CHAPTER 7

S E D I M E N T A T I O N

Grain size is one of the fundamental properties in characterising an aggregate (Griffith, 1967, p.46 and 104), and the grain size study provides useful clues in determining sedimentary environments (Visher, 1965, 1972; Potter, 1967; Oomkens, 1970 etc.). Facies and paleocurrent maps become more meaningful if those are weighed by bed thickness or grain size, the two correlated scaler variables whose magnitude is related to current velocity. Pettijohn (1962, p.1488) has also mentioned that scaler properties are important mappable attributes of sedimentary rocks, that furnish valuable information on sedimentation.

Out of all samples collected from the field, only the sandstone samples from the representative stratigraphic horizons in the different sections spread all over the area were subjected to grain size analysis; and mean size and sorting values were calculated for each sample.

SAMPLING PROCEDURE AND SAMPLE PROCESSING

Samples for grain size study were collected from the various sections. Since the author could establish a complete litho-stratigraphic correlation of the area (Figs. 4.1, 4.2 and 4.3), samples representing different known and definite horizons from various localities could be easily collected. The position of each sample with respect to the top or the bottom of the respective stratigraphic column as well as the top and the base of the particular bed was recorded and plotted in the stratigraphic column. About 5 kg of each fresh sample was collected at every sampling location.

Out of the total 300 samples collected, 110 representative sandstone samples were subjected to grain size analysis by sieving method.

All the friable samples were disintegrated by fingers. Weakly consolidated samples were disintegrated with the help of porcelain pestle and mortar, by a gentle pounding. The disintegrated sample was then chekced under binocular microscope for any aggregate content. If necessary, the sample was again put into the mortar and further pounded till the aggregates were completely destroyed.

The hard samples, usually cemented by calcareous or ferruginous cements were initially broken into small chips with the help of iron mortar. These chips after weighing were treated with dilute hydrochloric acid. In some cases the sample with the acid was heated. Later the acid was poured off and the sample was washed and separated out by means of pre-weighed filter paper. Next, the sample was dried in oven. The weight lost in this process was added to the 'pan fraction' of the sieve analysis.

Out of the each bulk disintegrated sample, about 60 gm was selected by coning and quartering for sieving by electrically operated Ro-Tap machine. Following set of British standard sieves were used:

7	mesh	(2.411 mm)
14	"	(1.204 mm)
25	"	(0.599 mm)
36	"	(0.422 mm)
52	"	(0.295 mm)
100	"	(0.152 mm)
150	"	(0.104 mm)
200	"	(0.076 mm)
240	"	(0.062 mm)

Each sieve fraction was weighed on a chemical balance upto fourth decimal place. Besides, these fractions were viewed under binocular microscope for any aggregate content left in it. Visual estimation of aggregate percentage was made and in cases where the total aggregate percentage was found less than 20, the same was subtracted from the particular sieve fraction weight of the sample (Folk, 1968, p.35). If the aggregate content was more than 20%, the entire sample was again disintegrated and the whole process of sieving and weighing repeated.

CALCULATION OF STATISTICAL PARAMETERS OF GRAIN SIZE

The grain size data of the samples obtained as above formed the basis for preparing various graphic representations, histograms and cumulative curves.

The cumulative curves were prepared by plotting grain size in 'phi-scale' along the abscissa and the cumulative weight percentages along the ordinate. Probability ordinate paper was used for preparing these cumulative curves. The advantages of using probability ordinate paper, have been ideally listed by Folk (1968, p.41-42). Such curves have been constructed for all the samples.

The curves which furnish the quantitative data of size distribution of the samples have been utilised to calculate the statistical parameters as per below, following the procedures suggested by Folk and Ward (1957, p.12-15) and Folk (1968, p.44-46).

(1) Graphic Mean (M_z):

It is a measure of average grain size and calculated as : -

$$M_z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

(2) Inclusive Graphic Standard Derivation (σ_I):

This is a measure of average dispersion or spread of the distribution around the mean size and is calculated as:

$$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

The following classification scale (Folk, 1968, p.46) of sorting was adopted:-

σ_I - Under	0.35ϕ	very well sorted
0.35 -	0.50ϕ	well sorted
0.50 -	0.71ϕ	moderately well sorted
0.71 -	1.00ϕ	moderately sorted
1.00 -	2.00ϕ	poorly sorted
2.00 -	4.00ϕ	very poorly sorted
Over	4.00ϕ	extremely poorly sorted.

PRESENTATION OF DATA

In the following pages variations of grain size parameters i.e. mean size and sorting have been presented. Maps displaying areal variations of mean grain size for the Washtawa Formation and for the Lower and the Upper Kanthkot Formations have been prepared. The author has followed Pelletiar (1965) in preparing such maps. Besides vertical variations of mean grain size have been studied for the different sections representing all the formations. The vertical variations have been studied in relation to the bedding thickness and different sedimentary structures and presented in the form of graphs and stratigraphic columns. Also (i) histograms representing sorting patterns for different formations and (ii) scatter diagrams showing mean size plotted against sorting have also been prepared. In addition to this size distribution patterns of individual samples have also been studied and the pertinent data is presented in the form of frequency curves.

AREAL VARIATION OF GRAIN SIZE

Figures 7.1, 7.2 and 7.3 display the areal variations of mean grain size for the Washtawa, the Lower Kanthkot, and the Upper Kanthkot Formations. The contours have been shown in 'phi-scale' with ½ phi as contour internal.

The Washtawa Formation

The mean grain size in the eastern part of the area around Dabunda and Dedarwa-Mewasa, is comparatively coarser being around 2 phi, i.e. the average grain size in this area is of fine to medium grade (Fig. 7.1). On traversing from E to W, a comparatively finer grained clastics are met with. Around Rapar-Chitrod in the central part of the area, the average mean grain size is 2.5 phi. In the south western part of the area i.e. south of Kanthkot-Chitrod axis the mean grain size is still less around 3.0 phi. Thus the sand size in this south western part is of very fine grade.

The contour lines over the entire area show an open 'Z' shape pattern having roughly NNW-SSE regional strike. The strike slightly swings towards WNW-ESE in the south western part of the area. This contour pattern when compared with that of the isopach contours show a good conformity.

<u>The Lower Kanthkot Formation</u>

The eastern half of the area around Dabunda-Bhimasar-Mewasa and Chitrod show a broad 'V' shape pattern of mean grain size contours with an approximate E-W axis (Fig. 7.2). The average grain size in this area varies from 1.0 to 2.0 phi. In the Adhoi-Washtawa area the axis shows a swing towards SW, where the grain size is about 2.5 phi. This relatively finer grain size concentration around the Washtawa area appears to be a local phenomenon. Further westward, around Nara-Adhoi-Kanthkot-Mae, the mean grain size varies between 2.0 and 2.5 phi. In this area, the contours roughly show NE-SW strike. In the extreme northwestern part of the area around Bharodia, the average mean grain size value is about 3.0 phi. Thus the variation in mean sand size is from medium sand grade in the E to fine sand grade in the W.

Except for the parts around Washtawa, regionally, the entire area shows a gradual decrease in the mean grain size from E to W. The contour pattern shows a broad parallelism with the facies maps of this formation, especially the sand percentage map.

The Upper Kanthkot Formation

The mean grain size contours for the Upper Kanthkot Formation which is confined only in the western half of the area show roughly NW-SE strike with a swing towards N-S in the southern parts (Fig. 7.3). The value for the average mean grain size varies from less than 2.0 phi in the eastern parts around Narada-Chitrod to nearly upto 3.0 phi in the westernmost parts of the area around Mae-Manfara. Thus, like the Lower Kanthkot and the Washtawa Formations, the Upper Kanthkot Formation also shows a general decrease in the mean grain size from E to W, i.e. from medium to fine grade sand.

On comparing the three areal grain size variation maps it is noted that in the eastern part of the area the fine grade sand of the Washtawa Formation is directly overlain by medium grade sand of the Lower Kanthkot Formation. Similarly, in the western half of the area very fine grade sand of the Washtawa Formation is seen to be overlain by fine sand of the Lower Kanthkot Formation.

However, the sediments of the Upper Kanthkot Formation in the western parts, shows more or less the same fineness of sand deposits as those of the Lower Kanthkot Formation which they overlie.

VERTICAL VARIATION IN GRAIN SIZE

Variations in the grain size in vertical profiles are of great value in environmental reconstruction. Several workers (Visher, 1965, 1970; Selley, 1972; Oomken, 1970; Pottor, 1967 etc.) have freely used this criteria in deciphering the sedimentation pattern in space and time. Since a comparative study of grain size is a function of energy levels and hydrography of the depositional environments, their study in vertical profiles as well as in space directly sheds light on these factors. In the present study too the author has made an attempt to study mean grain size variations in several sections of the various formations.

The grain size variations were studied in relation to bed thickness as well as different sedimentary structures exposed within the sections (Figs. 7.4,7.5, 7.6 and 7.7).

The Washtawa Formation

Three sections of the Washtawa Formation viz., the Washtawa dome, the Dabunda dome and the Mewasa dome sections were studied for the vertical variability of the grain size (Fig. 7.4).

The basal part of the Washtawa dome section shows parallel bedded to massive sandstone having an average mean grain size of 2.5 to 3.0 phi which falls in fine sand grade category. Further upward the section comprises a cross-bedded sandstone and laminated shale-siltstone alternation unit. The section is further followed up by parallel bedded and rippled sandstone unit which shows finer mean grain size ranging from 3.0 to 3.5 phi i.e. very fine sand. The upper part of the section consists of a lower cross-bedded sand-unit followed by a parallel bedded sandstone and sandstone-shale alternations. Again the top is marked by a massive sandstone unit. The mean grain size from the central part upto the top almost uniformly goes on coarsening upwards i.e. from 3.5 phi to as much as 2.0 phi.

The total thickness encountered in the section is 650'. Except for some deviation in the lower part, there is an overall tendency for upward coarsening of mean grain size.

The Mewasa dome section in the south eastern part has a basal massive sandstone with mean grain size of about 2.6 phi. There is progressive coarsening of grain size upwards and the overlying massive sandstone unit shows mean grain size of 2.25 phi, while the cross-bedded sandstone unit above this shows mean grain sizes of 1.9 to 1.3 phi towards top. The upper part shows again 'fining-up' pattern with mean grain size varying from 2.25 phi to 3.0 phi from the middle part towards the top.

In general, out of the 400' section of the Mewasa dome, the lower 270' shows an increasing upward coarsening while the sequence above this shows a progressive decrease in grain size.

In the Dabunda dome section, which forms the eastern limit of the Washtawa outcrops, basal 100' show mean grain size variation from 2.25 phi to 2.60 phi decreasing from base to top. The upper 240' of the section show coarsening up pattern and mean grain size varies from 2.6 to 1.0 phi, gradually showing an increase towards the top of the section.

Broadly speaking the 250' Washtawa section of the Dabunda dome shows progressive upward coarsening, the mean grain size variation being fine grade at the base to almost coarse grade at the top.

The Lower Kanthkot Formation

Since the Lower Kanthkot Formation occupies the maximum areal extent in the Wagad hills, several sections namely the Kanthkot dome, the Adhoi anticline, the Washtawa dome, the Chitrod dome and the Bhimasar cliff section from W to E respectively were sampled (Figs. 7.5 and 7.6).

The basal 170' of the Kanthkot section in the western part of the area mainly consists of shales. The overlying flaggy laminated sandstone shows a mean grain size of 2.5 phi, while the cross-bedded unit that overlies the flaggy sandstone has the mean grain size values upto 2.0 phi. The uppermost sandstone units which show parallel bedding as well as cross bedding, indicate grain size values of about 2.0 phi to almost 1.0 phi from base to top.

The Adhoi anticline section shows similar upward coarsening pattern of the mean grain size. About 300' of the Adhoi section shows grain size variation from 3.0 phi to about 1.1 phi increasing from the base towards the top, i.e. the size varies from fine to medium sand grade.

Similarly in the Washtawa dome section, though there is no appreciable variation in the mean values, it is seen that the values do indicate a little size increase from base to top. The size values for lower flaggy to laminated sandstone is 2.8 phi while the same for upper massive sandstone is 1.8 phi. A slight deviation toward finer side in the lower part is noted where the size of about 3.2 phi is noted. In general the variation is from fine to medium grade sand.

Out of 550' thick section of the Chitrod dome in the southcentral part of the area, the lower 430' of section shows a gradual increase in the grain size upward. The size gradually increases from 2.5 phi to as much as 1.0 phi. But the rest of the upper part again shows 'fining up' pattern.

The Bhimasar section (250' thick) in the easternmost area shows an interesting grain size pattern. The lower 100' of the section show gradual coarsening up pattern where the size varies from 2.0 to 0.75 phi. While the upper 150' shows a sharp fining up patterns, such that the mean grain size decreases showing values from 0.75 to 3.25 phi. Thus, the grain size within the upper part varies from coarse to very fine grade. The upper part of the section is also marked by transverse current ripples and trough and tabular cross bedding.

The Upper Kanthkot Formation

The Upper Kanthkot Formation being confined mainly in the western half of the area, is sampled at two localities only viz. the Kakarwa anticline and the Adhoi anticline (Fig. 7.7).

The Kakarwa anticline section in the westernmost part of the area shows a very good 'fining up' pattern of the mean grain size from the base to the top. The lithologic column here shows three distinct cycles from massive to flaggy or laminated sandstones. The massive sandstone is usually current bedded. The size variation and increasing fineness is encountered taking all the cycles as a whole. The massive sandstone in the lower part shows mean grain size value of 1.2 phi. The size varying from fine to very fine upwards.

The Adhoi anticline section in the south central part of the area, shows an almost identical variations, the mean grain size varying from medium to fine and very fine grade from the base upwards towards the top. The graded bedded sandstenes in the lower part of the section shows a mean grain size of about 1.9 phi while the same changes to roughly 3.5 phi towards the top. The middle part of the section shows development of cross bedding as well as ripple marks. The cross bedding is usually of small to medium scale and of both trough and tabular types. A few graded bedding horizons are also noted towards the lower part of the section.

The Gamdau Formation

The exposures of the Gamdau rocks occur mainly along the Gamdau synclinal low in the south western part of the area, and a hill section occurring just E of the Gamdau village was sampled for the study of vertical variations. (Fig 7.7)

Out of a total of 250', the lower 70' of the section comprising flaggy sandstones has a mean grain size of 3.0 phi. In about 50' of section above this coarsening of the grain size upward is noticed, such that at about 120' from the base the value is observed to be 1.9 phi. There is a gradual 'fining up' pattern of the grain size starting from this horizon right upto the top. The grain size values gradually vary from 1.9 to 3.2 phi, towards the top, i.e. roughly medium to very fine grade size.

The lower and the middle parts of the section is flaggy and laminated as well as ripple marked. The upper part is cross bedded usually of the trough type. The top marked by highly ferruginous, hematetic band indicate the shallowing of the basin.

The grain size variation pattern of this Gamdau section is quite similar to that of Bhimasar cliff section of the Lower Kanthkot Formation which also shows 'fining up' pattern.

A comparative study of all the sections reveal an interesting picture of the grain size variations. All the three sections of the Washtawa Formation broadly show 'upward coarsening' pattern. Except for the Bhimasar cliff section in the eastern part of the area, the same is the case for all the sections of the Lower Kanthkot Formation as well. The Bhimasar cliff section however shows a 'fining up' pattern. The Adhoi and the Kakarwa sections of the Upper Kanthkot Formation also broadly represent 'fining up' pattern, which also is the case for the Gamdau hill section of the Gamdau Formation.

Thus on visualising the entire stratigraphic section of the Wagad hills, there appears to be two distinct cycles of 'upward coarsening' pattern of the mean grain size followed upward by a 'fining up' cycle which continued right upto the close of sedimentation.

GRAIN SIZE DISTRIBUTION PATTERN OF INDIVIDUAL SAMPLES

A grain size distribution curve (cumulative weight percent against size in phi - units) when plotted on a simple arithmatic paper, tends to be of a very open, smooth 'S' shape. But the same when plotted on probability scale ordinate paper shows multiple straight line segments and truncation points. Usually a sample exhibits two or three straight line segements and each segement represents a separate log-normal population. Each population is truncated and joined with the next population to form a single distribution. Thus a single grain size distribution curve comprises one or a mixture of more than one log-normal population and it is found that each log-normal population reflects its characteristic transportation process. Sedimentologists have invoked three modes of sediment transport viz. suspension, saltation and surface creep (Visher, 1969, p.1076). Each mechanism of transport is represented by separate log-normal population on the distribution curve. The actual amounts, the degree of slope of different segements, the psotion of points of truncation, degree of mixing and other characteristics reflected by suspension, saltation and surface creep populations are the factors controlled by energy environments, provenance etc. The characteristics of the individual grain size distribution curve, thus provide a good basis for an environmental classification (Visher, 1969, p.1103).

The grain size distribution curves prepared by the author for the Wagad hills area, fully substantiate the views expressed in the previous paragraph. In all, he has included here, representative diagrams for six groups as per their geographic and stratigraphic distribution - two for the Washtawa Formation in the E and W, two for the Lower Kanthkot Formation in the E and W and one each for the Upper Kanthkot Formation and the Gamdau Formation.

The curves for the two samples (Fig.7.8) from the Washtawa Formation (the Washtawa dome proper) show a good similarity to those of the Pennsylvanian sandstone of north eastern Oklahoma and the offshore marine sample from Altamaha River estuary (Visher, 1969, p.1091,1098, fig. 18C and 13A respectively). Both these curves show a probable offshore marine environment of a delta complex. Three curves for the samples from the eastern outcrops of the Washtawa Formation are also shown in Fig. 7.8. The curves 1 and 2 representing the samples from the Dabunda and Mewasa domes are similar to that of the samples from the distributary mouth bar of the Mississippi delta complex (Visher, 1969, p.1088, fig.11B). The third one from the Chitrod dome is similar to that of the Almond Formation, Wyoming (Visher, 1969, p.1098, fig. 18A), which is of probable marine origin.

The coarse and the fine truncation points of the saltation population of these Washtawa curves lie mostly within 1.3 phi to 3.0 phi, with an average of 90% of saltation population. These values are quite close to the average values suggested by Visher (1969, p.1104, table 1) for deposits of plunge or shoal zone. The Washtawa Formation could also be taken to indicate a similar environment.

The curves of the three samples of the Lower Kanthkot Formation from the Adhoi anticline and the Washtawa dome in the W, are shown in Fig. 7.9. The two Adhoi curves appear similar to that of the Wann Formation, Pennsylvanian sandstone, north eastern Oklahoma and the third one of the Washtawa to the Almond Formation, Wyoming (Visher, 1969, p.1098, fig. 18A and C). Visher has said that these curves represent probable marine environments associated with a delta complex. The coarse truncation points of the saltation population of the Adhoi curves around 1.2 to 1.4 phi probably indicate more turbulance. The fine truncation points lie between 2.5 and 3.5 phi.

Figure 7.9 represents curves of the samples of the Lower Kanthkot Formation from the Dabunda dome and the Kidianagar and Bhimasar cliff sections of the eastern parts of the area. The curve No. 1 of the Kidianagar sample matches quite well with that of the tidal inlet zone of the Altamaha river estuary (Visher, 1969, p.1091, fig. 13D). The coarse and the fine truncation points of the Kidianagar curve are about 1.25 and 2.5 phi. These roughly match with similar points for the saltation population for the tidal inlet sands. The curves representing the Kidianagar, the Dabunda and the Bhimasar samples respectively, are comparable with those of the fluvial sands of the Missourian age, Oklahoma and modern channel sands of the Brazos river, Texas (Visher, 1969, p.1095, 1093, fig. 16A and 15A).

Three curves of samples (Fig. 7.10) of the Upper Kanthkot Formation from the Mae dome and the Kakarwa and the Adhoi anticlines show coarse and fine truncation points of their saltation population between 1.25 and 2.0 phi; and 2.75 and 3.5 phi respectively. The Kakarwa sample curve can be compared with that of the Altamaha river estuary belonging to wave zone area of shallow marine bar, and those of the Adhoi and the Mae samples roughly match with Wann Formation of the Pennsylvanian sandstones of north eastern Oklahoma (Visher, 1969, p.1091, fig. 13B and p.1098, fig. 18C). Both these curves thus indicate a marine origin in relation to a delta complex.

Figure 7.11 which represents the curves for the Gamdau Formation samples from the Gamdau syncline, Adhoi dome and the Mae dome show good similarity with those of the modern samples of Altamaha river (main channel), Degonia sandstone, Illinois basin (Mississipian age) and Brazos river Texas (Visher,1969,p.1092,fig.14D, p.1093,1095, fig. 16C and 15B) respectively. All these deposits of Visher represent modern and ancient river systems.

SCATTER DIAGRAMS

Four scatter diagrams(mean size plotted against standard deviation) for the Washtawa, the Lower and the Upper Kanthkot Formations have been prepared (Fig. 7.12). Such scatter diagrams provide valuable information about the environments of deposition (Inman, 1949, cf. Folk et al., 1957, p.17).

The diagram representing the Washtawa Formation shows mean grain size variation from 2.0 to 4.0 phi with sorting varying from 0.4 to 0.8 phi. This plot broadly resembles with similar size and sorting plot calculated by moment measures of the sands from the modern Niger delta representing delta front platform environments (Allen, 1970, p.142, fig.3).

The plots for the Lower Kanthkot Formation for the western and the eastern parts of the area show more variations of size as well as of sorting, varying between 1.0 to 3.0 phi and 0.3 to 1.3 phi respectively.

Their distribution patterns can be broadly compared with the diagrams representing sands from the modern Niger delta belonging to swamp and flood plain environments (Allen, 1970, p.142, fig. 3). The plot for the samples of the Upper Kanthkot Formation shows sorting variations from 0.3 to 0.75 phi while the size variations in between 1.0 and 3.0 phi range. This diagram resembles well with similar diagram for the modern Niger delta sand representing mouth bar environments (Allen, 1970, p.142).

SORTING

Figure 7.13 displays a sorting pattern for the various formations.

The sandstones of the Washtawa Formation show well to moderately well sorted pattern. A few samples also show moderate sorting. The majority of the samples are moderately well sorted.

Most of the samples from the Lower Kanthkot Formation are well sorted (of about 40%), while the moderately well sorted pattern is represented by about 30%. A few samples, especially those from the eastern part of the area show moderate to poor sorting.

The sorting variation among the samples of the Upper Kanthkot Formation show a pattern similar to that of the Washtawa samples. The majority of the samples here (about 50%) show moderately well sorting while a few samples are well sorted as well as moderately sorted.

The samples from the Gamdau Formation show higher range of sorting variations from very well to moderate with a maxima around moderately well sorting. Almost equal number of the samples fall in the other sorting categories.

PART III : STRUCTURE