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Textural attributes of Sandstones from extra-peninsular Kalijhora Gondwana Basin in Darjeeling District, West Bengal, India

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ABSTRACT

Extra-peninsular Gondwana rocks are exposed in and around Kalijhora in Darjeeling district of West Bengal. The Kalijhora lithostratigraphic column is largely arenaceous. An attempt was made to analyse the textural attributes of these Gondwana sandstones which was unknown till date. Kalijhora sandstones are largely medium grained, poorly sorted, positively skewed and leptokurtic. The main mode of transportation for the sandstones seems to be combination of traction and suspension mechanism. Mixing of finer grains imparted bimodality to the distribution. Addition of fines to the relatively coarser main mode suggests the occurrence of a temporary turbid like condition in the otherwise calm riverine depositional environment leading to the transport of both coarser and finer fragments side by side. A phase of transgression also affected the sediments that show affinity towards deltaic (fluvial) as well as shallow marine depositional setting.

KEYWORDS: *Gondwana sandstones, Kalijhora, Extra-peninsular India, Textural attributes*

INTRODUCTION

Sedimentary textures bear impressions and influences of physico-chemical dynamism as well as biological attributes of a system affecting the sediments across space and time. Although these facets of sediments were recognised more than hundred years back, works of Folk and Ward (1957) and Cadigan (1961) particularly proved that many attributes of sediment distributions could be understood through statistical applications and, this relationship has been found to be exploited successfully by many workers like Inman, 1949; Passega, 1957; Friedman, 1961; Moss, 1962; Sahu, 1964, 1983; Moiola and Weiser, 1968; Glaister and Nelson, 1974; Joseph et al., 1997; Mycielska-Dowgiallo and Ludwikowska-Kedzia, 2011 etc. later on through various bivariant and multivariate tests.

It has been proved that sediment distribution is environmentally sensitive as grain size depends on the source rock character and its tectonic framework, climatic and weathering processes, physical framework of depositional environment, nature of the agents of denudation, abrasion and selective sorting during transportation of terrigenous deposits. Environmental sensitivity of clastic sediments is a very important facet that helps one to work out palaeoenvironmental framework of sedimentation.

Reconstruction of Gondwanaland has always remained a global obsession amongst geologists (Chandra and Singh, 1996). Gondwana Supergroup which is now scattered across many continents is largely made up of alternations of sandstones, shale and coal. While tectonism ensured preservation of Gondwana sediments to a large extent (Chakravarty and Sarkar, 2005), post-depositional fragmentation of Gondwanaland triggered spatial separation of the sedimentary sequences deposited under conditions which varied from glacial to fluvial, alluvial, lacustrine and deltaic, (Valdiya, 2010). Palaeoflow directions and environmental framework have been worked in almost all the lower Gondwana basins of Peninsular India (Casshyap, 1977; Veevers and Tewari, 1995; Biswas, 1999; Chakraborty et al., 2003). While textural attributes of Peninsular Gondwanas have been worked out by many workers (Casshyap, 1970; Casshyap and Tewari, 1988; Quidwai and Casshyap, 1978; Mazumdar and Ganapathi, 1998; Baruah and Das, 2001) the same for extra-peninsular Gondwana sediments exposed in and around Kalijhora have never been attempted. The present attempt seeks to understand the textural attributes and environmental framework of deposition of the sandstones of the extra-peninsular Gondwana exposures in and around Kalijhora, Darjeeling District, West Bengal, India in detail through grain size analyses. Kalijhora is at a distance of about 30 kms from Siliguri city of West Bengal on the national highway NH 31A, (Figure 1).

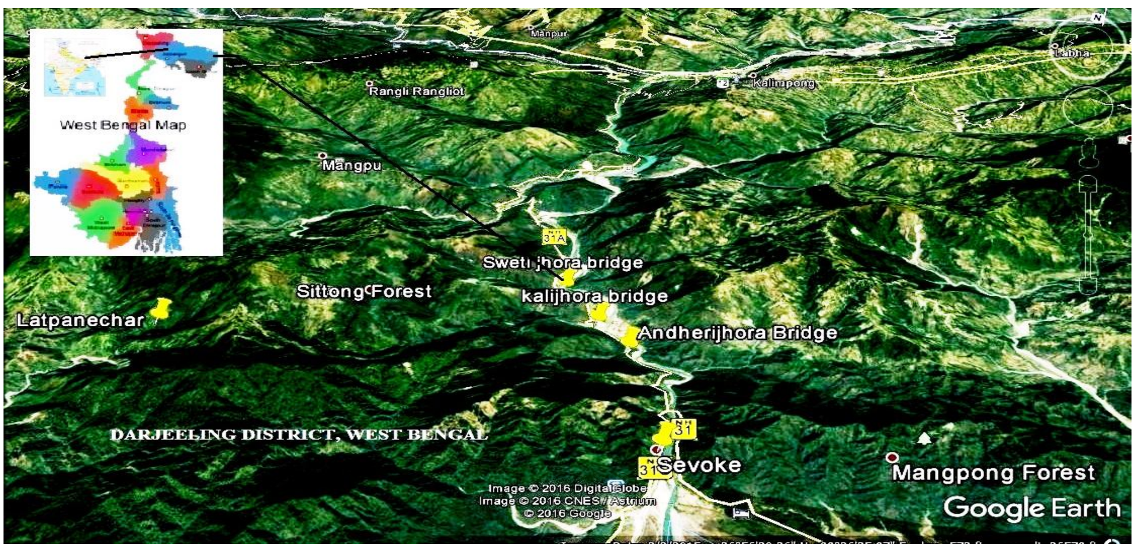


Figure 1: Location map of Kalijhora in West Bengal, India; Source: Google Earth image.

GEOLOGY OF THE STUDY AREA

Kalijhora rests on the lap of Darjeeling-Sikkim Himalayas. Gondwana rocks exposed in this area are a part of the fold and thrust belts sequences of North-East Himalayas and locally known as Rishi Group, (Basu, 2013). These Gondwana rocks are sandwiched between Siwalik Group of rocks towards south and Precambrian Dalings towards north and, positioned in a roughly ENE-WSW to WNW-ESE trend (Figure 2; Table 1).

Figure 2: (a) Photograph showing intermixing of sandstone, and coal; locality: Right bank of Kalijhora river; (b) Photograph shows alternation of sandstone and coal; locality: south of Kalijhora bridge; (c) Photograph shows sandstone shale alternations; locality: left and right banks of Kalijhora river; (d) Photograph showing ductile coal layers bearing Z type crenulations and imprints of dextral shear sense; locality: Right bank of Kalijhora river.

The Kalijhora lithostratigraphic column is largely arenaceous, (Kar *et al.,* 2019). Gondwana sandstones are relatively more compact than the Siwalik sandstones which are exposed south of the Andherijhora Bridge. Gondwana sandstones are largely medium grained, dark grey, grey, buff coloured varieties and, a little bit recrystallised. As one moves north from the Andherijhora bridge, Gondwana sequence starts with texturally and compositionally homogenous dark grey sandstones. Grey sandstones which are exposed along the Kalijhora river bed hosts variable calcareous components. These sandstones are primarily dipping north and display the occurrences of warped, discontinuous bedding planes, curviplanar joint planes, several cross joints, especially on the right bank of Kalijhora river bed. Carbonaceous shale, sandy shale and coal are some of the other litho-units found in this middle unit. Further north from the road leading to Latpanchor are seen the fine to medium grained buff coloured compositionally homogenous sandstones. Coal largely exudes almost an anthracitic look owing to thrusting. Kalijhora is devoid of fossils. A larger antiform with east-west axial planar trend and a moderately westerly plunging fold axis can be worked out across the Kalijhora River which also exudes signatures of dextral shear sense.

Table 1: Synthesised lithostratigraphy of Kalijhora area (HFT: Himalayan Frontal Thrust; SKT: South Kalijhora Thrust; MBT: Main Boundary Thrust; DT: Daling Thrust).

Age	**Group**	**Lithotypes**
Recent		Alluvium
	~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ *Thrusted* (HFT) ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~	
Tertiary	Siwalik	Medium grained sandstone, carbonaceous shale intercalated with sandy shale, silt, minor marl and pebbly sandstones, conglomerate: Repetitive sequence
North	~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~~ *Thrusted* (SKT) ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~	
		Fine to medium sandstone, sandy shale, shale, minor coal, pebbly sandstones, conglomerate
	~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ *Thrusted* (MBT) ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~~ ~ ~ ~ ~	
Permo-Carboniferous	Gondwana / Rishi	Fine to medium grained buff coloured sandstones
		Grey coloured sandstones intercalated with slaty shale, carbonaceous shale and coal; minor gritty sandstones; few sandstones exude a calcareous look
		Grey to dark grey recrystallised sandstone
	~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ *Thrusted* (DT) ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~	
Precambrian	Daling	Massive quartzites Intercalations of foliated quartzites and phyllites

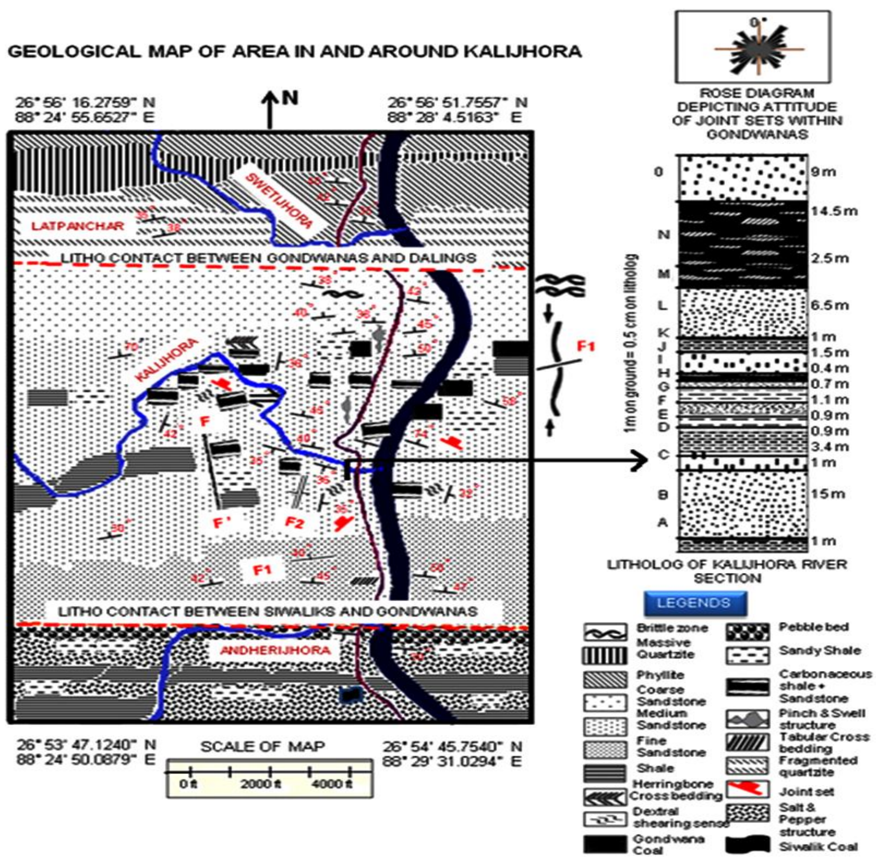


Figure 3: Geological map of the areas in and around Kalijhora, Darjeeling district, West Bengal (after Kar *et al*., 2019).

METHODOLOGY

Twenty four representative samples were disaggregated following Carver (1971) and applied to "Composite Sieve and Pipette Method" analysis (c.f., Krumbein and Pettijohn, 1938). Experimental results were utilised to extract inclusive graphic univariant statistical parameters like mean grain size (M_z), sorting (σi), skewness (Sk_i) and kurtosis (K_G) following Folk and Ward (1957) and Cadigan (1961). These basic parameters were then subjected to several in-vogue statistical combinations and discriminant figures following Folk and Ward (1957); Friedman (1961, 1967); Sahu (1964); Moiola and Weiser (1968) and, Glaister and Nelson (1974). Additionally, Folk and Ward's textural parameter relationships, Complete C-M pattern plots of Passega (1957) and Passega and Byramjee (1969) as modified by Ludwikowska-Kedzia (2000); Mycielska-Dowgiallo (2007) and Mycielska-Dowgiallo and Ludwikowska-Kedzia (2011) were analysed in order to understand the sediment attributes in a better way and, log probability plot (Visher, 1969) were used to understand nature of sediment movement. The three varieties of sandstones: dark grey, grey and buff coloured were coded as Ar_1, Ar_2 and Ar_3 in the field to figure out if any sharp distinctiveness exists between these distributions when tested in certain discriminatory tests.

RESULTS

Statistical tests in this investigation were initiated with construction of frequency and cumulative curves to have an initial understanding of the nature of sediment distribution.

Frequency and Cumulative Frequency Distribution Curves

Frequency curves are bimodal (Figure 4a) with the highest distinct peak at 2ϕ interval for 95.83% of the samples and another secondary peak at 3ϕ interval for 75% of the samples. Spread of size classes ranging from 2.5ϕ to 5ϕ is also noted for 25% of the samples. Cumulative frequency curves for Kalijhora sandstones (Figure 4b), however, tend to be apparently unimodal with a prominent mode occurring between 2ϕ and 2.5ϕ. The coarser ends show good sorting and mixing of finer particles in the distribution is distinctly clear towards the finer end.

Grain size parameters: Univariant Analyses

Statistical grain size parameters facilitate in discriminating between two or more sediment distributions displaying almost similar nature of curves. Use of these parameters in various combinations throws light on provenance, tectonic framework of sedimentation and mode of transportation of the population distribution. These parameters have been deduced following Folk and Ward (1957) and Cadigan (1961) and a summarised representation is made in Table 2.

Table 2: **Variations in grain size parameters of Kalijhora Sandstones.**

	Univariant Grain Size Parameters	**Kalijhora Sandstones**
1	Graphic Median (P_{50})	1.4ϕ – 2.6ϕ
2	Graphic Mean Size (M_z) As per Cadigan (1961)	1.37ϕ and 2.65ϕ 70.83% medium, 25% fine and 4.17% coarse sand.
3	Inclusive Graphic Standard Deviation (σ_i) *As per Folk and Ward (1957)* As per Cadigan (1961)	1.03ϕ to 2.28ϕ *87.5% poor sorted* 90% moderately well sorted
4	Inclusive Graphic Skewness (Sk_i) *As per Folk and Ward (1957)* As per Cadigan (1961)	-0.065 to 0.729 *66.67% very fine skewed, 29.17% are fine skewed* > 90% slightly skewed.
5	Inclusive Graphic Kurtosis (K_G) *As per Folk and Ward (1957)* As per Cadigan (1961)	0.900ϕ and 2.664ϕ *25% leptokurtic, 41.67% very leptokurtic, 33.3% mesokurtic* > 90% moderately peaked.

Some inherent statistical attributes of a distribution can be reflected by frequency variations of grain size parameters. Mean size variation curve for the Kalijhora sandstones show distinct unimodality with the main mode hovering at 2.2ϕ. Sorting and skewness variation curves show bimodal nature reflecting addition or mixing of finer materials in the main mode that distort or spread the distribution towards finer grain sizes. Kurtosis variations however show a dominant unimodal nature in the leptokurtic sector.

Scatter Plots: Bivariant analyses

Univariant parameters when tested in combination reveal many subtle attributes of sediment distributions as well as their environmental affinities. Bivariant environmental reconstruction tools have been quite popular although criticised by some workers like Amaral and Pryor (1977) and Moshrif (1980). Certain scatter plots of Folk and Ward (1957); Stewart (1958); Friedman (1961, 1967); Moiola and Weiser (1968); Thomas *et al.* (1972); Glaister and Nelson (1974) and Mycielska-Dowgiallo and Ludwikowska-Kedzia (2011) were attempted in this endeavour to find out inherent statistical characteristics of the distribution and the depositional environment.

Graphic Mean Size (M_z) vs. Inclusive Graphic Standard Deviation (σ_i)

Grain sorting is strongly influenced by mean diameter of the grains and standard deviation is a sinusoidal function of the mean size (Griffiths, 1967) and, both M_z and σ_i are sensitive to environmental impacts also. The present test shows admixing of finer particles (Figure 5a) impacting the sorting. Environmental discrimination plots after Moiola and Weiser (1968) shows affinity towards a riverine setup while the same combination in the test after Glaister and Nelson (1974) concentrate in the braided bar zone indicating influence of a probable high energy condition that may be related to an onset of transgression phase (Figure 5b).

Graphic Mean Size (M_z) vs. Inclusive Graphic Skewness (Sk_i)

As soon as a distribution begins to deviate from unimodality, the skewness tends to become more and more sensitive to mean size. In case of the Kalijhora sandstones the statistical plots following Folk and Ward (1957), show concentration in the positive skewed sector of the finer end supporting admixing of finer particles. Environmental plots after Moiola and Weiser (1968) predominantly fall in the river field with some affinity towards beach environment. Similarly, the test after Mycielska-Dowgiallo and Ludwikowska-Kedzia, (2011) highlights occurrence of mainly river channel and over bank deposits (Figure 5c).

Inclusive Graphic Standard Deviation (σ_i) vs. Inclusive Graphic Skewness (Sk_i)

Both inclusive graphic standard deviation and inclusive graphic skewness are the functions of mean size. Statistical plot of Folk and Ward (1957) when tested in this combination highlights the additions of finer grains in the distribution. Environmental plots after Friedman (1967), Moiola and Weiser (1968) and Mycielska-Dowgiallo and Ludwikowska-Kedzia (2011) hint at riverine setting (Figure 5d and Figure 5e).

Admixing of finer particles and affinity towards riverine environment is reflected in the tests of Inclusive Graphic Standard Deviation (σ_i) vs. Inclusive Graphic Kurtosis (K_G) and Inclusive Graphic Skewness (Sk_i) vs. Inclusive Graphic Kurtosis (K_G) also.

Linear Discriminant Functions – Multivariant Analyses

Linear discriminant functions (Sahu, 1964) brought about remarkable advancement in the field of textural analysis as it combined all the grain size parameters into a single linear equation and used them for the two group discrimination. Sahu discriminated between different depositional environments (Table 3) like aeolian and littoral (beach), beach and shallow agitated marine water; shallow marine and fluvial (deltaic) environments and fluvial and turbidity environments; and for distinguishing these environments, the following equations were used

i. $\overline{Y}$ (Aeolian: Beach)
[$-3.5688M_z + 3.7016\sigma_i^2 - 2.0766Sk_i + 3.11$]
$\overline{Y} < -2.7411$ = Aeolian depositional environment
Result: All samples show *Aeolian affinity*.

ii. $\overline{Y}$ (Beach: Shallow Agitated Marine Water)
[$15.6534M_z + 65.7091\sigma_i^2 + 18.1071Sk_i + 18.5043K_G$]
$\overline{Y} < 65.3650$ = Beach setting deposition
Result: All samples show *Shallow Agitated Marine Water affinity*.

iii. $\overline{Y}$ (Shallow marine: Fluvial (deltaic))
[$0.2852M_z - 8.7604\sigma_i^2 - 4.8932Sk_i + 0.0482K_G$]
$\overline{Y} < -7.4190$ = Fluvial (deltaic)
Result: All samples show *Fluvial (deltaic) affinity*

iv. $\overline{Y}$ (Fluvial: Turbidity current)
[$0.7215M_z - 0.4030\sigma_i^2 + 6.7322Sk_i + 5.2927K_G$]
($\overline{Y} < 9.8433$ = Turbidity deposition).
Result: *66.67% samples show Fluvial affinity*

C-M Pattern Plots

Understanding hydraulic conditions under which clastic sediments were deposited have been a sought after objective of many workers. Mode of transport of sediments could be extrapolated by representing the deposit's texture in a C-M diagram. Passega (1957, 1964); Bull (1962); Passega & Byramjee (1969); Ludwikowska-Kędzia (2000); Szmańda (2002) and Ostrowska et al. (2003) summarised that C-M pattern plotted on a logarithmic diagram is presided over by the depositional agent where 'C' highlights the competence of transporting agent and 'M' indicates the static characters of entire range of grain sizes undergoing transportation by the agent of deposition.

Basic C-M pattern plot after Passega (1957) (Figure 6) depicts the present sandstones to clog around sectors reflecting river tractive deposits (area V, IV) close to beach deposits (area VII) and, a very minor amount plots in turbidity current field also (area VI b).

The Complete C-M pattern plots (Figure 7) after Passega (1964); Passega & Byramjee (1969) and after Ludwikowska-Kędzia (2000) have been prepared to understand the mechanism of transportation of sediments. Here, the sandstone samples concentrate mainly within the segment O-P of the C-M pattern (after Passega, 1964 and Passega & Byramjee, 1969) reflecting presence of a mixture containing variable proportions of rolled as well as suspension sediments and also within the segment P-Q corresponding to suspension sediments represented by point Q. When the same plots are considered following the modified version of Ludwikowska-Kedzia (2000), the plots reflect saltation and suspension (minor) as the main modes of transportation. Both the complete C-M plots thus reflect interaction between bed load and suspended load. Suspension could again be due to some agitation of the sediment load under influence of transgression.

Log Probability Plots

There were several trials to correlate the processes of transportation with the grain size curves (Moss, 1962) and demarcate sub-populations. Visher (1969) came up with one of the most impactful studies relating to distinction and interpretation of sub-populations in a log-normal sediment distribution and hydrodynamics of the depositional basin based on log-probability plots. This approach helped to have an understanding of traction, saltation and suspension processes on the deposits.

Table 3: Tabulated data of values obtained from Kalijhora Sandstone analyses based on linear discriminant function (after Sahu, 1964)

Sl.	Sample No.	Y^1 (Aeolian : Beach)		Y^2 (Beach : S.A.M. Water)		Y^3 (S.M. Water : F. Deltaic)		Y^4 (Fluvial : Turbidity)	
		Value	Result	Value	Result	Value	Result	Value	Result
1	1a	1.674	Aeolian	174.296	S.A.M. Water	-14.764	F. Deltaic	13.164	Fluvial
2	1b	3.767	Aeolian	187.467	S.A.M. Water	-16.084	F. Deltaic	15.547	Fluvial
3	1c	0.746	Aeolian	140.545	S.A.M. Water	-13.282	F. Deltaic	9.970	Fluvial
4	2_2	0.544	Aeolian	219.870	S.A.M. Water	-20.295	F. Deltaic	8.427	Turbidity
5	2	1.766	Aeolian	168.941	S.A.M. Water	-15.779	F. Deltaic	6.731	Turbidity
6	9	7.097	Aeolian	193.035	S.A.M. Water	-17.949	F. Deltaic	10.622	Fluvial
7	2a	0.631	Aeolian	168.843	S.A.M. Water	-15.198	F. Deltaic	6.833	Turbidity
8	22a	4.289	Aeolian	155.331	S.A.M. Water	-15.993	F. Deltaic	12.994	Fluvial
9	$20Q_3$	1.289	Aeolian	142.234	S.A.M. Water	-13.278	F. Deltaic	10.046	Fluvial
10	$20l_5$	2.429	Aeolian	175.585	S.A.M. Water	-15.526	F. Deltaic	12.708	Fluvial
11	18_4	3.083	Aeolian	155.419	S.A.M. Water	-13.628	F. Deltaic	9.004	Turbidity
12	21d	0.084	Aeolian	187.130	S.A.M. Water	-16.236	F. Deltaic	13.867	Fluvial
13	4b	3.631	Aeolian	197.190	S.A.M. Water	-18.318	F. Deltaic	9.873	Fluvial
14	$20l_2$	1.004	Aeolian	167.992	S.A.M. Water	-15.965	F. Deltaic	8.685	Turbidity
15	$20l_3$	3.975	Aeolian	152.825	S.A.M. Water	-11.204	F. Deltaic	14.763	Fluvial
16	4d	1.994	Aeolian	201.812	S.A.M. Water	-18.448	F. Deltaic	12.626	Fluvial
17	4e	5.434	Aeolian	161.987	S.A.M. Water	-11.686	F. Deltaic	17.679	Fluvial
18	$4d_2$	3.149	Aeolian	212.638	S.A.M. Water	-18.804	F. Deltaic	13.774	Fluvial
19	22e	1.549	Aeolian	144.306	S.A.M. Water	-12.181	F. Deltaic	10.084	Fluvial
20	18_{2a}	1.963	Aeolian	166.668	S.A.M. Water	-15.845	F. Deltaic	10.414	Fluvial
21	18_{2b}	1.096	Aeolian	135.765	S.A.M. Water	-12.323	F. Deltaic	9.189	Turbidity
22	5c	0.623	Aeolian	142.241	S.A.M. Water	-12.614	F. Deltaic	8.513	Turbidity
r23	6b	1.782	Aeolian	143.549	S.A.M. Water	-12.735	F. Deltaic	8.560	Turbidity
24	18_1	5.456	Aeolian	125.948	S.A.M. Water	-8.234	F. Deltaic	10.978	Fluvial

LEGEND: *S.A.M. Water = Shallow Agitated Marine Water, F. Deltaic = Fluvial Deltaic*

Log probability plots (Figure 8) show the Kalijhora Sandstones to be mixtures of mostly three or less than three log-normal populations resulting out of three basic transportation modes viz., surface creep, saltation and suspension. 50% of the analysed samples display two saltation sub-populations. Saltation sub-population shows better sorting which matches with that of many fluvial settings. Presence of two saltation sub-populations hints at influence of a beach like setup. Such accumulations are produced due to swash and backwash. Very poor sorting of the saltation sub-population 'B' is quite catchy and the same may be due to minor turbid like situation.

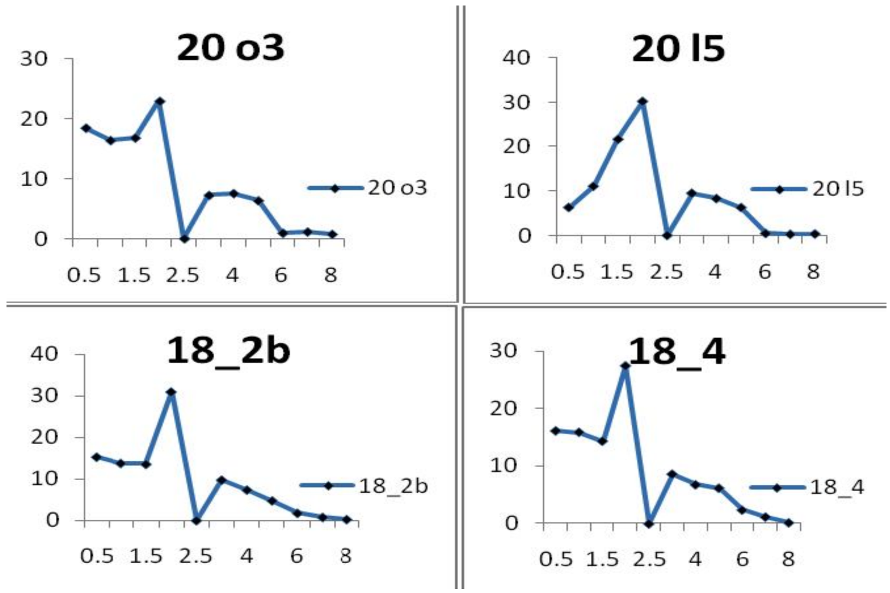


Figure 4: (a) Representative grain size frequency distribution curves of Kalijhora sandstones; N.B.: x-axis: Grain size in ϕ, y-axis: weight %

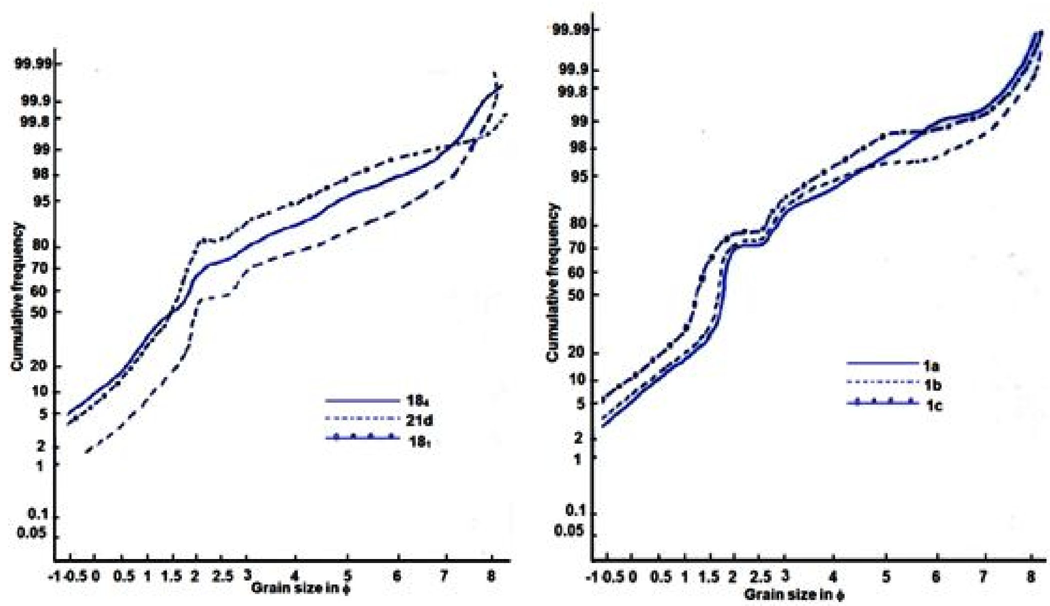
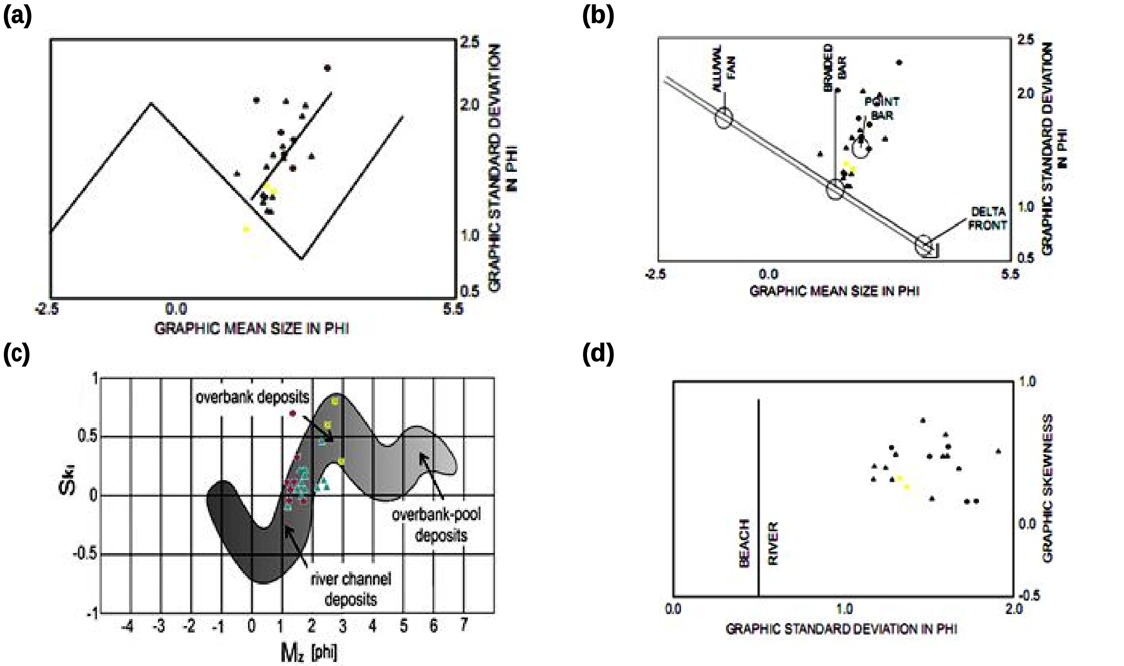
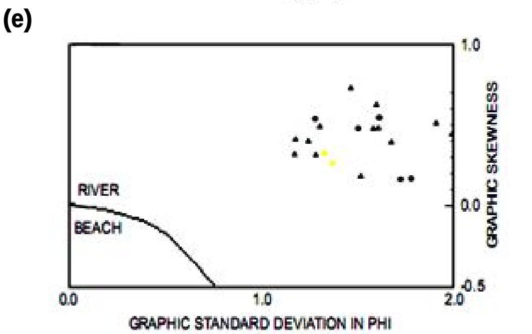


Figure 4: (b) Cumulative frequency plots of Kalijhora Sandstone





LEGEND: *Ar_1 unit: Filled circle; Ar_2 unit: Filled triangle; Ar_3 unit: Asterisk.*

Figure 5: (a) Inclusive Graphic Mean vs. Inclusive Graphic Standard Deviation, (after Folk and Ward, 1957); (b) Inclusive Graphic Mean vs Inclusive Graphic Standard Deviation, (after Glaister and Nelson, 1974); (c) Inclusive Graphic Mean vs. Inclusive Graphic Skewness, (after Mycielska Dowgiallo and Ludwikowska-Kedzia, 2011); (d) Inclusive Graphic Standard Deviation vs. Inclusive Graphic Skewness, (after Moiola and Weiser,1968; (e) Inclusive Graphic Standard Deviation vs. Inclusive Graphic Skewness, (after Friedman, 1967).

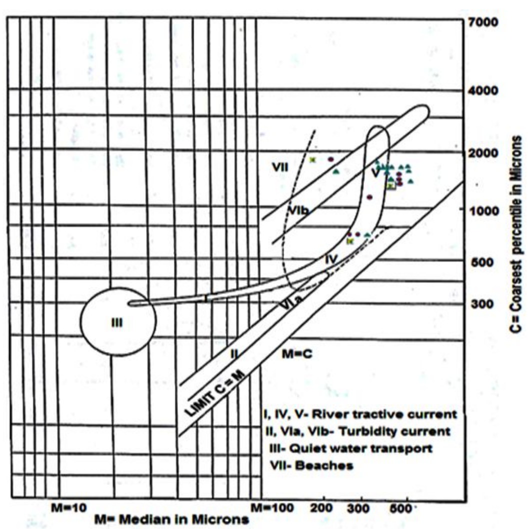


Figure 6: Basic C-M pattern of the Kalijhora Sandstones, (after Passega, 1957) *[Ar_1 unit: Filled circle; Ar_2 unit: Filled triangle; Ar_3 unit: Asterisk]*

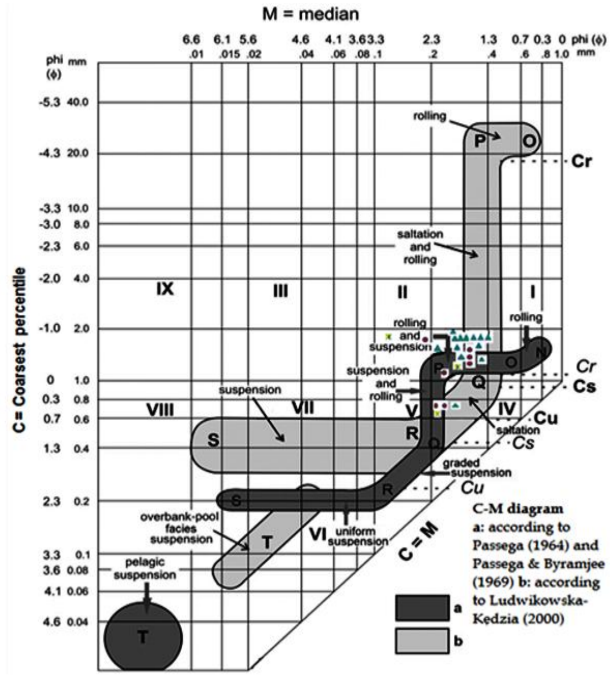


Figure 7: Complete C-M pattern of the Kalijhora Sandstones, (a: after Passega, 1964 and Passega and Byramjee, 1969; b: after Ludwikowska-Kedzia, 2000). *[Ar_1 unit: Filled circle; Ar_2 unit: Filled triangle; Ar_3 unit: Asterisk]*

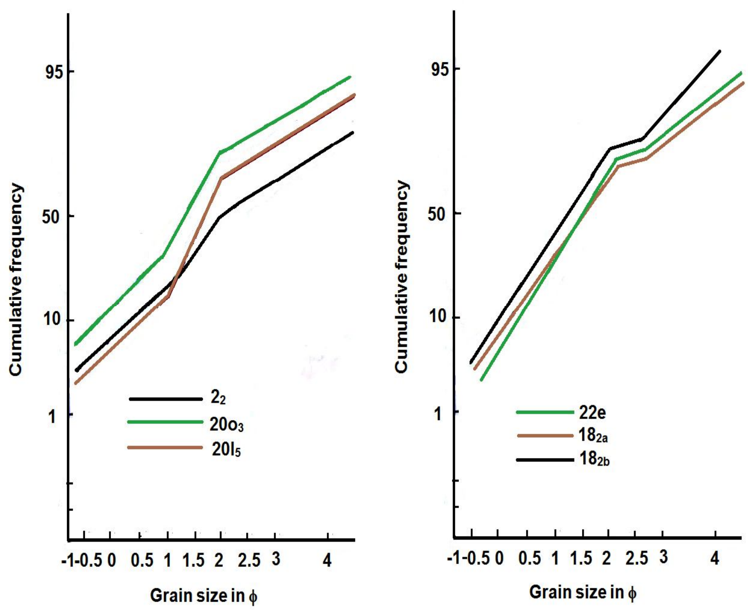


Figure 8: **Log probability plots of Kalijhora Sandstones**

DISCUSSION

Nature of sediments in a geological system of erosion, transportation and deposition is controlled by two factors: energy level of the system and the supply of the materials. Textural study of detrital sediments brings to light several attributes like the nature of the source rocks, the distance it travelled, the energy conditions in the depositing medium as well as the fluctuation of kinetic energy, the different cycles of deposition etc. Consistency as well as intensity of the energy system is very influential in moulding the nature of clastic deposits.

Frequency distribution curves of Kalijhora sandstones are bimodal with the highest distinct peak at 2 ϕ interval for 95.83% of the samples and another secondary peak at 3 ϕ interval for 75% of the samples. The development of a secondary peak at around 3ϕ, reflects addition of finer particles to the main mode and this might be a source control affect or post depositional contribution too. Bimodality in the distribution may arise owing to absence of certain grain size in the source materials which might be an effect of fluctuation in the kinetic energy of the depositing medium or might even hint at derivation of sediments from two or more varied sources. The cumulative frequency curves for the Kalijhora sandstones, however, tend to be dominantly unimodal with a prominent mode occurring between 2ϕ and 2.5ϕ while in some samples a bimodal characteristic is displayed with the presence of a smaller mode at around 5ϕ. The coarser ends show good sorting whereas the sorting is poor between 2ϕ and 2.5ϕ, followed by an improvement in the quality of sorting towards the finer ends. Poor sorting between 2ϕ and 2.5ϕ hints at mixing of grains in this range of grains.

The range of mean diameter sizes vary from 1.37ϕ and 2.65ϕ for the Kalijhora sandstones which implies relatively less velocity variation of the medium in a moderately low energy condition, a situation also highlighted by the mean size variation curve for the Kalijhora sandstones showing distinct unimodality with the main mode hovering at 2.2ϕ. This also implies subsequent addition of finer materials to the main mode. This observation is substantiated by the sorting range and variation curves which show a primary peak at 1.6ϕ and a secondary peak at 2ϕ. Skewness values are largely positively skewed. Positive skewness values represent a calm and sheltered environment (Duane, 1964, Friedman, 1967) which can also be associated with a riverine setting. Skewness variation curve for the Kalijhora sandstones is bimodal with a prominent mode at 0.5ϕ and a minor mode at 0.3ϕ further indicating the mixing of finer grains that acquire dominance in some samples within the grain size population. Kurtosis speaks a lot about the extreme statistical nature of a distribution. Kurtosis values in the present endeavour lies between 0.900ϕ and 2.664ϕ and is distinctly unimodal. Largely leptokurtic and very leptokurtic trends suggest that sorting is good in the central portion of the distribution compared to the tail portions thereby referring to an overall consistency in the influence of energy in the medium of deposition. Addition of finer fractions could not disrupt the overall internal sorting of the distributions.

Bivariant statistical tests have largely hinted addition of a finer fraction in the distribution that deviate the plots a little bit from the trends of standard plots. The environmentally biased bivariant plots display arrangement of the samples mainly in the river field with some samples plotting in / close to the beach environment also, depending upon the combination of parameters.

Energy and fluidity variation factors show noteworthy correlation with the different processes and depositional environments. Multivariant analyses utilising linear discriminant functions of Sahu (1964) helped to understand finer attributes of the present sediment distribution. The $\overline{Y}$ (Aeolian : Beach) equation seems to be insensitive in the present case. The second equation refers to presence of agitated shallow marine water deposits leading to deposition of poorer sorted, less uniformly distributed sediments bringing in addition of finer materials, unlike the deposits in the beach zone where the constant pounding of waves make the beach deposits better sorted and more uniformly distributed. The third equation indicates a fluvial (deltaic) deposition implying the time to time influence of seawater in an otherwise fluvial environment as suggested by the fourth equation of Sahu, 1964. The $\sqrt{\sigma_i^{-2}}$ against [S K_G / S M_z X S (σ_i^2)] plot (not shown here) of Sahu (1964) demonstrates that the sandstones fall mainly within the deltaic (fluvial) as well as shallow marine depositional setting.

The influence of river tractive currents in the distribution has been well established. However, some sample of sandstones from northern part of the Kalijhora sandstones plots show deviation towards over bank deposit sector indicating a high energy condition similar to swash and backwash as witnessed in a beach zone. The deposits were mainly a combination of rolling and suspension deposits as suggested by the complete C-M pattern. The coarser fragments were rolled or slided but the suspension fragments in the overall coarser population can be a product of turbidity or rapid sedimentation, a situation similar to a transgression event.

The log probability plots of the Kalijhora sandstones after Visher (1969) shows the presence of mostly three or less than three log-normal sub-populations. Samples showing the presence of two saltation sub-populations can be related to swash and backwash transport in a foreshore beach deposit (Visher,1969) or can be attributed to mixing of variable size particles taking place due to density stratified turbulent current under the influence of fluctuating flow conditions (Moss, 1962; Taira and Scholle, 1979a).

CONCLUSIONS

The following points may be forwarded as conclusions based on observations made in the present endeavour:

- Presence of substantial content of finer materials in the sandstones within the inter-granular spaces is the most notable feature of the sandstones. These finer additions which are responsible for bringing about distortion in sorting and skewness have presumably infiltrated into the inter-granular network during various stages of sedimentation. There are no marked textural differences between the three sandstone types coded as Ar_1, Ar_2 and Ar_3.
- Kalijhora sandstones are largely medium grained, poorly sorted, positively skewed and leptokurtic.
- Energy condition was not that high leading to the deposition of these dominantly medium sands. Bimodality in the mean size distribution curve may be due to absence of certain grain size in the source materials, fluctuations in kinetic energy of the depositing medium or derivation of sediments from two or more varied sources.
- The sandstones depict a strong tendency of clogging in the riverine environment in a broad spectrum. Here, besides the typical fluvial processes in operation, certain other formative processes also played their role during various stages of sedimentation in varying degrees of influence. Most of the sandstones plot in point bar setting with slight inclination to the braided zone in some plots while in other parameter bound plots, some sandstones give indication of overbank deposits which seem to be steered by size factor, energy level and sorting parameters.
- The main mode of transportation for the sandstones seems to be combination of traction and suspension mechanism. Addition of fines to the coarser main mode suggests the occurrence of a temporary turbid like condition in the otherwise calm depositional environment leading to the transport of both coarser and finer fragments side by side. This may be also related to a transgression phase which is indicated by the multivariate plot after Sahu (1964) whereby the sandstones fall mainly within the deltaic (fluvial) as well as shallow marine depositional setting.

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REFERENCES

1. Amaral, E.A., and Pryor, W.A. (1977). Depositional environment of St. Peters sandstone deduced by textural analysis. Jour. of Sed. Pet., v. 47, no. 1, pp. 32-52.
2. Baruah, H. and Das, P.K. (2001). Textural attributes of the Singrimari sandstones, West Garo Hills district, Meghalaya and Dhubri district, Assam. Pal. Soc. Ind., v. 46, pp. 133-140.
3. Basu, Swades Kumar (2013). Geology of Sikkim state and Darjeeling district of West Bengal. Geological Society of India, Bangalore, 1st edition, pp. xiv+256.
4. Biswas, S.K. (1999). A review on the evolution of rift basins in India during Gondwana with special reference to Western Indian basins and their hydrocarbon prospects. Proceedings of the Indian National Science Academy (PINSA), 65, A, no. 3, pp. 261-283.
5. Bull, W.B. (1962). Relation of texture (CM) to depositional environment of alluvial deposits. Jour. Sed. Pet., v. 32, pp. 211-217.

6. Cadigan, R.C. (1961). Geologic interpretation of grain size distribution measurements of Colorado Plateau sedimentary rocks. Jour. Geol., v. 69, pp.121-144.
7. Carver, R.E. (1971). Procedures in Sedimentary Petrology, Wiley Intersciene, New York, 653 p.
8. Casshyap, S.M. (1970). Sedimentary cycle and environment of deposition of the Barakar coal measures of Lower Gondwana, India. Jour. Sed. Pet., v. 40, pp. 1302-1317.
9. Casshyap, S. M., (1977). Patterns of sedimentation in Gondwana basins. Proc. IV Inter. Gondwana Symp. (Key paper), v. 2, pp. 526-538.
10. Casshyap, S.M. and Tewari, R.C. (1988). Depositional model and tectonic evolution of Gondwana basins. The Palaeobotanists, v. 36, pp. 59-66.
11. Chakraborty, C., Mandal, N. and Ghosh, S. K. (2003). Kinematics of the Gondwana basins of peninsular India. Tectonophysics, v. 377, pp. 299-324.
12. Chakraborty, T., and Sarkar, S. (2005). Evidence of lacustrine sedimentation in the Upper Permian Bijori Formation, Satpura Gondwana basin: Palaeogeographic and tectonic implications. Jour. Earth Syst. Sci., v. 114, pp. 303-323.
13. Chandra, S. and Singh, K.J. (1996). Plant fossils from the Type Locality of Talchir Formation and Evidence of Earliest Plant / Animal Activity in Gondwana of India. In: Mitra, N.D. et. al. (Editors) - Gondwana Nine, v.1, 9th International Gondwana Symposium, Hyderabad, Oxford & IBH Publishing Co. Pvt. Ltd. New Delhi, pp. 397-414.
14. Folk, R.L. and Ward, W.C. (1957). Brazos River Bar - A study on the significance of grain size parameters. Jour. Sed. Pet., v. 27, pp. 3-26.
15. Friedman, G.M. (1961). Distinction between Dune, Beach and River sands from textural characteristics. Jour. Sed. Pet., v.31, pp. 514-529.
16. Friedman, G.M. (1967). Dynamic processes and Statistical Parameters Distribution of Beach and River sand. Jour. Sed. Pet., v.37, pp. 327-354.
17. Glaister, R.P. and Nelson, H.W. (1974). Grain size distribution: an aid in facies identification. Bull. Can. Petrol. Geol., v. 22, pp. 203-240.
18. Grifiths, J.C. (1967). Scientific methods in analysis of sediments. McGraw Hill, 508p.
19. Inman, D.L. (1949). Sorting of sediments in the light of fluid mechanics. Jour. Sed. Petrol., v.19, pp. 51-70.
20. Joseph, S., Thrivikramaji, K.P. and Anirudhan, S. (1997). Textural parameters, discriminant analysis and depositional environments of Tertiary sands, Southern Tamil Nadu. Jour. Geol. Soc. India, v.50, pp. 323-329.
21. Kar, R., Baruah, H. and Phukan, S. (2019). Signatures of Marine Influences in the Gondwana Sandstones of Kalijhora, Darjeeling district, West Bengal, India. Earth Sci. India, v.12, no.1, pp. 24-37.
22. Krumbein, W.C. and Pettijohn, F.J. (1938). Manual of Sedimentary Petrology, Appleton Century Crofts, New York. 549p.
23. Ludwikowska-Kędzia, M. (2000). Ewolucja środkowego odcinka doliny rzeki Belnianki w późnym glacjale i holocenie [Evolution of the middle segment of the Belnianka River valley in the Late Glacial and Holocene]. Dialog Press, Warsaw, 180 p.
24. Mazumdar, P. and Ganapathi, S. (1998). Grain size frequency distribution in ancient depositional environment - a case study from Lower Gondwana sediments, Pranhita Godavari Basin, Andhra Pradesh. Jour. Geol. Soc. India, v. 52, pp. 219-228.
25. Moiola, R.J. and Weiser, P. (1968). Textural Parameters: An Evaluation. Jour. Sed. Pet., v. 8, pp. 43-45.
26. Moshrif, Mohamed A. (1980). Recognition of Fluvial Environments in the Biyadh-Wasia Sandstones (Lower-Middle Cretaceous) as Revealed by Textural Analysis. Jour. of Sed. Research, v. 50, no. 2, pp.603-612.
27. Moss, A.J. (1962). The physical nature of common sandy and pebbly deposits: Part.1. Amer. Jour. Geol., v. 260, pp. 337-373.
28. Mycielska-Dowgiałło, E. (2007). Metody badań cech teksturalnych osadów klastycznych i wartość interpretacyjna wyników [Research methods for textural features of clastic deposits and the significance of interpretational results]. In: E. Mycielska-Dowgiałło & J. Rutkowski (Eds): Badania cech teksturalnych osadów czwartorzędowych i wybrane metody oznaczania

ich wieku [Research into the textural features of Quaternary sediments and some dating methods]. The Family Alliance School of Higher Education Press, Warsaw, pp. 95–180.
29. Mycielska-Dowgiallo, E. and Ludwikowska-Kedzia, M. (2011). Alternative interpretations of grain-size data from Quaternary deposits. Jour. Geologos, v. 17, no. 4, pp. 189–203.
30. Ostrowska, A., Oświecimska-Piasko, Z. and Smolska E. (2003). Cechy sedymentologiczne różnowiekowych osadów korytowych na przykładzie doliny górnej Czarnej Hańczy (Pojezierze Suwalskie) (Sedimentological indices of channel-facies deposits with the upper Czarna Hańcza River valley (Suwałki Lakeland) as an example). In: E. Smolska & P. Szwarczewski (Eds): Cechy teksturalne osadów stokowych i fluwialnych (Textural indices of slope and fluvial deposits). Prace i Studia Geograficzne (Warszawa), v. 33, pp. 59–70.
31. Passega, R. (1957). Texture and characteristics of clastic deposition. Bull. Amer. Assoc. Petrol. Geol., v. 41, pp. 1957-1984.
32. Passega, R. (1964). Grain Size Representation by C-M Pattern as a Geological Tool. Jour. Sed. Pet. v. 34, pp. 830-847.
33. Passega, R. and Byramjee, R. (1969). Grain Size Image of Clastic Deposits. Sedimentology, v. 13, no. 3, pp. 233-252.
34. Quidwai, W.A. and Casshyap, S.M. (1978). Grain size characteristics of ancient fluvial deposits- An example from Lower Gondwana. Jour. Geol. Soc. India; v.19, no. 6, pp. 240-250.
35. Sahu, B.K. (1964). Depositional mechanism from size analysis of clastic sediments. Jour. Sed. Pet., v. 34, pp. 73-83.
36. Sahu, B. K. (1983). Multigroup discrimination of Depositional environments using size distribution statistics. Indian Jour. of Earth Sci, v. 10, pp. 20-29.
37. Stewart, H.B. Jr., (1958) Sedimentary reflections on depositional environments in San-Migue Lagoon, Baja California. Bull. Amer. Assoc. Petrol. Geol., v. 42, pp. 2567-2618.
38. Szmańda, J. B. (2002). Litofacjalny zapis powodzi w wybranych fragmentach równin zalewowych Wisły, Drwęcy i Tążyny (Lithofacies flood record in some fragments of the Vistula, Drwęca and Tążyna River valleys). Nicolaus Copernicus University (Toruń), 125 p.
39. Thomas, R.L., Kemp, A.L.W. and Lewis, C.F.M. (1972). Distribution, composition and characteristics of the surficial sediment of Lake Ontario. Jour. Sed. Pet., v. 42, pp. 66-84.
40. Valdiya, K.S. (2010). The Making of India: Geodynamic Evolution, Macmillan Publishers India Ltd., New Delhi, pp. 300-320.
41. Veevers, J.J. and Tewari, R.C. (1995). Gondwana master basin of Peninsular India between Tethys and interior of the Gondwanaland province of Pangea. Mem. Geol. Soc. America Bull., 187, pp. 1-72.
42. Visher, G.S. (1969). Grain size distribution and depositional processes. Jour. Sed. Pet., v. 39, pp. 1074-1106.