CHAPTER - 11

ENVIRONMENT OF DEPOSITION.

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A sedimentary rock is not only a product of a specific provenance and depositional history, but also it reflects environmental conditions of deposition of the sediment. The chemical and biochemical sediments reflect only their environment of deposition, whereas the clastic rocks can provide informations regarding their environment of deposition, and at the same time produce informations about the provenance and depositional history (Verma and Prasad, 1981).

In spite of some difference on the ability to identify and describe sedimentological environments from grain size characteristics, yet it remains an important tool in the field of sedimentology. The size parameters of sands reflect the mode of transportation, mode of deposition, and the energy of transporting medium. Sedimentologists have used the granulometric parameters of sediment population obtained from analysis of modern environment, to interpret the ancient environments of deposition. Modern environments whose grain size distribution have been extensively studied include rivers, beaches and dunes. Detailed accounts for this type of work have been produced by Folk & Ward (1957), Friedman (1967), Folk (1966), and Moiola and Weiser (1968). It is apparent that statistical coefficients can very often differentiate sediments from modern environments (Selley, 1976). Various studies reveal that, for example, beach and dune sand are negatively and positively skewed respectively (Mason and Folk, 1958; Friedman 1967).

Some sediments are resulted by the combination of two
or more different grain size populations of different origins (Doeglas, 1946). This variation of sizes in sediments reflect the mixing of sediments of different environments. It is possible that the presence of several populations in one sample indicates the function of different physico-chemical processes. Moreover, the various populations present in the sediments influenced by wind, wave, current and gravitational processes and they were all deposited in the same environment (Klovan 1966; in Selley 1976). In the same way, Visher (1965), has observed the existence of different size populations in the sediments in one environment and also demonstrated how these different populations in the sediments were inter-related to the depositional process. Passega (1957, 1964), has shown that CM (C, the one percentile, and M, the median diameter) patterns on a logarithmic diagram are the characteristic of the depositional agent.

The trend of modern research has been guided towards a definition of individual samples of a deposit by parameters of their texture and a definition of the deposit as a whole by the variation of these parameters. Textural parameters can give useful informations in determining the environments. Friedman (1967), showed that mean, standard deviation and skewness provide clear distinctions between beach sands and dune or river sands, and also established an useful correlation between sorting, measured by standardized deviation, and the depositional environment of sediments. Passega (1957) observed that a relationship exist between sediment texture and transport and that these relationships can lead to the derivation of useful informations about the environment of depositions. In sedimentological analysis, it has been recognised that sediment size fractions approximate a log normal distribution. But most sediments donot follow log normality and deviation from the normality (Gaussian model) provides environmental interpretations (Folk and Ward, 1957; Masson and Folk 1958; Friedman 1961 and 1967). Others demonstrated a distinct breaks within the complete
size range and have differentiated log normal sub-populations of the
samples (Moss 1962; Visher 1969; and Middleton, 1976). Each
subpopulation is interpreted as representative of a specific mode of
transport and relative concentration of each subpopulation indicates
specific depositional environment (McLaren and Bowels, 1985).

Passega, 1957; Passega and Byramjee, 1969 has tried
to reconstruct the depositional environment as well as the grain size
'C' is the coarsest – one percentile in micron and 'M' is the
median – 50th percentile. 'F', 'L', 'A' are the percentages by
weight, in the samples of grains finer than 125, 31 and 4 micron
respectively. Variety of environments can be recognised by C-M
diagram and F-M, L-M and A-M diagrams, providing additional
informations characterising the coarser and finer sediments along with
their environmental informations. C-M diagram and grain size images
also indicates the hydrodynamic conditions under which the sediment
was deposited. Hydrodynamic conditions vary with the environments,
and help the reconstruction of ancient environments. Williams and
Rust (1969), attempted to reconstruct the energy process by means
of C-M plot and thus four energy fields have been recognised.

Many workers, in the field of sedimentology, tried to
obtain informations about the environments of deposition from the
statistical parameters obtained from the grain size distribution data.
Stewart, 1958; Folk and Ward, 1957; Friedman, 1967; Moiola and
Weiser, 1968 established the relationship between grain size
distribution parameters and environment of deposition with the help
of bivariate scatter plots. Friedman (1961, 1967) arrived at the
conclusion that a plot of skewness Vs. standard deviation was most
effective in differentiating between river and beach sands, while
Moiola and Weiser (1968) observed that most effective combination
plot is mean size Vs. Standard deviation for discrimination beach
and river sands. Sahu (1964), has recognised four discriminant
functions basing on Folk and Ward's (1957) graphic measures to
differentiate between environments. Asseez, (1972), has shown a
pattern for distinguishing between environments by plotting grain size
data in a triangular diagram. Visher (1965 and 1969) has shown the
relationship that exists between shape of grain size curves and mode
of transport from both modern and ancient environments. He has
demonstrated the occurrence of various sub-populations within the
individual grain size distribution curve. He also indicated that each
sub-population present in the grain size distribution curve bears a
relationship with a separate mode of transport. Grouping of these
sub-populations together lead to the identification of hydrodynamics
of the transporting field and depositional basin. Visher 1972, Visher
and Hower 1974, and Siemers 1976 have produced detailed accounts
of this view.

To know the environment of deposition of the two
groups of sediments presently under study, all these methods have
been attempted which are discussed in this text.

11:2 C-M, F-M, L-M AND A-M PATTERN::

The C-M pattern consists of two parameters "C", the
1 percentile (approximate value of maximum grain size.), and "M", the median (50th percentile). Passega (1957), indicates that these
two parameters of grain size distribution are more suitable for
knowing the relationship of depositional agent and texture. He has
observed that the other parameters, namely, coefficient of sorting,
skewness and Kurtosis, etc. are not appropriate to established
the depositional behaviour of the grain size distribution. The
maximum grain size value of coarser fraction "C", is a measure of
the competency of current and the minimum value is an indication of
the maximum turbulence at the bottom of the current, whereas the
median parameter is used as a parameter for overall texture. "M"
also indicates the statistical characteristic of the total range of
particle size undergoing transportation. Passega and Byramjee (1969), suggested the F-M, L-M and A-M pattern of plots together with the plots of C-M, will provide additional informations for characterising sediments and its environmental information. F-M, L-M and A-M characterises the finer fraction and C-M characterises the coarser fraction, as 'F', 'L' and 'A' are the percentages by weight in the samples of grains finer than 125, 31 and 4 micron respectively.

11 : 2 a. METHODS OF STUDY ::

The basic and complete C-M pattern of the two sandstones groups were studied, following Passega (1957, 1964), and Passega and Byramjee (1969) respectively. The values of "C" and 'M' were plotted along the co-ordinate and abscissa respectively in a log-log graph paper and the C-M line has also been drawn. The complete C-M pattern environmental fields were drawn following Passega (1957), and Passega and Byramjee (1969) of the Surma and the Tipam sandstones to study the depositional pattern of the sediments (Fig. 11 : 1a (i), 11 : 1 a(ii), and 11 : 1 b(i), 11 : 1 b(ii)).

The F-M, L-M and A-M Pattern plots were also prepared for the two groups of sandstones, following Passega and Byramjee (1969). The values of 'F', 'L' and 'A' (Table 43 and 44) were plotted as co-ordinate, while the values of 'M' were plotted as abscissa, in a log-normal graph paper (Fig. 11: 2a and 11 : 2b). The sediments were also classified according to the C-M diagram of Passega and Byramjee (1969), to know their genesis in relation to the mechanism of transport.

11 : 2b OBSERVATION ::

11 : 2b(1) Surma Group of Sandstones:

The graphic plots of the basic C-M points of the
Surma sandstones are shown in Fig.11.1a(i). The maximum values of 'C' and 'M' for the sandstones are 1000.0 micron and 217.6 microns respectively. The basic C-M pattern of the sandstones shows that the concentration of points lies within the field specified for turbidity current (Fig. 11.1a(i)). The distance between the pattern and limit C-M is a possible indication of the concentration of the evenly dispersed fine materials in suspension. Few points fall in the field specified for typical beach pattern. Points are concentrated near the higher values of C. The plotting of points in the complete C-M pattern diagram of the Passega and Byramjee (1969), (fig.11.1a(ii)) shows that the concentration of points lies mainly in classification quarter V of the diagram, and occupied segments 'PQ' of the field of sedimentation mechanics.

The study of the F-M, L-M and A-M diagram of the present sandstones shows that the points are scattering type in their distribution (Fig.11.2a) and also indicates bimodal nature of the sediments in the A-M plot, where the value of 'A' is 0.003 to 1.639 and most of the points are seen to appear in a line, whereas F-M and L-M plots appeared as inclined line in the diagram.

11.2c(i) INTERPRETATION AND CONCLUSIONS:

The C-M patterns are a means for analysing transportation mechanism and determining the mechanism that favour a particular deposit. Sediments are transported by rolling or in suspension. Suspensions are sub-divided into graded bottom, uniform bottom and pelagic suspension. Turbidity currents are formed by graded suspension (Passega, 1964).

From the study of the basic C-M patterns of the Surma Group, it has been inferred that the sandstone were mainly deposited by turbidity current; where evenly dispersed fine materials concentrated in suspension field.

Turbidites and certain tractive current deposits have several common characteristics. They may have a common origin. A clastic deposit is formed by sediments transported in different ways. The finest fractions may be transported independantly of the
coarser particles. Bottom currents capable of transporting sediments are of two types. Tractive currents are capable of transporting their load either by rolling or in suspension. Turbidity current carry their load essentially in suspension. Exceptionally, turbidity current can also roll grains to a relatively short distance from their origin. The graded suspension deposit of tractive current have certain characteristics in common with turbidity current (Passega, 1964).

In the quieter part of the bottom, the particles of 200 microns or larger are placed in suspension in the area of tractive currents in the quiet conditions of the bottom areas and deposited with the finer particles. This view is also supported by the smaller medium value of the present Surma Sandstones which ranges between 0.125 and 0.176 microns (Table, 5).

The complete C-M pattern diagram of Passega and Byramjee (1969), indicate that the sediments of the present Surma sandstones fall within quarter V and segment "PO" (Fig. 11.1b(ii). Concentration of points in the segments "PO" of the complete C-M pattern diagram represent graded suspension and tractive deposit in which a small amount of rolled grains are added (Passega, 1964, P.542). In this segment the coarseness of the grains increases without change in the value of medium diameter, perhaps due to addition of small quantities of rolling grains. Therefore, more and more coarser grains will be transported by rolling as one moves from this "PO" segment to another segment "ON". But in the present case there is not a single point in the segment "ON". It is assumed that segment "LO" of the tractive pattern represent a deposit formed by the sediments at point 'O' to which rolling adds a small amount of grains (Passega, 1964, P.832).

The bend "OPO" of the tractive pattern represent a gap between grain sizes transported as graded suspension and transported as rolling. This gap in sizes between rolling and graded suspension indicate that rolling and transportation as a graded suspension are independent mechanism of transport which is shown by Adige river sediments in Northern Italy (Passega, 1964, P.833). This gap makes well the change from transport controlled by turbulence to transport in which the main motive force due to the drag of the water is horizontal (Passega, 1964).

Therefore, it may be concluded that the present Surma sandstones contain sediments deposited by the mechanisms of graded suspension and rolling.
The study of F-M, L-M, and A-M of the Surma sandstones shows that most of the finer fractions were carried by suspension and mixed with the coarser fractions and transported by bottom current as graded suspension. The scattering nature of the points also indicates rolling and suspension deposits of the sandstone.

The 20% value of 'F', 'L' and 'A' corresponding to the value of "M" is considered as perfect sorting. The deviation from the above mentioned values, is considered as departure from the perfect sorting. The median (M) of the sediments of the present sandstones found between 085.4 and 217.6 microns, for which the values of 'F' are mostly between 22.662% and 66.405%, and 'L' are between 2.990% and 34.800% and 'A' are between 0.003% and 1.639% (Table 43) . This clearly indicate the departure from perfect sorting, and this also indicated graded suspension. Therefore, from the overall studies of C-M, F-M , L-M and A-M, it may finally be concluded that the sediments of the Surma group were formed by a mixture of rolled and suspended grains and were transported by tractive currents through graded suspension and uniform suspension (by bottom current) and deposited under varying energy conditions in a nearby basin.

11 : 2b.(11) Tipam sandstones : 

The study of basic C-M pattern (following Passega 1957, 1964) shows that the concentration of points of the Tipam sandstones lie within the field specified for turbidity current and river tractive current fields (Fig. 11:1b(ii) of Passega and Byramjee (1969), indicated that the concentration of points lies in the classification quarter IV and V of the diagram and occupied segments 'PQ' of the fields of sedimentation mechanisms.

The study of the F-M, L-M and A-M diagram of the
Tipam sandstones shows that the points are scattering type in their distribution (Fig. 11:2b). The value of "A" is almost zero (0.001) to 3.616 and a few appeared in concave line, whereas F-M and L-M plots appear in concave lines.

11 : 2 (ii) Interpretation and conclusion:

In the sediments transport various processes are involved according to their size, shape and specific gravity. Generally coarser particles are transported along the bottom by rolling, and clay, silt and flaky minerals are carried by suspension (Passega, 1957, 1964).

The C-M values of the present Tipam sandstone shows that the overall pattern are medium to fine grained, but minor amount of coarser fractions are also present. From the study of the basic C-M pattern, it has been inferred that the sandstones of the Tipam group was mainly deposited by river tractive current, but a few samples occupy... the field of turbidity current. The complete C-M pattern diagram of Passega and Byramjee (1969) indicates that the sandstones fall within the quarter IV and V and segment 'PQ'. Concentration of points in the 'PQ' segment indicates that the sediments are mixture of rolled and suspension grains. In this segment the coarseness of the grains increases without change in the values of median diameter, and more and more coarser grains will be carried by rolling to the segment 'ON'. Absence of grains in 'ON' segment indicates that gravel fractions are absent in the present sandstones. From these it may be concluded that the coarser fractions of the sediments contained rolled grains and they mixed with the suspended grains and transported, and were deposited under moderate turbulent conditions. As a whole the size of the sediment of the present Tipam sandstone is intermediate.

The study of F-M, L-M, and A-M diagram of the
present Tipam sandstones, indicates that most of the finer fractions were carried by suspension and mixed with the coarser fractions and carried by bottom current as graded suspension. Scattering nature of the points suggest rolling and suspension deposits of the sandstones.

The median (M) values of the Tipam sandstones vary between 116.6 and 341.5 microns, for which the values of "F" are between 8.470% to 61.656%, and 'L' are between 0.600% to 8.90%, and 'A' are between 0.001% to 3.61%. They may also indicate graded suspension and departure from the perfect sorting.

Therefore, it may be finally concluded from the overall studies that the sediments of the Tipam Group of sandstones were formed by a mixture of rolled and suspended grains and were transported by tractive currents through graded and uniform suspension and were deposited under various energy conditions in a near by basin.

BIVARIANT DISCRIMINATING PLOTS:

With the help of grain size parameters, it is possible to draw various schemes for the classification of sedimentary environments (Swan et al., 1979). Attempts were made to analyze, the environmental significance of textural parameters calculated from grain size data, and few investigators have been able to agree on their sensitivity in differentiating environment. Textural parameters can give useful informations about the environment (Passega, 1972). Friedman (1961), demonstrated that with the help of mean, standard deviation and skewness can be differentiated between beach sands and dune or river sands. Discrimination of depositional environments using bivariate plots (any two of the statistical size parameters) has been employed on recent and ancient sediments as there is an interrelationship between
statistical grain size parameters and environments of deposition (Friedman, 1961, 1967; Passega, 1957, 1964; Moiola and Weiser, 1968; Amaral and Pryor 1977; Hails and Hoyt 1969). Moiola and Weiser (1968) employed the combination plot of mean size versus standard deviation in discriminating between river and beach environments. Friedman (1961), pointed out that for recognising beach and river environments the combination plots of standard deviation versus skewness is most effective. Friedman (1967) proposed a plot of first percentile values and standard deviation values to differentiate between river and beach environments, and also suggested that skewness and Kurtosis combination plot did not give any satisfactory separation between environmental fields. Effective environmental discrimination are mainly related to the tail portions of the distribution.

11:3a METHODS OF STUDY:

The textural parameters of the Surma and the Tipam Groups of sandstones were plotted in the following forms and shown in Fig. 11:3a and 11:3b respectively.

(i) Mean size (M₀) versus standard deviation (δ₁)
(ii) Mean size (M₂) versus skewness (SKi).
(iii) Standard deviation (δ₁) versus skewness (SK₁)
(iv) Mean diameter versus standard deviation (δ₁).

11:3b OBSERVATION:

11:3b (i) Surma Group of Sandstones:

The combined plotting of the textural parameters, viz. Mean size vs. standard deviation, mean size Vs skewness, standard deviation Vs skewness, and mean size Vs standard deviation (Fig.
11: 3a), shows that concentration of the points, in all the four bivariant plot, lie on the right hand sides specified for river deposits.

11: 3c INTERPRETATION AND CONCLUSIONS:

From the observation of the bivariant plots of the Surma sandstones it may be concluded that the sediments of the sandstones were deposited in the river environment. The scattered pattern of the points in the various combination plots also indicates deposition in river environment. Some samples show negative skewness combined with poorly sorting nature, are indicative of marine or beach environment besides the river environment of the Surma sandstones. This might be due to development of local lagoonal or deltaic conditions in the parent rivarine environment.

11: 3b (ii) Tipam Sandstone:

Moiola and weiser 1968, observed that most effective is the mean diameter Vs standard deviation to differentiate between river and beach sand even with the whole phi data. For the present Tipam sandstone both whole phi data and quarter phi data were used in combination plots of mean diameter Vs. standard deviation (Fig. 11: 3b I and II). The combination plot obtained by using whole phi data (Fig. 11:3b I and II), shows that all the points lie towards the right hand side specified for river environment. Friedman (1961), was able to outline dune, river and a mixed river-dune, field by using the combination plot of mean diameter Vs. standard deviation. The same type of combination plots tried for the present Tipam sandstones (Fig. 11: 3b II) shows that only one point falls in the dune field out of analysed 28 Nos. samples. More than half, about 17 Nos., samples lie within the mixed river-dune field while 10 Nos. points included in the river field.
The plot of skewness (SK) versus standard deviation (σ) (Fig. 11.3b(iii)) shows that only one point lies within the beach field and the rest fall towards the right hand side specified for river environment. According to Friedman (1961, 1967) this type of combination plot is most effective in differentiating beach and river sand.

A combination plot of standard deviation versus skewness (After Friedman, 1967) for the present sandstones (Fig. 11.3b iv) shows that almost all the points lie within river field except one point which is included in the beach field.

11.3d INTERPRETATION AND CONCLUSION:

The plotting of statistical parameters in various combination plots for the Tipam sandstones shows that the sediments were deposited mainly in the river environment. The scattered nature of the points in the combination plots and the bimodality of the sediments together indicates river environment. The deviation of few points from river environment may be due to use of different equations (Folk and Ward, formulas vs. moment summation) which were used to calculate parameters (Chappel, 1967 in Moliola and Weiser, 1968).

11.4 ENERGY PROCESS EVALUATION:

The relationship of particle size distribution to the process of transportation and deposition is complex (Stewart, 1958). Valuable contributions towards the better understanding in this complex field, have been made by Inman (1949, 1952), Inman and Chamberlain (1955), Folk and Ward (1957), Passega (1957), Moliola and Weiser (1968). The grain size distribution is largely influenced by energy fluctuation in the transporting and depositing medium and due to this fluctuations in energy conditions, various
textural parameters developed. Hence, environment of deposition may be defined on the basis of the energy condition of the transporting media. Stewart (1958), has put forward his energy process diagram to differentiate between river, wave and quite water processes of deposition of the sediments. Stewart (1958), demonstrated that a plot of standard deviation and skewness versus median diameter was effective in differentiating various energy processes, viz. river, wave and quite water processes of deposition. In this type of plot, he has demarcated separate environments by drawing boundary line for each energy process involved in the deposition of the sediments.

11.4a METHODS OF STUDY:

Stewart (1958), studied the energy conditions by using Inman's (1952) formulae. The textural analysis of this present Surma and Tipam sandstones were done by using the formulae given by Folk and Ward (1957). The combination plots were made following Stewart (1958), and the environmental fields were drawn to study the energy processes by which the Surma and the Tipam sandstones of the present area were deposited (Fig. 11.4a and 11.4b).

For illustrative purpose the mean size vs. standard deviation boundary of Moiola and Weiser (1968) was redrawn on the median vs. standard deviation plots of Fig. 11.4a and Fig. 11.4b.
11.4b OBSERVATION:

The combination plots of Median vs. standard deviation of the present Surma and the Tipam sandstones, according to Moiola and Weiser (1968) and Stewart (1958), show that all the points of Surma sandstones lie within the energy field meant for river process of Moiola and Weiser (1968); while in case of Tipam sandstones almost all the points fall in the energy field of river process of Stewart (1958) and Moiola and Weiser (1968), (Fig. 11.4a and 11.4b).

11.4c INTERPRETATION AND CONCLUSIONS:

From the overall studies of energy process of deposition of the Surma and the Tipam sandstones it may finally be concluded that the sediments of both the groups were deposited mainly by river processes. This is also supported by other relevant characteristics of river deposition of the sediments.
Asseeze's triangular diagram:

Asseeze (1972) attempted to establish a pattern for the identification of environments with the help of size data from known environments. Asseeze (1972) studied the results of mechanical analysis of one hundred samples of sand collected from four major different environments, namely, river, desert, beach and lagoon by using raw sieve data. He plotted the data thus obtained on triangular graphs, where the three corners of the graph represent very coarse and coarse (A), median (B), and fine sand to silt (C). He viewed that as the statistical parameters are sensitive to the variations at the tails, the size distribution data are comparable environmental significance like statistical parameters, which are used for environmental interpretations.

So, a similar attempt is made for the present study to interpret the environmental condition under which the Surma and the Tipam sandstones were deposited.

Methods of study:

The size data of the Surma and the Tipam sandstones grain size distribution were divided into three size grades, viz., A, B, C. Group A includes up to 0.5 mm size grade, group B includes size grade from 0.25 to 0.5 mm, and group C contains from 0.25 to 0 mm size grade (Table 45 and 46). These values were plotted in a triangular graph paper to obtain the distribution pattern. The triangle is divided into four sectors, viz., I, II, III, and IV, and each sector is specified for a particular environment. (Fig. 11: 5a and 11: 5b).

Observation and conclusion:

The different size grades obtained from raw sieve
data were plotted on the three corner A, B, and C, in the triangular graph paper. It shows that (Fig. 11 : 5a and 11 : 5b) majority of the samples fall in sector (triangle) I, and few points lie in triangle II, and not a single point falls in the triangles III and IV in case of the Surma sandstones; while in case of the Tipam sandstones the distribution is widespread and majority of the points fall in the triangle III and few points lies within the triangle I and II.

The distribution pattern of the different size grades indicates the river environment of deposition of the present Surma and Tipam sandstones; which is also the case with the majority of river sands studies by Asseez (1972).

LINEAR DISCRIMINANT FUNCTION ::

The method, as given by Sahu (1964), combines all the grain size parameters into a single linear equation. Sahu (1964), stated that this study involved with certain quantitative methods of discrimination between the different mechanisms and environments of deposition, considering that the size distribution of coarse clastic sediments reflects the fluidity factor of the depositing medium and the energy factors of the depositing medium and the energy factors of the environment of deposition. Every environment of deposition can be assumed to have characteristic energy conditions and energy fluctuations through space and time. These fluctuations, as revealed by the grain size distribution parameters, are useful for discriminating environments. The linear equation (Sahu, 1964), substitution of size parameters of the unknown into the equations that gives a value, which can be compared to values obtained from modern depositional environments. Sahu (1964), has given four discriminant functions based on Folk and Ward's (1957) statistical parameters to differentiate between shallow marine and fluvial, fluvial and turbidite, and aeolian and beach environments. Sahu
(1964), concluded that significant difference between the aeolian dune and the aeolian flat environments could not be found and so these were deal together to form the aeolian deposits.

11 : 6a METHODS OF STUDY ::

The study was made for the Surma and the Tipam groups of sandstones using the graphic measures of Folk and Ward (1957), in the formulae of linear discriminating functions as given by Sahu (1964). In the present study the discriminating functions " Y_3 " and " Y_4 " has been employed as follows :

(i) \( Y_3 \) (shallow marine ; fluvial ) : \( 0.2852 \, M_z - 8.7604 \, S_1 - 4.8932 \, S_1 K_g + 0.0492 \, K_g \).

(ii) \( Y_4 \) (Fluvial ; turbidity current ) : \( 0.7215 \, M_z - 0.4030 \, S_1^2 + 6.7322 \, S_1 K_g + 5.2927 \, K_g \).

If \( Y_3 \) is less than \( -7.4190 \), it is fluvial (deltaic), and if more than \( -7.4190 \), it is shallow marine deposit.

If the value of \( Y_4 \) is less than 9.8433, it indicates turbidity current, and if \( Y_4 \) more than 9.8488 , it indicates fluvial (deltaic deposition).

The result thus obtained (Table : 47 and 48) were compared with the given range of Sahu (1964), to distinguish the different environments.

11 : 6b OBSERVATION ::

From the above study, it is seen that the \( Y_3 \) values for the Surma sandstones ranges from \( -9.6657 \) to \( -54.6363 \), and \( Y_4 \) values ranges from 9.8695 to 16.0103, while in case of the Tipam
sandstones, $Y_3$ values vary from (-) 4.7869 to (-) 23.5212 and $Y_4$ values vary from 9.0569 to 18.9453. This range of $Y_3$ and $Y_4$ values shows that the Surma sandstones were deposited in fluvial while the Tipam were deposited in fluvial to shallow, agitated water environments.

**INTERPRETATION AND CONCLUSION**

From the results of this study, it may be concluded that the Surma group of sandstones were deposited under fluvial (deltaic) environment, while the Tipam group of sandstones were deposited in dual environmental conditions, namely fluvial (deltaic) to shallow marine, under wide energy conditions. The shallow marine conditions show by the Tipam, might be developed locally at the early stage of its deposition during the transitional phase from the Surma to the Tipam.

**LOG-PROBABILITY GRAIN SIZE PLOTS**

Many sedimentologists attempted to know the relationship between grain size distribution and environment of deposition. Inman (1949), recognised that the sediments were transported by the processes of rolling, saltation and suspension. Doeglas (1946), observed that grain size distribution are a mixture of two or more populations and these distributions were produced by different transport conditions. Shapes of grain size distribution curves of sediments from both modern and ancient environments were described by Sindowski (1957). Moss (1962), recognised subpopulations produced by the sediment transport processes of rolling, saltation and suspension. Visher (1965), studied various sub-population from fluvial sediments and shown the existence of different populations in log-probability plots. The visual curve shape method has an advantage over statistical parameter as no grain size information is lost in this method. Visher (1969), established
the relationship of the shape of grain size curves to the mode of transport and their breaks or truncations with each other in individual grain size distributions and also stated that each sub-population indicates a log-normal distribution and differ from each other in median and standard deviation. Visher (1969) used size frequency curve shapes for recognising sedimentary processes and depositional environments.

11: 7a METHODS OF STUDY ::

The cumulative percentages of size analysis for each sample of Surma and the Tipam sandstones were plotted on log-probability papers against their respective size scale. Following Visher (1969), straightlines were drawn to construct different sub-populations and their truncation points with each other. Percentages of different sub-populations in the curves, positions of their truncation points in the curves, and the slope of each sub-population were measured from each of the curves, and the percentages of different sub-populations were also calculated out (Table 49 and 50).

11: 7b OBSERVATION ::

The log-probability plots of the Surma and the Tipam group of sandstones were constructed following Visher (1969) and shown in fig. 11: 7a and 11: 7b. These curves show that suspension, saltation, and surface creep sub-populations are present in almost all the curves.

11: 7b(i) The Surma group of sandstones ::

The log-probability plots of the Surma group of sandstones were constructed following Visher (1969) and shown in fig. 11: 7a. These curves show that saltation, suspension, and surface creep sub-populations are present in all the curves out of 25
log-probability plots, only 6 samples exhibit two truncation points between surface creep and saltations, and saltation and suspension load; and 19 samples with three truncation points recognises two saltation sub-populations, naming them as saltation sub-population A and B in the text. The curves have well developed saltation population which varies from 33.33% to 71.31%, and surface creep population ranges from 17.33% to 37.24%, while majority of the samples shows variation of suspension population from 6.83% to 27.52%, and in few cases it varies from 30.28% to 40.91% (Table-49). The coarse truncation points for backwash (Saltation A) portion of saltation population fluctuate between 0.75 ϕ and 1ϕ. The backwash and swash segments (saltation A and saltation B) populations truncated around 2ϕ and 3ϕ and rarely lie on finer side 3.50ϕ. The truncation between saltation and suspension populations occur within the range of 3ϕ and 4ϕ. Saltation sub-population A varies from 14.66% to 51.55% and sub-population 'B' ranges from 13.42% to 42.23% (Table 49). Slope of the saltation sub-population A and B varies from 18° to 43° and 41° to 63° respectively. The suspension slope varies from 18° to 45°, while surface creep slope ranges generally between 50° to 70°. These variation in slopes of the three populations produced variable sorting, such as moderate to moderately well sorted and poorly sorted sediments. Particle size of truncation points at coarser end, between surface creep and saltation sub-population A ranges from .25 ϕ to 1ϕ; between saltation sub-population A and B varies from 1.50 ϕ to 3ϕ, and for those at finer and between saltation B segment and suspension from 3ϕ to 4.50ϕ.

11 : 7b(ii) THE TIPAM SANDSTONES ::

The log-probability plots of Tipam sandstones show that saltation, suspension, and surface creep sub-populations are present in almost all the curves. The curves have well developed saltation population and majority of the samples show truncation
points between the saltation and suspension populations in between 2.50 $\phi$ and 3.50 $\phi$; sometimes occurs at 4 $\phi$. The size of the saltation populations ranges from 1.75 $\phi$ to 3 $\phi$. The slope of the saltation population generally varies from 52° to 65° suggesting that sediment fractions is moderate to moderately well sorted. The suspension population generally occur between 3 $\phi$ and 4.50 $\phi$. Suspension plots are inclined mostly at an angle between 22° and 44° which producing poor sorting. The truncation between saltation and surface creep populations occurs between 1 $\phi$ and 1.75 $\phi$. The size of the surface creep population is coarser than 1 $\phi$ and slope varies between 30° and 75°. Majority of the samples shows surface creep slope variation from 50° to 65°, and producing variable sorting nature from moderate to moderately well sorted; in few cases slopes are less than 50°, hence poor sorting (Table 50).

The saltation population varies from 32.05% to 68.42%; suspension population generally ranges from 7.60% to 30%, in very rare cases exceeds 40%, and surface creep population varies from 11.63% to 40%. It also observed that in few samples surface creep population are absent.

Few log-probability plots exhibits three truncation points recognises two saltation sub-populations herein called sub-population A and B. The truncation occurring between sub-population A and B between 1.75 $\phi$ and 2.75 $\phi$. The slope of saltation sub-population A varies from 30° to 50°; and B type shows variations from 55° to 75° suggesting that saltation sediment fraction is moderate to moderately well and well sorted (Table 50).

11: 7c INTERPRETATION AND CONCLUSION ::

11: 7c(i) The Surma Group of sandstones:

Transporting materials from the source area to the depositional site follow a log-normal distribution and produced a
deposit which is a mixture of three or less than three log-normal populations (Moss, 1963; Visher, 1969). The deposit consisting of variable particle size mainly produced by surface creep, saltation and suspension mode of transport. The log-probability plots of the Surma sandstones reveals that the sediments were deposited by surface creep, saltation and suspension mode of transport. The position of truncation of probability plots, sorting and mean size of individual sediment populations help in understanding the nature of the depositional processes (Moss, 1962 and 1963; Visher, 1969).

The Surma sandstones mainly shows two saltation sub-population A and B. Saltation population varies from 34.85% to 69.70% is dominating over the suspension and surface creep populations of the present sandstones. The slope of the saltation population are variable (range from 35° to 60°) suggesting that sediment fraction is poorly to moderately sorted and leptokurtic.

Visher (1969), mentioned two sub-populations of saltation load, recognised in beach foreshore deposits, to swash and backwash. Theoretically two saltation sub-populations may occur in deposits of other subaqueous environments (Qidwai and Casshyap, 1978). Moss (1963) has observed these two saltation sub-populations in sandy river gravels. In fluvial processes, due to higher buoyancy during highly turbulent condition of flow, or during floods, when it is loaded with higher proportion of sediments with higher density, part of the saltation load was uplifted temporarily into suspension to infiltrate subsequently into pore spaces of saltation load (sub-population A), during retarding phase (Moss, 1963; Krumbein and Sloss, 1963). The saltation sub-populations of the present Surma group of sandstones were under the similar conditions of turbulent flow along with higher amount of load with higher density in a fluvio-deltaic environment. Sample to sample variation of textural parameters found in the sandstones indicates that attending hydraulic
and flow conditions of the depositing currents were not similar in both area/ally and through time (Qidwai and Casshyap, 1978).

Visher (1969) produced a well defined suspension population for river type of deposits, consisting about 20% of the distribution with truncation between suspension and saltation occurring between suspension and saltation occurring between 2.75 $\phi$ to 3.5 $\phi$. Suspension load in the Surma sandstone occurs in variable quantity and majority of the samples contains this load in between 6% and 34%. The truncation between suspension and saltation occurs between 2.75 $\phi$ and 4 $\phi$. The slope of the suspension population ranging from 18° to 45° and sorting is poor, sediments consisting generally of fine to very fine sand to coarse silt (size range in between 3 $\phi$ and 4.50 $\phi$). These fine to very fine clastic suspension load of the present Surma group of sandstones were deposited down into the existing pore spaces of sandy bed load when velocity and vertical turbulence (buoyancy) of flow sufficiently reduced. Jopling (1966), recommends an arbitrary increase in competent velocity of about 20% for poorly sorted mixes. Presence of small amount of suspension load may suggest the operation of unidirectional fluvial transport. Overall, the characteristics of suspension load revealed by the Surma sandstones are more or less similar to those described by Visher (1969) for modern fluvial channel sands and ancient fluvial sands.

Most coarse sediment is transported and deposited by streams during flood stage, and the range of velocity are assume to represent minimum flood velocities in or near stream channel (Royse JR, 1970). In fluvial channel environments larger grain starts to roll at a lower angle of slope than smaller ones and they roll faster and further (Brush, 1965; in Taira & Scholle, 1979). Taira and Scholle, (1979) stated that larger particles can be transported together with the saltation population, whereas intermediate particles tend to be left behind. Fine grained sand is the size range which is
most easily transported in both fluvial and eolian environments, because it has the lowest threshold velocity of entrainment (Bagnold, 1941; Inman, 1949). The size range of 0-2.70\(\phi\) materials in fluvial environments could be other easy-to-move population. It is to be expected that easy-to-move coarse fraction which is transported out of fluvial environments then will be dispersed along shoreline by long shore litoral drift. In the light of above discussion, it may be stated that the coarse and finer grains present in the Surma sandstones were transported by surface creep and saltation in turbulence fluvial system, while the intermediate size grains were left behind and the suspension load, consisting of fine to very fine grains were settle down into the available pore space under the influence of sufficient reduced velocity. The surface creep loads of the Surma sandstones exceeds 15\%, and particle size varies from .25\(\phi\) to 1\(\phi\) indicating that the fluvial system became torrential and attended high intensity, possibly during flood time, sediments containing coarse particles as were available in the source area was rapidly transported on the depositional site. Visher (1969) remarked that surface creep is strongly provenance controlled, and is developed most frequently in the deepest portion of the channel. The size grade generally range from .25\(\phi\) to 4.50\(\phi\) suggesting that the grains coarser then .25\(\phi\) lagged behind and finer than 4.50\(\phi\) were carried further away. The trend of the curves also revealed that the maximum accumulation of the grains takes place between .75\(\phi\) (0.59 m.m.) and 4\(\phi\) (0.062 m.m.) . Middleton (1976), opined that the variation in the proportions of each population was the function of the shear velocity of the transporting medium and the setting velocity of the transporting individual grains. The truncation points of the Surma sandstones occur, in general, at 1\(\phi\) and 4\(\phi\) and hence it can be interpreted that the transportation of the sediments took place mostly by saltation, and processes of surface creep and suspension played subordinate role.

From the above observation and interpretation it may
be concluded that the Surma Group of sandstones were deposited in the fluvio-deltaic environment under the influence of varied energy (transporting) conditions.

11: 7c(ii) The Tipam sandstones:

Majority of the Tipam sandstones show two truncation points between saltation and suspension, and between saltation and surface creep population. The truncation occurs between saltation and suspension around 3°; and between surface creep and saltation around 1°. This wide range in the occurrence of the truncation points shown by the samples indicating the hydraulic conditions of depositing currents tended to vary in competency. As the deposition currents vary from time to time, the variable sorting of saltation load of the Tipam sandstones takes place which is evident from the variable steepness (52° to 70°). The surface creep population generally less than saltation and suspension population (ranging from 11% to 35%) and their narrow distribution suggest that overall potency of traction currents was enough to carry from the source area to the depositing site (Moss, 1963; Visher, 1969). The surface creep population represent by the grains are coarser than 1°. The concentration of the traction load (exceeds 30%) in the present Tipam sandstones indicates that the debris containing coarser particles in the source area were transported rapidly to the depositional site by the high intensity current, possibly periodic cloud burst, of the stream (Qidwai and Casshyap, 1978).

In few cases two saltation sub-populations (type A and B) developed (Fig. 11: 7b). This was occur due to higher buoyancy during highly turbulent current and greater sediment loads in the stream, probably at the time of flood. Moss (1963), stated that during retarding phase of the highly turbulent current with high density condition of the stream, a part of the saltation load was uplifted temporarily into suspension to produce subsequently saltation.
sub-population A. Visher (1969) suggested that small changes in current velocity can modify a single detrital population.

From the above observation and interpretation it may be concluded that the Tipam sandstones were deposited in river environment under varied energy condition.

As a whole, both the Surma and the Tipam sandstones bears common characteristics to the depositing processes. Some of the significant characteristics observed in both the sandstone groups from the above study are that saltation and suspension dominate the size population. In spite of the presence of all the three populations, there occurs a break in the saltation population, assuming to be due to swash and backwash processes in the fluvio-deltaic environment. The slopes and sorting of the various population are moderately variable.

The well developed saltation population in both the sand group along with moderate slope, and their gentle truncation with the suspension populations shows that at the depositional interface of the current was not very high to produce complete mixing of these two populations and also not very slow to permit excessive deposition of these populations. The moderate saltation population together with moderate slopes of the population, indicates moderate energy condition. But due to the presence of small rolling or surfact creep population, the sediments become moderate to poorly sorted nature. Some what well sorted sediments reflects re-working or winnowing by waves and tides. Also, poorer sorting suggest the incompetency of the transporting media.

From the overall assessment of the log-probability study, it may be concluded that the Surma groups of sandstone were deposited primarily in river environments, though influence of local lagoon or, deposited in a model of "coalescent deltas" (Carozzi et al. 1975, in Mabesoone, 1977). In the Assam-Arakan basin, two megacycles of delta building takes place during late Eocene to end of Miocene period. The first megacycle is represented mainly by the Barail group. The second megacycle of delta building commenced
after the Barail unconformity and encompasses mainly the Surma and the Tipam groups which filled up the gulf or lagoon that formed to the north of the rising axial zone (Roy and Asthana, 1989). This delta prograded forming time transgressive deposits. The Tipam group is mainly fluvial deposit under continental environment.
EXPLANATION OF THE FIGURES:

FIG: 11:1a(i) BASIC C-M PATTERN, PLOTS OF THE SURMA SANDSTONE (AFTER PASSEGA, 1957).


FIG: 11:1b(i) BASIC C-M PATTERN, PLOTS OF THE TIPAM SANDSTONE (AFTER PASSEGA, 1957).


Figure 11: M = Median in Micron

M = 50%

M = Median in micron

FIG. 11 : 19(11).
Fig. 11:1b(i)
INCOMPLETE CM-PATTERN.
After Passega, 1957, 1964
and Passega and Byramjee, 1969.

M = Median in Micron

FIG. 11: 1b(ii).
Percentages by weight of fractions finer than 125(F), 31(L) & 4(A) Microns.

100%  30%  0%

A H 6 A A A A

M = Median in Microns

F-M(A), L-M(●) and A-M(+) of Surma Group sandstone samples (After Passega and Byromjee, 1969)
Percentages by weight of fractions finer than 125 (F), 30 (L) & 4 (A) Microns.

F-M- (A), L-M (Θ) and A-M (•) diagram of Tipam Group.

EXPLANATION OF THE FIGURES:

FIG: 11:3a I  MEAN DIAMETER Vs. STANDARD DEVIATION PLOTS (AFTER MOIOLA AND WEISER, 1968) ON WHOLE PHI (\(\phi\)) DATA OF THE SURMA SANDSTONE.

FIG: 11:3a II  MEAN DIAMETER Vs. STANDARD DEVIATION PLOTS (AFTER MOIOLA AND WEISER, 1968) ON QUARTER PHI (\(\phi\)) DATA OF THE SURMA SANDSTONE.


FIG: 11:3a(iii) STANDARD DEVIATION Vs. SKEWNESS PLOTS OF SURMA SANDSTONE (AFTER FRIEDMAN, 1967).
FIG. 11: Graph showing deviation of mean diameter in different environments.
EXPLANATION OF THE FIGURES :::

FIG: 11:3b I MEAN DIAMETER Vs. STANDARD DEVIATION PLOTS (AFTER MOIOLA AND WEISER, 1963) ON WHOLE PHI (φ) DATA OF THE TIPAM SANDSTONE.

FIG: 11:3b II MEAN DIAMETER Vs. STANDARD DEVIATION PLOTS (AFTER MOIOLA AND WEISER, 1968) ON QUARTER PHI (φ) DATA OF THE TIPAM SANDSTONE.

FIG: 11:3b(1) MEAN DIAMETER Vs. SKEWNESS PLOTS OF THE TIPAM SANDSTONE (AFTER MOIOLA AND WEISER, 1968).


Bivariate plot of inclusive standard deviation Vs. median (after Stewart, 1958, Moiola and Weiser, 1968) of the Surma Group of sandstone.
Fig. 14: Bivariant plot of inclusive standard deviation Vs. median (after Stewart, 1958, and Moiola and Weiser, 1968) of the Tipam sandstone.
Fig. 53: Triangular Diagram illustrating Textural Groups of the Surma Group sandstones. (After Asseez, 1972).

A = Coarse sand.
B = Medium sand.
C = Fine + Very fine sand + Silt.
Fig. 12. Triangular Diagrams illustrating Textural Groups of the Tipam sandstone.
(After Asseez, 1972).
EXPLANATION OF THE FIGURES ::


Fig. 11.7a
Fig. 11:7a
Fig. 11.7a
Fig. 11:7b.