GRANULOMETRIC STUDIES TO INTERPRET THE ORIGIN OF THE SEDIMENT TRAPPED WITHIN A POCKET ALONG THE PRAVARA RIVER BASIN, MAHARASHTRA, INDIA

Environmental Science

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ABSTRACT

Sediment populations may have characteristics associated with multiple sources. Grain size parameters will therefore reflect spatial as well as temporal variations in transport mechanism and flow direction along with the nature and energy flux of the transporting agents. Herein, the author has investigated a small watershed area along Mahalungi River in Maharashtra, India. Samples were collected from the surface and from lithofacies at various depths and were subjected to granulometric analysis. The sediment sizes were separated principally on the basis of their intermediate axial diameter and shape using microscope, sedigraph and pipette method appropriately. Bivariate relationships from textural parameters were obtained and Visher's log-probability plots were constructed. Incorporation of all results of the analyses and a careful inspection of the geomorphic settings of the area lead us to the conclusion that the present deposits are part of the alluvial deposits of Pravara and haven't descended from the footslope to form colluvial deposits. The fact that the silt population is found right at the footslope indicates that during the floods, flood waters must have entered and hit the amphitheater. As the flood water receded, the narrow outlet did not allow free retraction of the flow but created an eddy effect every time and gave a temporary ponding effect within the amphitheater.

KEYWORDS

granulometric analysis, Mahalungi, amphitheater, alluvium, colluvial deposits, eddy effect

INTRODUCTION

The environmental interpretation of the grain-size distribution found in sedimentary deposits has been and still is a fundamental goal of sedimentology [18]. Granulometric analysis is one of the most widely used sedimentological tools to unravel the hydrodynamic conditions of aquatic environments.

Sediment grain size parameters have been used to infer transport processes and morphodynamic behavior within many sedimentary environments at both local and regional scales for decades [6][13][5]. Often, the textural attributes of grain size parameters (mean size, sorting, skewness) are considered to reflect the transport pathways and mixing of two or more hydraulic populations in different proportions [1]. On many occasions, the sediment transport pathways and mixing may be derived from more qualitative methods such as visual comparison of sediment grain size distribution curves [2]. Sediment populations may have characteristics associated with multiple sources, with mixing taking place along the sediment transport pathways. Grain size parameters will therefore reflect spatial as well as temporal variations in transport mechanism and flow direction [1]. Further; they help to delve into the nature and energy flux of the agents transporting the sediments.

Visher (1969) has proposed a graphical interpretation of the grain size parameters through log-probability curve representing the cumulative grain-size distribution [21]. The combination of sub-populations in different proportions determines the grain-size characteristics of the overall sediment, which is very useful to differentiate the sediments according to the mode of transport i.e. traction, saltation and suspension, which can be related to the prevailing energy conditions. McLaren and Bowles (1985) suggested that mean, sorting, and skewness of grain-size frequency distribution follow a trend that identify the direction of transport and sedimentary processes of selective deposition, winnowing and total deposition [14]. This causes the sediment in transport to be finer and more negatively skewed than its source, whereas the remaining sediment (a lag) must become relatively coarser and positively skewed.

Miall (1996) classified river pattern defined by flow related parameters [15]. He proposed litho codes to the lithofacies during the identification of each of them. Each of these classes and subclasses have been described in terms of their structure, texture, mode of occurrence and the environment associated with them. Roman and Achab (1999) examined the grain-size trends which made it possible to characterize ancient and modern environments and to identify the net sediment transport patterns, using grain-size distribution and factorial multivariate analysis [17]. Hartmann (2007) in his article mentioned about trap sediments and demonstrated how the sediments trapped in a setup can defy the straight forward law of fluid dynamics found in an open environment [8]. Trap samples are strongly influenced by trap

properties and their efficiency as found by Rasmussen and Mikkelsen, (1998) [19]. Also their studies revealed that it is not always evident whether their particle-size distributions represent prevailing dynamic conditions or are a result of trap parameters.

Lithostratigraphical studies are also known to provide a good understanding of the environment since it preserves good sedimentary structures and grain-size variation in vertical column. The interpretative value becomes double fold when we combine the granulometric results and the litho unit's interpretation together in any sedimentary environment. The present work has been designed to interpret the sediment pulses associated during transportation and deposition of sediments within a small sediment pocket within the alluvial tract of Pravara River Basin, Deccan Trap, Maharashtra.

2) PHYSIOGRAPHIC SETTINGS OF THE STUDY AREA

The study area represents a small watershed along the Mahalungi basin, located in Ahmednagar District, Maharashtra. The site is locally known as Saikhindi, situated approximately 130 km NE of the city of Pune. River Mahalungi is a tributary of Pravara River. Alluvial deposits are found along the banks of the river. The deposits are quite thick (about 10 m) but are not continuous. River Pravara and the two of its tributaries namely Adula and Mahalungi are characterized by alluvial bank deposits that are deeply dissected by gullies. Fig. 1a depicts the location map of the basin and the study site and it can be seen from the field picture (Fig. 1b) that alluvial deposits are not exactly on the riverbank as its counterparts, but a little away from the river where they are sitting within an enclosed pocket of the amphitheater. Except for the narrow outlet, it is completely enclosed by a hill. The appearance of the deposits in the field resembles hillslope colluvial deposits. The deposits start exactly from a gradual footslope (Fig 1b).

Maharashtra is a sediment deficient region as it falls within the Deccan Trap Region, which reveals more of erosional landforms than depositional ones. Godavari Basin is one such basin where alluvial deposits of remarkable thickness are found [12]. Within the same basin hillslope colluvial deposits of thickness exceeding 10 m are also found along some footslopes and the best example is Chandanapuri, which is just a few km from the study site [11]. Such hillslope deposits do not cover extensive area. The present study site gives a strong field resemblance to such colluvial deposits (Fig 2). Due to the proximity of the river and unusually thick alluvium in proportion to the hillslope behind, an alternative probability of the river having deposited alluvial deposits within the enclosed space cannot be ruled out. The result of the investigation is expected to signify the transport and depositional characteristics of the deposits in the site and the analysis will also provide hints to infer about the source region of these sediments.

Fig 1 - a) Location Map of the basin and the study site and b) the field view of the starting point of the gully.

Figure 2 - Field views of Chandanapuri footslope colluvial gullies and Saikhindi gullies

GENERAL PHYSIOGRAPHICAL CHARACTERISTICS:

The area under investigation is characterized by a variety of landforms including hills that are off-shoots of the Sahyadris in the western part of the district called Kalsubai, Adula, Baleshwar and Harishchandragad hill ranges. Kalsubai (1647 m), the highest peak in Sahyadris and also in Maharashtra, lies within the watershed of Pravara. Harishchandragad, Ratangad, Kulang and Ajuba are some other peaks in the area. In the northern part of the district, floodplains though restricted in extent are found along the banks of river Godavari and Pravara and in the southern part along the rivers Bhima, Ghod and Sina.

The whole district lies on the elevated tableland of the Deccan which has a general slope from west to east. The western subdivision of Akola, which is located on the western margin of Sahyadris is the highest part of the district and of Deccan, averaging 762 m ASL. The plain of the Shevgaon which lies to the extreme east of the district is not more than 457 m ASL.

GEOLOGY:

The entire study area is covered by thick basaltic lava flows of the Deccan Trap belonging to Late Cretaceous to Eocene Period. Among the rock formations, Miocene, Pliocene and Quaternary laterites occur above an altitude of 1000 m ASL. No other rock formations have been reported from the region [12]. According to the Geological Survey of India (GSI, 1976), the region is predominantly covered by Pahohoe flows, that is evidenced by mature type of topography with smooth hill slopes, broad valleys and sub-rounded weathering products in and around the study area [7].

The study site is in Sangamner (Ahmadnagar District) which is situated 70 km southeast of Nashik and is located in a tectonically less active part of the Indian Peninsula. In the west of the study site, the major west coast fault is situated. North of the area of interest is the Tapi rift system elongated from east to west. Some influence of earthquakes within a radius of 200 km could be felt in Sangamner, but would not have led to enormous topographic changes in historic times. There is no evidence of more tectonic activity in the early Holocene.

CLIMATE and SOIL:

Fluvial systems of the Upland Western India are affected by the monsoon climate. The area under investigation is situated in the semi-arid climatic regions characterized by a hot summer and general dryness during major part of the year except during south-west monsoon season. From March to the first week of June it is hot season followed by monsoon which lasts till the end of September with an average rainfall of 501.8 mm. From November till February, winter starts, with typical dry air.

Overall, the area, which includes site under investigation, is covered by black cotton soil or regur soil along the valley plains, low lying divides, and medium height planation surfaces [3]. Black color indicates the poor soil drainage. The soil along the river is good enough for the cultivation of sugarcane, pulses, pomegranate, etc. Recently the area has been brought under agriculture. The study area consists mainly of thorny acacia which is typical of a semi-arid region. Hillslopes are bare [10]. In this region about 4.83% of the vegetation is under dense forest and 9.39% is scanty vegetation. Also the land under crop cultivation is increasing by land reclamation and it is about 30.11%.

3| MATERIALS AND METHODS

In the present investigation 64 samples were collected from the surface as well as from different litho-facies at various depths and were subjected to granulometric analysis using techniques developed by Folk and Ward (1957) [6]. Miall's (1996) geocoding system was adopted in the identification of the facies (Table 1) [15]. The sediment sizes ranging above phi 4 were dry sieved in a mechanical sieve using a series of progressively finer square-mesh sieves which separate particles principally on the basis of their intermediate axial diameter and sediments below phi 4 were analyzed using pipette method. Sedigraph and shape analysis was done using a microscope. Further bivariate relationships from the four textural parameters were obtained to interpret various aspects of the depositional environment. Visher's log-probability plots were also constructed representing the cumulative frequency curves [20] [21]. Shape and size of the sediments of each point on the profile is described below in the following section.

Table 1: Depositional facies of Miall (1985): a summary description of selected units

Facies Notation	Sediment Texture	Major Sediment Structure	Morphological Identification
Gmm	Matrix-supported gravel	Massive	Debris flow (plastic)
Gmg	Matrix-supported gravel	Vertical change in clast size	Debris flow
Gm	Predominantly massive gravel or weak bedding; some sand or fines as lenses	Imbricated or horizontal gravel	Channel bed deposit, longitudinal bars
Gt	Stratified Gravel	Trough cross bedding	Small channel fill
Gp	Stratified Gravel	Planar cross bedding	Bars

St	Very coarse to fine sand, pebbles may be present	Trough cross bedding	Dunes
Sp	Very coarse to fine sand, pebbles may be present	Planar cross bedding	Bars and sand waves
Sr	Coarse to very fine sand	Ripple marks, cross laminations	Ripples
Sh	Coarse to very fine sand, pebbles may be present	Horizontal lamination and lineations of different types	Plane beds
Ss	Very coarse to fine sand, pebbles may be present	Shallow, broad scours	Small channel and scoured depression fills
Fl	Fine sand, silt, and clay	Very small ripples, rootlets, bioturbation, calcrete, etc.	Shallow deposition: in waning floods, abandoned channels or overbank
	Silt and clay		
Fsm	Silt, clay	Massive	Backswamp, abandoned channel fills
Fm	Carbonate deposits	Massive, desiccation cracks, rootlets	Deposits draped round pools of water, in abandoned channels or overbank.
P		Nodules, linear forms in palaeosols	Palaeosols

Stratigraphical characteristics:

Total 11 litho-sections were taken from the 3 transects where, 7 litho-sections were taken from the 1st transect, 1 litho-section from the 2nd and 3 litho-sections from the 3rd transect, respectively. The present study of the facies is carried out with the help of Miall's (1985) classification. The 1st transect (730 m long) is the central to the maximum axis of the deposits with facies depth varying from 0.3 m at the foothill, 10 m in the middle to 8.5 m in the end. The least number of identified facies in the 1st transect is 1 and maximum is 11. The last section was mosaicked from the well where bedrock was exposed. The deepest litho-section of 15 m is the one taken from the 2nd transect (30 m long) where 14 facies were identified. It is a complicated profile with a boulder matrix embedded on the top of the profile which is not found in other profiles. The largest boulder found in this layer is 30 cm. The last 3 litho-sections from the 3rd transect (260 m long) were quite unique and were mosaicked from the well where bedrock was exposed. The depth is 9.5 m, 11 m, 10.5 m, respectively.

3.1 SEDIMENT SIZE AND SHAPE CHARACTERISTICS:

In general terms, 'size' of particles is not readily defined as it is a measure of the dimensions which best describe a specific group of particles. For determination of size, methods vary widely from calipers on the coarser fragments, through sieving and techniques dependent upon settling velocity (pipette method) or sedigraph. As the size of a particle is one of the fundamental textural characteristics of all fragmentary deposits and their lithified equivalents, no single technique of particle size assessment is applicable throughout the entire size spectrum, and each is suited to specific size ranges as different methods of particle size analysis describe different aspects of 'size'.

Grain shape is another fundamental property of particles and one that may provide important information about the history of sediment. Like grain size, shape may be expressed in several different ways, including-Roundness, a measure of the sharpness of the corners of a grain; Sphericity, a measure of the degree of similarity between a grain and a perfect sphere; Form, an expression of the overall appearance of a particle.

3.2 LITHOSTRATIGRAPHICAL CHARACTERISTICS:

"Stratigraphy is the study of rocks to determine the order and timing of events in the Earth history: it provides the time frame that allows us to interpret sedimentary rocks in terms of dynamic evolving

environments. The fundamental database for understanding life and plate tectonics through time and climate changes across the globe is the stratigraphic record of sedimentary rocks. In geological description, the appearance and characteristics of sedimentary deposition specially as they reflect the condition and environment of deposition, and serve to differentiate or distinguish the deposit from contiguous deposits are known as sedimentary facies. Explaining the facies of a body of sediment involves documentation of all the characteristics regarding its sedimentary structures, lithology, texture as well as its fossil content which can be helpful in determining processes of its formation. By establishing the associations of facies, it is possible to recognize the combinations of processes that were dominant in the formation; the characteristics of a depositional environment are determined by the processes that are present, and hence there is always a link between facies associations and conditions of deposition [16].

Litho-facies analysis is mainly employed in geomorphology and geology to elucidate the entire sequence of depositional environment. For that purpose, litho-facies were carefully studied and mapped. Representative litho-section for each site is presented in the supplementary file showing stratigraphical characteristics. In the present study eleven lithosections were investigated from the three profiles.

3.3 STATISTICAL INDICES:

Statistical techniques are used to characterize the grain size distribution data. Textural parameters are primarily related to mode of transportation and energy condition of the transporting medium. The results are described below in the following figure 3 and graphs.

Figure 3 - Depicting the gully transect, first lithosection, ϕ size distribution and particle shape.

Figure 4 - Graphs depicting the four statistical indices and their threshold of categorization.

(Comparative histograms of all the samples showing (a) mean, (b) standard deviation or sorting, (c) skewness and (e) kurtosis values)

3.3.1 Graphic Mean:

The mean grain diameter which is the most widely used distribution parameter is regarded as an indicator of the average energy of the transport and as sedimentation agents [6]. The fact that most of the sediments consist of particles of various sizes, mean diameter represents the easiest way to provide a granulometric characterization of the sediment through single value.

The calculated value of the graphic mean range from -0.07 to 5.67 (i.e. very coarse sand to coarse silt) and averaging at 1.96 (fig: 4 a). The average value denotes that sediments class falls in medium sand-size particles. The comparative chart shows the dominance of coarse silt population.

3.3.2 Graphic Standard Deviation or Sorting:

The graphic standard deviation is the measure of sorting or uniformity of particle size distribution. Sorting reflects variations in the energy of the transporting or depositing environment. Through the selective sedimentation the hydraulic sorting of the material is done, which is in movement. Fractions which are coarser or have higher specific weight are deposited as a result of reduced current competence, and the material transported further has an improved dimensional sorting. Morphological characteristics also influences the grain sorting, particles with similar shapes accumulates together, being moved from the same means of transport. The generalization in many cases is that the sorting increases with transport is due to the fact that the mean size of a sediment changes with transport and the better sorting is dependent only on the decreasing mean size, not the distance as explained by Folk and ward (1957) [6]. Inman (1949) suggested that once the sediment attains a minimum (best sorting), if it continues to get finer it will change and sorting will worsen with transport.[9]

All the values for sorting obtained from the samples ranges from 1.35 to 3.96 averaging at 2.5 reveals dominance of poorly sorted grain(Fig 4 b).

3.3.3 Graphic Skewness:

Skewness is the measure of asymmetry of data or predominance of fine or coarser sediments. It is geometrically independent of sorting [6]. Positive values of skewness indicate that the samples have a 'tail' of fines or fine-skewed material, whereas, negative values indicate a 'tail' of coarser grains or coarse-skewed material.

The skewness value of the samples ranges from -0.90 to 0.77 averaging at 0.03 indicating a trend from coarse-skewed (negative skewed) to neutral or near symmetrical to fine-skewed (positive skewed) category. (Fig 4 c)

3.3.4 Graphic Kurtosis:

It relates to the relative flatness or peakedness of the distribution and measures the ratio between the sorting in the tails and the central portion of the curve i.e. Platykurtic/Flat peak (better sorted then the central portion; Mesokurtic/Normal (both are equally sorted); Leptokurtic/High peak (central portion is better sorted).

The values obtained ranges from 0.48 to 2.86 averaging at 0.98 shows dominance of platykurtic sediments except four samples that

ranges to leptokurtic representing high fraction of fine-grained sediments. (Fig 4 d).

3.5 BIVARIATE PLOTS:

The scatter diagrams of the four parameters are used to understand the geological significance when plotted against each other as proposed by Folk and ward (1957) [6]. In this way their interrelationships and trends are revealed and a wealth of information can be obtained in terms of mode of deposition and also in identifying different environments of sedimentation by size analysis. On this basis, six different scatter plots have been plotted and depicted in Fig 5

Figure 5 - Bivariate plots showing the placement of present samples in the modal plot as proposed by Folk and Ward (1957). (A) mean vs. sorting (B) mean vs. skewness, (C) mean vs. kurtosis, (D) skewness vs. sorting, (E) sorting vs. kurtosis and (F) skewness vs. kurtosis.

3.6 MULTIVARIATE ANALYSIS:

The multivariate analysis made it possible to determine the relationship between the four statistical indices of grain-sizes distribution (mean, sorting, skewness and kurtosis) and the sediment transport and environmental characterization. Factor analysis was employed in the present study for these 4 statistical variables in order to establish their relationships.

The results indicated two principal component factors explained 72% of the total variance. The first component explains 37% of the variance and positively correlates of mean (component loading of 0.475) and sorting (component loading of 0.732). This represents where fine mean and poor sorting are associated, related to sandy silty and coarser silts. (Table 2)

The second factor explains 36% of the variance and associates positively the skewness (component loading of 0.598) and kurtosis (component loading of 0.613) represents negatively skewed and platykurtic distribution.

It shows major role of influence by Sorting (component 1) and Kurtosis (component 2).

Table 2: Showing factor loadings of the two components with Explained Variance

	Explained Variance	Component Loadings
COMPONENT 1	36.70%	Mean - (0.475)
		Sorting - (0.732)
COMPONENT 2	35.90%	Skewness -(0.598)
		Kurtosis -(0.613)

3.7 VISHNER'S PLOTS:

Visher (1969) proposed study of the sub-populations and hydrodynamics [21]. The combination of sub-populations in different proportions determines the grain-size characteristics of the overall sediment. The cumulative frequency curve of the grain size is regarded as a whole, and it is attempted to be interpreted on the basis of

hydrodynamic characteristics. Doeglas (1946) found that grain sizes follow the arithmetic probability function, and that their distributions represent a mixture of two or more populations that are the consequences of various transport mechanisms [4]. Inman (1949) distinguishes three basic types of transport: rolling, sliding and saltation on the bottom and suspension [9]. Later, Visher (1965) studied the dependence of grain size distribution on the sedimentary structures in fluvial deposits and various depositional processes in diverse depositional environments [20].

On the basis of these concepts an attempt has been made to determine the individual genetic populations from the cumulative frequency curves. All three populations of grain sizes transported by traction, saltation and suspension could be determined in the examined samples. Their presence is shown in the table 3 (suppl. material). Graphical plots or log-probability curves of all the samples are described below followed by the result table 4 (suppl. material).

4] Results

The objective of the present investigation is to understand the transportational and depositional behavior through the granulometric studies in an alluvial pocket with a unique geomorphic location and if possible also try to infer to the source area. In order to fulfill these objectives, data were generated using various methods and were analyzed. On the basis of this analysis, the findings of the study outlined in the previous chapter, have been summarized below in the following sections:

4.1 SEDIMENTOLOGICAL CHARACTERISTICS:

4.1.1 Size characteristics:

By and large the phi distribution for all the sediments ranges between very coarse sand to very coarse silt. The sediments peak invariably at 4 (coarse silt) and for few samples at -1 (coarse sand) category. Phi distribution also represents minor peaks indicating variations within the silt population due to slight variation in energy during the time of deposition. Predominance of smaller grain sizes of the deposits indicates the non aggressive energy level of the depositing medium and variability in energy levels of the depositing medium.

4.1.2 Shape characteristics:

All the sediments were showing predominance of sub-angular and sub-rounded shape category. Purely angular or purely rounded sediments are not common.

4.1.3 Stratigraphic al characteristics:

Fm or Fsm (silty-clayey) facies of Miall's (1975) lithocode predominate in this area. Sm or Sh (sandy) facies are not very frequent and Gm, Gh (gravel) facies were found only in one section.

All the facies do not follow any upward fining (fines at the top) or upward coarsening (coarse sediments at the top) pattern. All the facies are poorly sorted and platykurtic indicating variations in the energy levels of the depositing medium and mixing of 2 size-classes i.e. sand and silt.

The thickness of the deposits increases downstream.

The overall picture that emerges out of the facies examinations of the deposits is that the sediments reveal many characteristics of fluvial deposits deposited under not very high energy environment. The sediments are fine, silty and massive right from the footslope and it does not resemble hillslope colluvial deposits as how we generally find along the colluvial foothill zones, where one sees huge boulders, pebbles, gravels sands silts or mix without any sequence.

4.2 STATISTICAL INDICES:

Graphic mean shows dominance of coarse silt. Graphic standard deviation or sorting represents very poorly sorted grain. Skewness shows a trend from positively skewed (coarser grains) to near symmetry to negatively skewed (finer grains) sediments. Kurtosis shows dominance of platykurtic sediments with very few leptokurtic samples.

4.3 BIVARIATE PLOTS:

4.3.1 Mean vs. Sorting:

Clustering of the values on one limb of the V-shaped trend denoting very small size range. The nature of sediment is dominantly 'Unimodal' of which dominant constituent is coarse silt. Sorting reflects variations in the energy of the transporting or depositing environment. Sand is subordinate making the mixture very poorly sorted.

4.3.2 Mean vs. Skewness:

The sinusoidal nature is because of the proportionate admixture of two size-classes of sediment i.e. sand and silt. In general, the ideal fractions are near symmetrical but the mixing produces either positive or negative skewness depending upon the proportion of size-class in the admixture. It clearly indicates a unimodal nature of sediment with higher % of silt and subordinate sand.

4.3.3 Mean vs. Kurtosis:

The mixing of 2 size classes of sediment basically affects the sorting in peak and tail. Silty population is mainly platykurtic and sandy population varies between mesokurtic and leptokurtic.

4.3.4 Sorting vs. Skewness:

The two variables form a scatter trend in the form of a nearly circular ring. Majority of the samples are scattered inside the ring indicating unimodal samples with bad sorting due to admixture indicate fluvial deposition as proposed by Folk and Ward (1957) [6].

4.3.5 Sorting vs. Kurtosis:

In general, unimodal sediments produce normal kurtosis with best sorting but it could be reversed if we have unimodal samples of admixture with one mode dominant and the other subordinate then it will have poor sorting and low kurtosis/platykurtic.

4.3.6 Skewness vs. Kurtosis:

Again both of these two properties depend on the proportion of the two modes present i.e. as these proportion changes the mean size change on the regular path in the diagram. In this case, coarse sediments are negatively skewed (high energy environment) and finer once are positively skewed (low energy environment). It could indicate that coarse grained sediment trapping has occurred.

4.4 VISHER'S PLOTS:

The combination of sub-populations in different proportions determines the grain-size characteristics of the overall sediment. Visher's log-probability curve shows the dominance of saltation and bedload domains of population indicating fluvial characteristics.

The truncation between traction/bedload and saltation is normally noticed at 3.00 value and in all,

- Average amount of traction population is - 35.69%;
- Average amount of saltation population is - 58.9%
- Average amount of suspended population is - 6.74 %.

4.5 MULTIVARIATE ANALYSIS:

Shows major role of influence by Sorting (Factor1) and Kurtosis (Factor2). Factor1 correlates mean and sorting showing the transport path of saltation muddy particles depending upon its settling velocity. Factor2 correlates skewness and kurtosis which reflects low degree of textural maturity and no reworking of sediments.

5] Discussion

Predominance of smaller grain sizes of the deposits indicates the non aggressive energy level of the depositing medium and variability in energy levels of the depositing medium. When the shape of the sediments reveals the predominance of angular sediments, they indicate the local sources and if it is predominantly rounded, they are indicative of long transported sediments. In the present study it is sub-angular and sub-rounded in equally high proportion with very little percentage of completely round or completely angular sediments. The overall picture emerges out of the shape analysis is that majority of the samples are not long transported and source region is not very far. The small proportion of the angular sediments could be incorporated from the mass movement of the hillslope material that is at the back of these deposits. The overall picture that emerges out of the facies examinations of the deposits is that the sediments reveal many characteristics of fluvial deposits deposited under not very high energy environment. The sediments are fine, silty and massive right from the footslope and it does not resemble hillslope colluvial deposits as how we generally find along the colluvial foothill zones, where one sees unconsolidated admixtures of all size sediments ranging from boulders, pebbles, gravels sands silts and clays without any sequence. The grain-size trend we get within this amphitheater results from both sedimentological input (hillslope material) and transport pathways of coarser to medium fine sediments (riverine). Thus, skewness enabled us to characterize two grain-size trends. The first trend characterizes

fluvial environment with occasional silty material settling with negatively skewed coarser silty material in the central transect. The second trend characterizes mixture of coarse sandy silty material near the footslope and on the other two transect near the narrow opening of the amphitheater. It is evident by the smaller range of mean grain size, very poorly sorted and platykurtic nature of the sediments.

The efficacy of the transporting agent in doing its own sorting on the material contributed to it and this unimodality along with poor sorted sediments imply significance of fluvial environments as suggested by Folk and Ward (1957)[6]. The results that the trend is revealing in the present study are very similar to this interpretation.

The unequal proportion of two-class sediments affects the skewness. Folk and Ward (1957) suggested that the modal fraction are in themselves nearly symmetrical, but the mixing produces negative skewness if the finer mode is most abundant and positive skewness if the coarser mode is most abundant and an equal quantity of the two modes results in a symmetrical curve [6].

As Folk and Ward (1957) also suggested for fluvial environment that the further addition of a mode gives rise to a strongly bimodal sediment, and if the two modes are sub equal (in proportions anywhere between 25:75 or 75:25), then the sediments becomes very platykurtic and wherever the sorting in the tail is worsened by any mode while the sorting in the central part remains good, the curves become strongly leptokurtic [6].

According to Folk and Ward (1957) unimodal sediments of Brazos bar produced normal kurtosis and are best sorted for finest silty sands but in this case it is unimodal with coarser silty sands which produces lower kurtosis and poor sorting. Folk and ward (1957) suggests that the sediments with two modes closer together or more poorly differentiated would give more nearly "normal" values of skewness and kurtosis, and all the point would be clustered around the center of the diagram as happened in the present investigated samples [6].

In the present study, all the 64 samples have been analyzed, which, in general, shows dominance of saltation and traction domains of size-population and both are poorly sorted. The saltation population is divided into two sub-populations, truncating around 3 value, which may be internal forces causing rolling or sliding [21]. The present plots are comparable with established trend for modern and ancient fluvial deposits as illustrated by Visher (1969) [21].

The saltation particles do not require high settling velocity, when the sediments are rapidly dumped down there is little opportunity for sorting, as the sediments, once deposited, is buried rapidly and no gentle reworking takes place in the fluvial environment (Folk and Ward, 1957). On the contrary continuous reworking results in good sorting as beach sands tend to be raked back and forth by wave movement [6].

6| CONCLUSION:

The study has been able to highlight the aspects of transport mechanism and morpho-dynamic behavior of the sedimentary environment at a local level. These deposits within the amphitheater appears like the hillslope deposits in the field but after the actual analysis it has become evident that they are not solely hillslope deposits but show characteristics of alluvial deposits with some incorporation of hillslope material i.e. mixing of two hydraulic populations in different proportions. During a flood event, the water must have reached this far and with such high energy that within this amphitheater that eddy effect was created and churning of sediment must have occurred. Therefore, these deposits within this unique location require granulometric investigation. Granulometric studies using sedimentological tools and a lithostratigraphic characteristic along with the graphical method can reveal the hydro-dynamic conditions, transport mechanism and depositional environment of a region, as has been presented in the study.

The shape of amphitheater has played a major role in trapping and mixing of the sediments. From the data generated during the study, we could provide an answer to the questions on how the grain-size trends are associated to the transport and depositional pattern of the alluvial deposits within this unique geomorphic location. This is a clear case of trapping of sediments and mixing of incorporated hillslope sediments from the surrounding.

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