboratory analyses.

Samples were oven dried in 60°C for 24 hours prior to the sieving. Mechanical sieve analysis was done using at ¼ phi intervals (ASTM sieves) for 20 minutes using a digital shaker (Retsch AS 200 digit) and Grain Size Distribution (GSD)curves were plot for each sampling location. The statistical parameters were obtained using GRADISAT software following the Folk and Ward (1957) method for interpretations (Blott and Pye, 2001).

4. Results and Discussion

4.1 Physical and mineralogical characteristics

The sediment samples obtained from Navithanveli, Annamalei and Mandur sites were angular to sub angular in shape and majority of the sediments contain quartz (more than 70%) with minor amounts of K feldspars and heavy minerals**.** The sediments of Thuraineelavanai, Pandirippu, Periyakallar, Koddakallar and Mahiloorsites are sub rounded to rounded grains of quartz (90%) with minor heavy minerals. The beach face sediment samples of Pandirippu, Periyakallar and Mahiloor are mineralogically similar to other samples, however, they are mostly angular to sub angular grains.

The mineralogical and the physical characteristics of the sediments obtained from Navithanveli, Annamalei and Mandur sites might be influenced by the rock assemblages of the area such as granitic gneisses and quartz of eldspathicpegmatites that were subjected to long term insituweathering by river actions and tidal effects. On the other hand all other samples except beach face are characterized by similar mineralogical and physical characteristics indicating that they have been subjected to prolong period of weathering and abrasion by ocean currents (Mehring and McBride, 2007). The angularity of the beach face sediments indicate that they are younger sediments which derived from long shore currents of the ocean.

4.2 Grain size distribution

Most of the GSD curves of the present study show unimodal shape with different modes which indicate the less mixing of sediments during the deposition (Flemming, 1988).The GSD curves around the river paths are bimodal shape or platykurtic (Fig. 2). All sampling sites display two different modes around 0.25mm (phi 2) and 0.5mm (phi 1) with coarse tails (Fig. 2). The 0.5mm or higher mode sampling sites of barrier deposits are along the beach face or the places where marine influence is high (inlet face) and 0.25mm mode sampling sites are on the barrier depositsor shaded areas of inlet should be originated from fluvial influences or moderate energy environments of marine influences. The annual water budget of the estuary is controlled by both inlet opening during flood periods and natural closure during the other periods of the year. The patterns of sediment transportation have also been followed the annual water movements of the estuary.Fine to medium grained sediments are deposited on the barrier deposits or the shaded areas due to river actions. Medium to coarse grained sediments are deposited on the beach face and around inlet due to flood events and marine currents during the inlet closure period. Along the river paths, the sediments are characterized with high energy mixing environment. GSD curves and modes of mainland sediments represent insitu weathering characteristics. Hence GSD curves of barrier deposits demonstrate two different modes on barrier deposits or shaded areas (hereafter refer as shades), beach face and inlet associated areas (hereafter refer as inlet face) demonstrating the water movement and deposition of sediments during estuarine inlet management.

4.3 Statistical Parameters

The phimean grain size of barrier deposits varies from medium to coarse-grained sands with greater prevalence of medium sand size while that of mainland shows fine sands to very fine gravels (Fig. 3). The average mean size of inlet face (1.06) and shades (1.48) indicates that they were deposited in prolong moderate to high energy condition (Greenwood, 1969; Abdulkareem et al, 2011; Rajganapathi et al., 2013). The long term input from rivers and flood events as well as inlet opened marine currents are resulted for the mean size of the shades and inlet face of the barrier deposits respectively (Yaacob et al., 1995; Watson et al., 2013; Amireh et al., 2014). The finer fraction might have been washed away from the flood forces and coastal effect due to inlet flows. The few samples with medium to coarser mean sands are distributed along the beach and around the inlet due to the sweeping oscillatory motion of the breaker zone that removes away the finer part remaining the coarser parts (Friedman, 1967).The mean size variation of the mainland may be affected from both river banks and residual weathering.

The average sorting values of inlet face and shades are 1 and 0.91 respectively indicating moderately sorted nature (Fig. 3).The moderate sorting values of both areas indicate moderate energy fluctuations that lead to settle the wide range of particle sizes due to flood actions and marine influences (Greenwood, 1969;Amireh et al., 2014).

Most of the samples of shades show negative skewness while inlet face shows positive skewness (Fig. 3). The beach sediments show negative or fine to near symmetric skewness(Greenwood, 1969;Rajganapathi et al., 2013).Kurtosis relates the energy level and energy-time relationship within any given environment (Greenwood, 1969). Kurtosis of the inlet face samples show mesokurtic to platykurtic character (average 0.9) indicating the high energy, wide distribution and maturity of sediments (Rajganapathi et al., 2013). The shaded sediment samples show leptokurtic character (average 1.14) indicating that the central portion is relatively sorted in moderate energy environments (Venkatramanan et al., 2011). Skewness and kurtosis results revealed that the sediments of shades deposited in a long period with moderate energy environment having minor coarse sediment influences and inlet face sediments deposited in short period with high energy environment (Greenwood, 1969).

4.4 Bivariate scatter plots and depositional environments

The scatter plots (Fig. 4) were drawn considering the two different deposition areas of GSD curves that obtained from barrier deposits to compare the sedimentation of each sedimentary area with respect to the depositional environments (Falk and Ward, 1957; Pettijohn, 1984).

The mean versus sorting plot of the samples shows two clusters for shaded areas (medium size and moderately well sorted to moderately sorted) and inlet facing areas (medium to coarse and moderately sorted to poorly sorted) indicating that the depositions are hydraulically controlled (Griffths, 1967).The mean versus skewness graph shows mixing of subordinate population of sediments for the predominant population indicating either negative or positive skewness (Venkatramanan et al., 2011; Rajganapathi et al., 2013).Negative skewness for medium size sediments in shadesindicates mixing of coarse sediments due to the high energy floods and probably fluvial originated sediments. In contrast to the beach sediment characteristics, positive skewness of medium to coarse sands in the inlet face indicates the subordination of fine sediments during the low energy inlet closure period (Duane, 1964).

The relationship between kurtosis and mean indicates that the predominant medium size of shades are well sorted than subordinate coarser fractions and subordinate fine deposits of inlet facing areas are better sorted than the predominant medium to coarse sands. This is due to that the coarser fractions are deposited in high energy periods and finer fractions are deposited in low energy periods of both marine and flood events.

The interrelationships of the grain size parameters also reflect the difference of sedimentary characteristics of inlet face and shaded areas of the barrier morphologies. Well sorted medium size sediments are predominant in shaded areas with coarse size subordinate sediment fraction. The inlet face is common with medium to coarse sands with better sorted finer fractions.

Shaded areas and barrier sediments have prominently well sorted medium size sediments showing unimodal grain size distribution. This characteristics indicate moderately energized environment and probably the prolong river inputs and lagoon open environment to coastal actions deposited the sediments. The absence of finer fraction in those sediments indicates the removal of finer fraction by sweeping oscillatory motion of the breaker zone in exposed lagoon condition (Friedman, 1967). The absence of finer fraction further indicate that there is no estuarine closed basin environment as the inlet management occur since the environmental shift from lagoon to estuary (Watson et al., 2013). The prominent coarser fractions with moderate to unsorted sediments around beach and inlet areas indicate the deposition occurred in moderate to high energy environments. This might be due to the traffic events of floods, marine currents and inlet openings.

5. Conclusions

The grain size distribution of studied surface sediment samples of lagoonestuarine environment, Batticaloa, revealed that a clear relationship between the intermittently open-closure nature of the inlet with the mode of the GSD curves and statistical parameters of inlet face and shaded areas of the barrier morphologies. Prominent medium size component of sediments shows that the barrier deposits have been formed under moderate energy of open lagoon environment and the formation of estuarine environment has been shifted due to the deposition of coarser components. Further, the results of the present study showed that the textural characteristics and distribution of sediments can be used to interpret the movements and depositional processes of lagoon estuarine systems.

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and (D), (E), (F), (G) and (H) sampling sites are from barrier deposits. All sampling sites display two different modes around 0.25mm (phi 2) and 0.5mm (phi 1) with coarse tails.

Fig.3:Comparative histograms of all samples showing (A) Mean (B) Sorting (C) Skewness (D) Kurtosis

Fig. 4:Scatter plots of statistical parameters for inlet face, shades and beach sediment samples (A) bivariate plot of mean vs. sorting (B) bivariate plot of mean vs. skewness (C) bivariate plot of mean vs. kurtosis

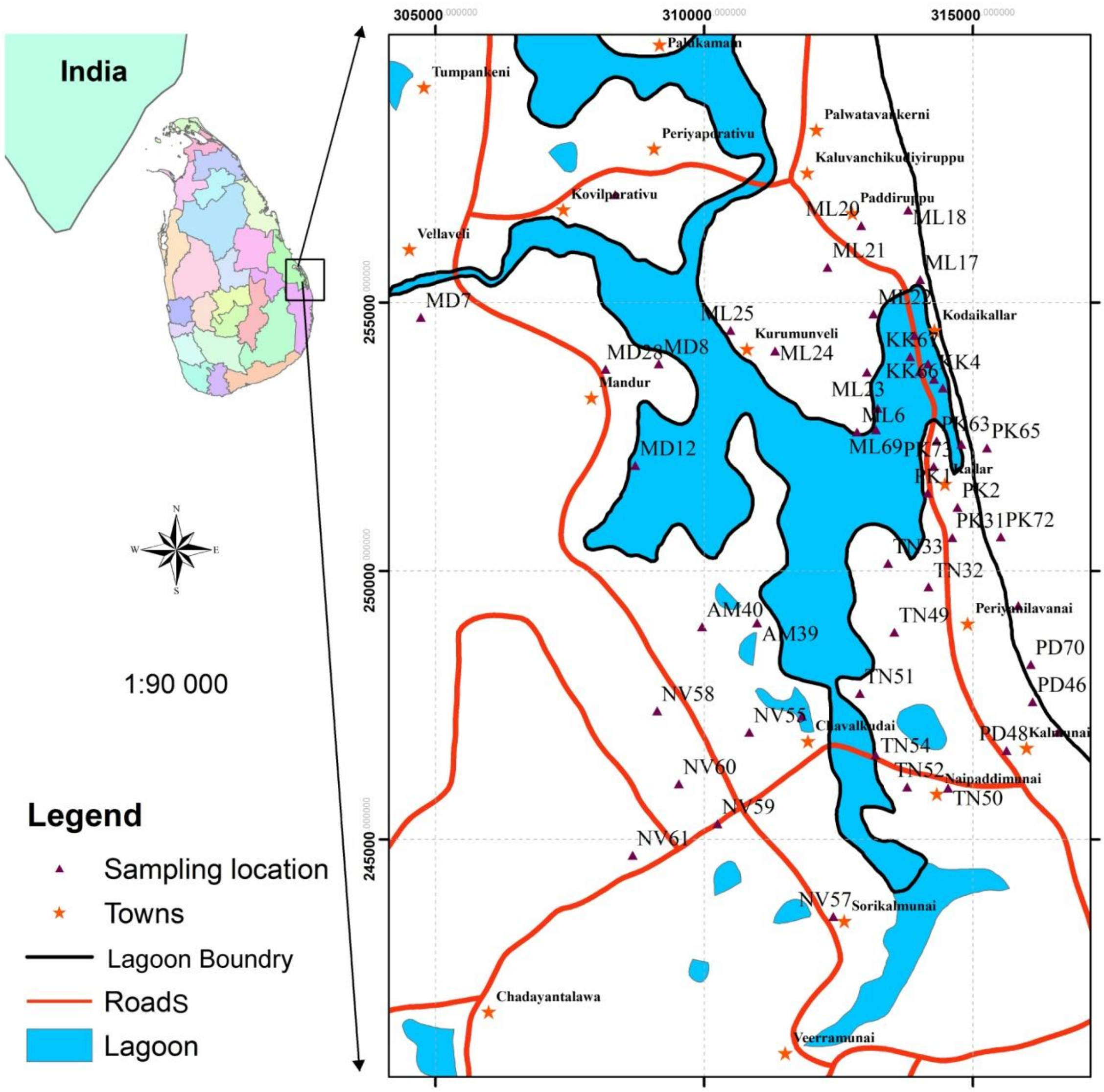

Figure 1

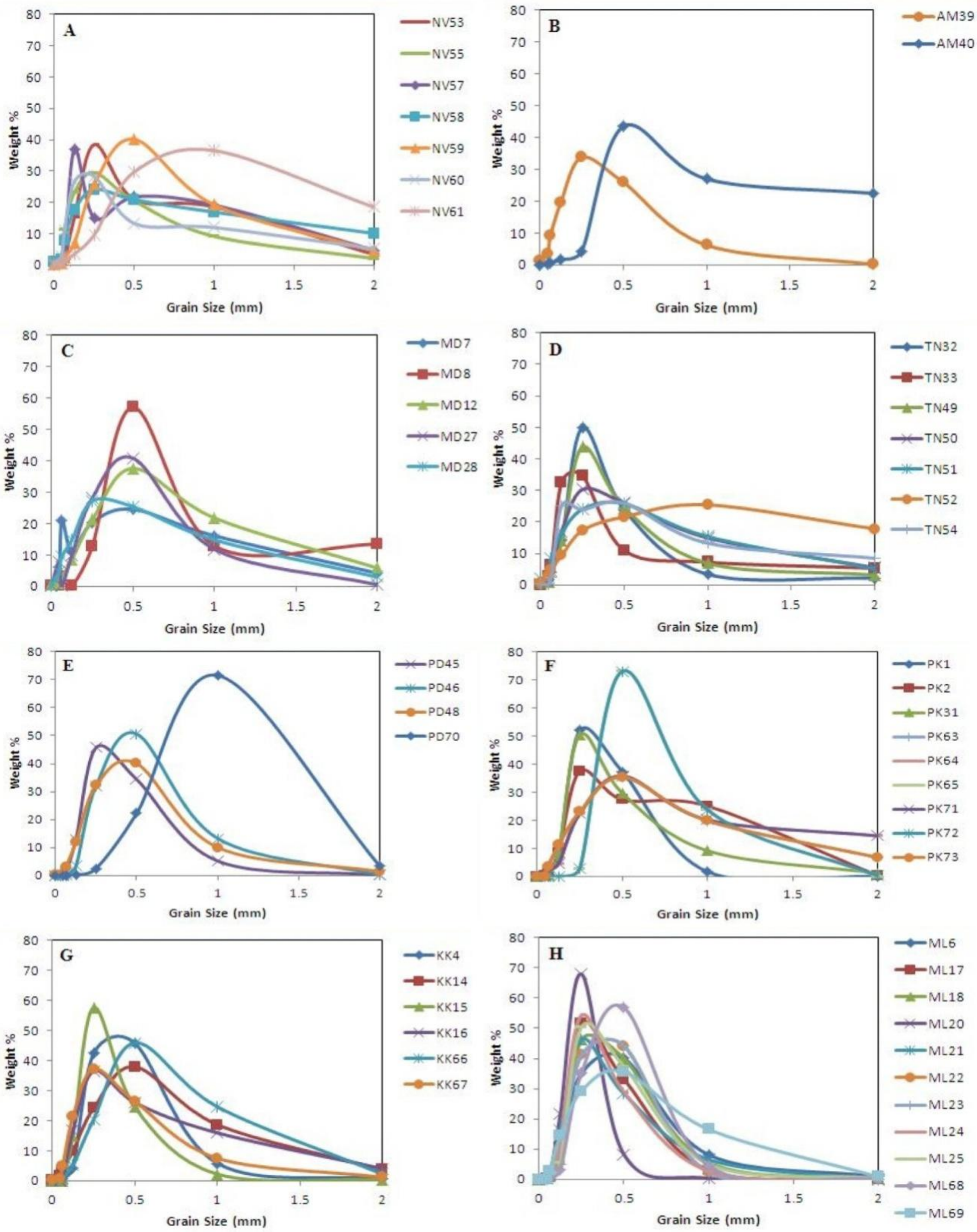
A
NV53
NV55
NV57
NV58
NV59
NV60
NV61
B
AM39
AM40
C
MD7
MD8
MD12
MD27
MD28
D
TN32
TN33
TN49
TN50
TN51
TN52
TN54
E
PD45
PD46
PD48
PD70
F
PK1
PK2
PK31
PK63
PK64
PK65
PK71
PK72
PK73
G
KK4
KK14
KK15
KK16
KK66
KK67
H
ML6
ML17
ML18
ML20
ML21
ML22
ML23
ML24
ML25
ML68
ML69
Weight %
Grain Size (mm)

Figure 2

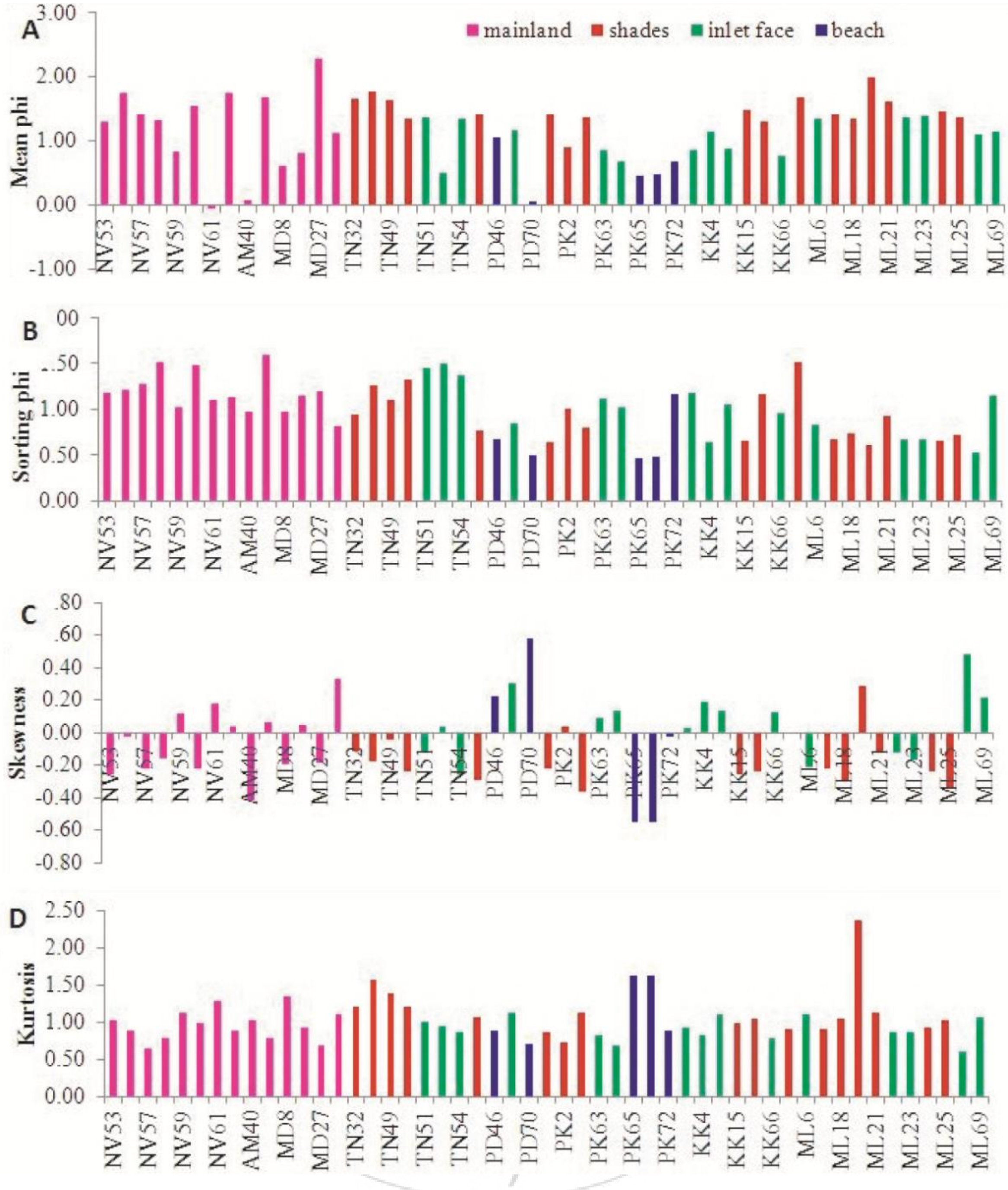
A
B
C
D
Mean phi
Sorting phi
Skewness
Kurtosis
mainland
shades
inlet face
beach
NV53
NV57
NV59
NV61
AM40
MD8
MD27
TN32
TN49
TN51
TN54
PD46
PD70
PK2
PK63
PK65
PK72
KK4
KK15
KK66
ML6
ML18
ML21
ML23
ML25
ML69

Figure 3

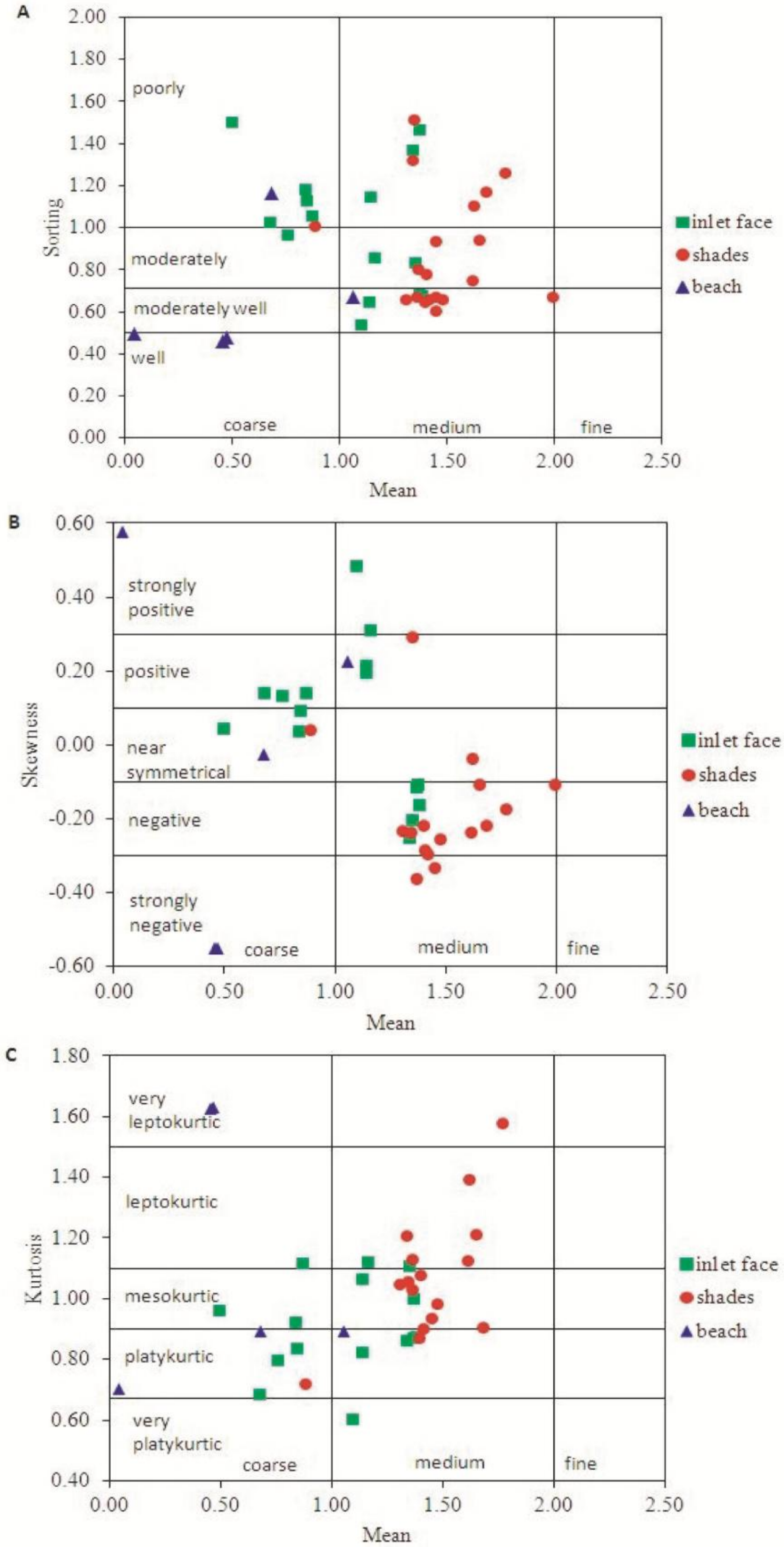
A
Sorting
poorly
moderately
moderately well
well
coarse
medium
fine
Mean
inlet face
shades
beach
B
Skewness
strongly positive
positive
near symmetrical
negative
strongly negative
coarse
medium
fine
Mean
inlet face
shades
beach
C
Kurtosis
very leptokurtic
leptokurtic
mesokurtic
platykurtic
very platykurtic
coarse
medium
fine
Mean
inlet face
shades
beach

Figure 4