PART IV : CONCLUSION

CHAPTER 10

ENVIRONMENTS OF DEPOSITION, BASIN ANALYSIS AND SEDIMENTARY MODEL

Krumbein and Sloss (1963, p.501-502) write, "In search for generalising principles, it is useful philosophical device to recognise models - actual or conceptual frameworks to which observations are referred as an aid in identification and basis for prediction. The common factor in all these models is that they provide a framework for organising observational data". This concept of models has been very usefully applied to the sedimentation studies and several recent workers have attempted to visualise sedimentary models to indicate the processes and the results of sedimentation.

Potter and Pettijohn (1963, p. 227) have listed the basin geometry, the lithic fill, the arrangement or distribution of the lithic fill within the basin and the tectonic setting as factors which constitute a sedimentary model.

The depositional model worked out by Pryor (1960, p.1502) includes basin geometry, depositional pattern, paleoslope, depositional strike, transport direction as essential factors.

A sedimentary or depositional model, thus determines the distribution, orientation and the make up of the sedimentary bodies which constitute the basin fill, which in turn is an organised response to a relatively few major dispersal patterns (Potter and Pettijohn, 1963, p.226).

Krumbein and Sloss (1963, p.502) have further developed the idea, and they have suggested models each for the processes of sedimentation and the response to these processes. They write, "with respect of modern environments where the results of energy applied to sediments may be directly observed, it is possible to set up a process model on the one hand and a response model on the other. The process model specifies the kinds of activities that occur in the environment, and it predicts what the response model should be. The response model is thus a structuring of the resultant deposits within the framework of the causative factors that are included in the process model".

Basin analysis, on the other hand, is closely related to paleogeography (Potter and Pettijohn, p.224).

Since a sedimentary facies is a product of depositional environments, the author is of the opinion that comprehensive basin study should include the concepts of basin analysis and sedimentary model coupled with study of environments of deposition, since all these aspects are interrelated.

Selley (1972, p.12) has very rightly stated that geometry, lithology, sedimentary structures, paleocurrents etc are descriptive properties of the sedimentary facies which is a effect of sedimentary environments.

Visher (1965, p.41-42) has mentioned that each fundamental sedimentary process produces both a specific environmental description and a specific vertical profile and therefore there are specific orderly environmental successions with the sedimentary models. He has further stated that there can only be a limited number of overall sedimentary processes and, therefore, corresponding limited number of sedimentary models.

On the basis of the data collected and analysed, the author has presented here a three dimensional picture of the Wagad basin comprising environments of deposition, basin geometry, directional structures, lithic fill, lithic arrangement and tectonic setting. He has finally attempted to construct the process models based on the different response models discussed in the earlier chapters. Several interpretation maps viz. sedimentary framework maps for different formations, environmental section, basin configuration and depositional model etc have been prepared in order to achieve this goal.

THE WASHTAWA FORMATION

Environments of Deposition

Some of the basal and top beds of the Washtawa Formation (e.g. the gastropod band at the base and the fossiliferous mudstone band at the top) are highly fossiliferous in some parts. The exposures of these basal fossiliferous beds in the Washtawa, Mewasa and the Narada domes contain marine fossils like gastropods, brachiopods, and lamellibranchs. Besides, at these localities a few sporadic marine fossil assemblages are also met within the younger sections of this formation. The fossil assemblages noted in these domes from the base upwards show good preservation of their form and ornamentation and thus appear to be in-situ. Obviously, this fauna flourished in a marine environment and according to Heckel (1972, p.234), while cephalopods and brachiopods thrive only in 'normal marine' environments with salinity varying between 30 and 40 ppt, gastropods and pelecypods also shewed maximum growth under similar conditions. It is interesting to note that while the above mentioned fossiliferous basal beds exposed in the Narada dome contain marine fossils, the Dabunda dome section only about 5 miles SE of Narada, is completely devoid of any marine fauna. It thus appears that during the Washtawa deposition, marine environments prevailed only to the W of Dabunda-Mewasa axis. (Fig 10.1)

It is pertinent to mention here that the sand-shale ratio of this formation decreases and the isopach values increase as one traverses from E to W. This fact also indicates prevalence of marine environments in the western parts.

It is evident that the strand line at the start of the Washtawa deposition followed the present Rapar-Mewasa axis, indicating marine environments to the W and deltaic environments to the E. This fact is amply supported by the following observations:-

(1) The Nara shales occurring in the W, grade into Chitrod sandstones in the E.

(2) Gross lithology of the Washtawa Formation in the western part is mainly calcareous sandstones and dark grey shales, while it is ferruginous sandstones and variegated and reddish brown shales in the E. The red colouration of the shales and sandstones in the eastern part is due to oxidising conditions prevalent in a shallow water deposition (Meckel, 1972, p.230; Forgotson Jr., 1954, p.2494).

The Washtawa Formation to the W of the Rapar-Mewasa axis (characterising the strand line) show various evidences of marine deposition while the rocks nearer to the strand line typically indicate estuary environment. The estuary environment prevalent nearer to the shore line is indicated by the bimodal nature of the cross bedding (with NE-SW azimuths, about 180° apart) around Bedarwa-Mewasa area. Klein (1967, p.373, Table 1) has suggested that such cross bedding phenomenon is common in estuary or beach environments.

The rocks occupying the Washtawa and Narada domes indicate nearshore shallow marine environments on the basis of cross bedding data. The rose diagram for this area shows trimodel pattern but the population distribution is mainly within 180°. MacCave (1968, p.84-85, fig. 4) has assigned similar nearshore shallow marine environments to the Catskill Complex, Middle Devonian of New York. As regards the area in the extreme W, around Kanthkot the occurrence of thick shales along with mudstone beds indicates a slight deeper and open sea conditions (Scott, 1970, p.1240, Table 1).

X

Parallel and thin bedding is a dominant sedimentary structure of the Washtawa rocks. This fact coupled with occasional occurrence of ripple marks is indicative of the wave zone or the distal bar area of a delta environments (Visher, 1965, p.45, fig. 2; Coleman and Gagliano, 1965, p.147, Table 1).

The sediments of the Washtawa Formation exposed in the Washtawa, Dabunda, and the Mewasa dome sections in general show upward coarsening pattern of mean grain size. The upper part of the Mewasa section however, shows a 'fining up' pattern. This fact is of considerable significance. While a progressive coarsening of grain size indicates a regressive marine environment, the fining up is indicative of a different environment. The upward coarsening pattern has been regarded as due to regressive marine model by Visher (1965, p.44-45, fig.2). Oomkens (1970, p.204-209, fig. 6) has also assigned the upward coarsening grain size pattern as indicative of marine regressive or offlap sequence. Selley (1972,p.77,108) has stated that ancient delta sections grading from marine sequence at the base to fluvial at the top indicate a grain size variation sequence that shows upward coarsening followed by a fining up in the top part. It appears that marine regressive deposition in all parts of the Washtawa Formation continued right upto the top except in the area in the E where the marine regression was followed by delta channel environments.

The grain size distribution pattern of the individual samples reveal that the curves from the Washtawa dome in the western part are similar to the curves of samples from Pennsylvanian sandstones and Altamaha river estuary (Visher, 1969, p.1091, 1098, fig. 13A, 18-C), while those representing the Dabunda and the Mewasa domes are similar to distributary mouth has area of Mississippi delta complex (Visher, 1969, p.1088, fig. 11B).

Taking into considerations all the above facts together, the author has concluded that the Washtawa deposition took place during a marine regressive cycle mainly represented by shallow marine environments in the SW and delta mouth bar environments in the NE with the Rapar-Sai-Mewasa axis area forming roughly a lobate shore line in relation to the delta (Fig.10.1).

Basin Geometry

The author has been able to decipher the geometry of the Wagad basin during the Washtawa deposition with the help of paleocurrent data, formation thicknesses, and gross lithology. Based on sediment dispersal pattern and the stratigraphic thicknesses, he has reconstructed the diagramatic sketch model of the Wagad basin (Fig.10.5).

It is seen that the basin was an arcuate or semi oval in shape at the start of the Washtawa deposition. The basin opened up and deepened to WSW and eventually merged with the main Kutch basin, in that direction.

The cross section of the basin is of asymmetrical type with steeper northerly slopes of the southern parts. A small kink in the basin geometry is noticed on the basis of cross bedding in the Chitrod area. The regional depositional strike is due NW-SE direction, and the paleoslope was towards SW to WSW directions.

Directional Structures

The Washtawa sandstones show a fairly good development of medium to small scale cross bedding and ripple marks. The cross bedding directions show a subparallelism to the basin axis. The ripple marks also show orientation of currents more or less in the same directions. Thus directions of dispersal of sediments inferred from the paleocurrent data varied from the W to S.

Lithic Fill

The eastern half of the area comprises nearly 75% sandstones and 25% shales, while the western part contains about 60% to 70% shales and siltstones and the rest sandstones. The sandstones occurring in the eastern parts around Dabunda-Chitrod are comparatively more ferruginous and red coloured. Similarly, the shales occurring in the E are principally brown to khaki to variegated in colour while those occurring in the W are grey to dark grey.

Sandstones are mainly of quartz arenite type with certain percentage of variations towards quartz wacke (Krumbein and Sloss, 1963, p. 166-174). They show usually fine to medium grained particle size, good sorting and subrounded grains with minor amount of matrix.

Lithic Arrangement

The general transport direction is seen to be longitudinal to the basin towards WSW and SW along the paleoslope, and there is a gradual increase in the formation thickness in these directions (Figs. 5.12, 5.13, 5.14 and 5.1). The Southern Range stratigraphic section (Fig. 5.13) shows two main sandstone lithosomes and two shale lithosomes in the E. However, the shale thickness is seen to increase down the paleoslope direction, and partly replaces the sandstone thickness resulting in three shale lithosomes. Similar phenomenon is observed in the northern area section (Fig. 5.12), though shales and sandstones are represented by one lithosome each.

The striking feature is the sharp increase in the formation thickness along the transverse section (Fig. 5.14). The increase in the discrete number of shale and sandstone beds is noted on traversing from N to S. Shale lithosomes appear to pinch out towards E, while the sandstone lithosomes do so towards W. Thus the facies distribution shows a close relationship to the paleoslope and current directions.

The Washtawa Formation shows a wedge shaped clastic body with tapering end towards NE.

<u>Tectonic Setting</u>

The occurrence of pure quartz arenite along with quartz wacke, silty shales and siltstones indicates a stable shelf to mildly unstable shelf tectonic conditions of the depositional area (Dapples, Krumbein and Sloss, 1948, p.1943, Table I). Such a tectonic framework is supported by the general occurrence of cross bedding and ripple marks. Besides, the faunal assemblage like gastropods, brachiopods, lamellibranchs etc. also indicates unstable to stable shelf tectonic conditions of transitional to epineritic environments (Krumbein, Sloss and Dapples, 1949, p.1876).

However, it has been found that within the basin the conditions somewhat varied from place to place. The stratigraphic section of the Northern Range (Fig.5.12) for example shows a very gradual change in the formational thickness and lithology, and this indicates a rather stable tectonic setting for northern and north eastern parts of the basin. Further, exposures of comparatively thin stratigraphic columns within the various Northern Range structures is a result of mild uplift.

In contrast to the above, the south central and south western areas show a sharp increase in the thickness which is depicted by isopach map and stratigraphic cross section of the Southern Range, as well as transverse cross section (Figs. 5.1, 5.13 and 5.14). This fact coupled with occurrence of quartz wacke, silty shales, and widespread development of cross bedding and ripple marks, strongly reflects unstable conditions (Krumbein, Sloss and Dapples, 1949, p.1876).

As the Southern Range structures like the Kanthkot dome, Nara dome, Washtawa dome, and the Mewasa dome expose much older horizons than those exposed in the northern range, it is, obvious that the southern part of the basin has underwent a much higher degree of uplift than the northern part.

Summing up, the northern stable part of the basin has undergone a mild subsidence and a mild uplift, while the comparatively unstable southern part is characterised by a higher degree of subsidence followed by greater uplift.

THE LOWER KANTHKOT FORMATION

Environments of Deposition

The Lower Kanthkot Formation contains a rich marine faunal assemblages in the western half, the eastern half being devoid of any fossils. The easternmost localities upto which the formation is fossiliferous are the Tramau nala, Narada dome, and the western flanks of Chitrod dome. The characteristic fossil (as reported by Cox, 1935, cf. Pascoe, 1959, p.1148) from the Tramau nala is Mytilus (Falumytilus ?) Tramauensis Cox. Author has noted various species of lamellibranchs and brachiopods from the above three localities. The occurrence of marine fauna is uniformly common throughout the western parts of the area. Heckel (1972, p.234-237, Table 3,4) has stated that cephalopods and brachiopods essentially occur in the subtidal zone of normal marine environments with salinity varying from 30 to 40 ppt. So the above fossils indicate a marine environment. The shore line existed along Narada-Chitrod axis during the Lower Kanthkot deposition with sea to its W (Fig. 10.2).

The Lower Kanthkot Formation shows a general increase in thickness from E to W and this increase is partly a function of depth of depositional environment. Gross sand-shale ratio shows high values in the southern and eastern areas while the ratio decreases towards W. Pryor (1960, p.1496) has mentioned that the area of high clastic ratio coincides with that having low percentage of marine beds and generally occurs in the area of thinner deposition. Thus occurrence of thicker shale bodies in the W is a clear indication of marine environment. The shale isolith map also shows a gradual increase of shale thickness towards W due to progressively increasing marine influence. Besides, shale colour varies from brownish red, red, khaki, to variegated in the E to grey to dark grey in the W. Red and reddish brown shales are characteristic of non-marine environment while grey to dark grey shales indicate open circulation shallow marine environments (Forgotson Jr., 1954, p. 2484).

The sandstone isolith also furnishes valuable information. In the eastern part it depicts an elongate-dendroid or belt type of sand body of Potter (1962, p.1893, fig. 3,4,5), which opens out in the W and SW. This elongate sand body comprising the rocks around Pragpur, Bhutakia, and Bhimasar, having NE-SW trend indicates deposition under delta channel environment. Potter (1962, p.1894) has postulated similar origin for such sand bodies of Pennsylvanian age of Illinois basin.

The orientation of delta channel (Fig. 10.2) as revealed from the geometry of sand body in the eastern Wagad is roughly perpendicular to the depositional strike which is NW-SE.

It is significant to note that the deposits to the N and S of this elongate sand body (around Sonalwa and Kidianagar) show low sand-shale ratios. This fact illustrates that flood plains existed on the two flanks of the delta channel. Selley (1972, p.42 and 77) supports the idea of deposition of finer silts and clays on the flood basins of the inter distributary area.

The rose diagram for the cross bedding data of the north eastern part of the formation around Rapar, Bhutakia, Bhimasar and Hamirpur shows a strong unimodal character such dispersal pattern is a result of fluvial or foreset and bottomset parts of delta environment (Klein, 1967, p.373, table 1). The rose diagram for the south eastern part resembles to a similar diagram prepared by McCave (1968, p.84-85, fig. 4) for the Catskill Complex in the middle Devonian of New York indicating marginal channel complex deposits. Similar diagram for the south eastern part is somewhat trimodal, though one mode is quite strong and others rather weak. Following the McCave's (1968, p.84-86, fig. 4) interpretation for Catskill Complex, the author also thinks that the large modes showing WNW trend might indicate the principal channel trend while the small modes indicate the small tributary channels.

Thus, the cross bedding data for the entire eastern part clearly indicates a delta channel environment. The prevalence of fluvial or delta channel environment for this part is further supported by occurrence of asymmetrical ripple marks. (Allen and

Friend, 1968, p. 42; Coleman and Gagliano, 1965, p.147, table 1).

Besides, in the eastern half of the area, several sedimentary structures like scour and fill, erosional truncation, trough cross bedding and load casts are encountered. These structures are typically developed in delta channel or tidal channel environments (Coleman and Gagliano, 1965, p. 147, table 1; Masters, 1967, p.2040). Allen and Friend (1968, p.36) have also noted several scour and fill structures between finer and coarser grades of sandstones within Catskill facies of Appalachian region representing alluvial deposits. Visher (1972, p.94-95, table II) has classified the scour surfaces and the separation of channel and flood plain deposits as responses of channeling and seasonal discharge peak processes.

The cross bedding rose diagrams for the western half of the area show bimodal and trimodal type of dispersal patterns (Fig. 6.6). These types indicate estuary, beach or shallow marine environments (Klein, 1967, p.373, table 1; Selley, 1968, cf. Barrett, 1970, p.410, table 8). This also resembles with the dispersal pattern of Catskill complex, Middle Devonian of New York, representing shallow marine environments (McCave, p.84-86, fig.4). The frequent occurrence of symmetrical ripple marks around Adhoi and Kanthkot in the western parts, also supports marine environment (Coleman and Gagliano, 1965, p.373, table 1).

The lower parts of the Chitrod and Bhimasar sections in the eastern parts of the formation show upward coarsening patterns of mean grain size of sediments, and the upper portions show a 'fining up'. This sequence of 'coarsening up' followed by 'fining up' is indicative of a deltaic model. The initial coarsening up suggests a progressive marine regression, while the 'fining up' at the top characterises a delta environments (Selley, 1972, p.77). Selley (1972,p.77) has stated "Vertical section of a delta reveals a fine grained marine facies, which pass up transitionally into coarser fresh water sediments and in searching for ancient deltas, therefore, we must look for thick clastic sequences showing repeated cycles of upward coarsening grain size".

The author has, therefore, assigned the eastern part of the Lower Kanthkot Formation as a result of mainly deltaic deposition (marine regression followed by delta channel). Visher (1965, p. 44-54, fig. 2 and 11) has also stated that 'coarsening up' pattern of grain size characterises marine regression model while 'coarsening up' followed by 'fining up' pattern characterises a deltaic model. Similarly, Oomkens (1970, p. 204-206) has also described 'coarsening up' pattern as a result of fluvio-marine regressive environments.

The Washtawa, Adhoi and the Kanthkot sections of the western half of the area show an upward coarsening pattern of the mean grain size, and this fact typically indicate a marine regression cycle of environment for this area. Further evidence to support this conclusion is drawn from the frequency curves of the individual samples. The curves from the Adhoi and the Washtawa area resemble to those from the Wann and the Almond Formation of marine origin in relation to a delta complex (Visher 1969, p.1098, fig. 18). In contrast to this, the curves of the samples representing eastern part viz. the

Dabunda, Kidianagar and the Bhimasar sections are comparable with those from fluvial sands of Missourian age, Okla, tidal inlet zone of Altamaha river estuary, and modern channel sand of Brazos river Texas (Visher, 1969, p.1091-95, fig. 13D, 15A, and 16A).

Considering all the above facts. the author has, with sufficient confidence, assigned shallow marine environments of deposition for the western half and the delta complex environments for the eastern half of the area during the Lower Kanthkot deposition (Fig. 10.2). The strand line probably existed along the Rapar-Chitrod axis. The delta complex is further differentiated into channels and flood plain deposits occupying the interdistributary areas of the eastern part. The region close to the shore line to its immediate E probably represents the distributary mouth bar sub-environment. The western half of the area experienced pre-delta or shallow marine environments associated with a delta.

Figure 10.4 represents a generalized environmental cross section during the Lower and Upper Kanthkot deposition and lithofacies relationships. This cross section matches well with the conceptual diagram of the deltaic sedimentation (prograding delta indicative of greater rate of deposition than sedimentation) as proposed by Curtis (1970, p.293-295, fig. 1).

During the entire course of Lower Kanthkot deposition, the western half of the area experienced a continuous marine regression cycle, while the eastern half experienced initially a marine regression followed by a deltaic model.

Basin Geometry

During the Lower Kanthkot deposition the Wagad basin broadly retained its architecture that existed during Washtawa time. The general paleoslope continued to be towards WSW. The maximum thickness of this formation is thus encountered in the south western parts. The basin also retained its asymmetrical cross section with deeper southern and south western parts. Towards the close of Lower Kanthkot deposition the north eastern part shallowed up and probably the extreme north eastern portion became positive, i.e. area of non-deposition.

Directional Structures

As such, cross bedding and ripple marks are well developed all over the Lower Kanthkot exposures. The cross bedding directions in most of the area closely follow the basin axis. The ripple mark strikes show broad parallelism to the basin margins. The vector structures indicate the general direction of sediment transport from ENE to WSW. This is further supported by increase in isopach values in that direction. Thus a longitudinal transportation prevailed during the Lower Kanthkot Formation.

<u>Lithic Fill</u>

The eastern half of the area comprising southern and northern elongate patches represents non-marine rocks and shows a high percentage of sandstones varying between 60 to over 90, shales occupying the rest of the volume. Highest sandstone percentage is encountered around Chitrod in the S and Bhimasar-Hamirpur in the NE. The sandstone percentage gradually decrease to the W, and the westernmost area contains about 50% sandstones and 50% shale.

The sandstones are mainly of quartz arenite to quartz wacke type and of fine to medium grade size with occasional variations towards fine to coarse grained in the eastern parts.

Lithic Arrangement

The lithic arrangement is characterised by the longitudinal in filling along the paleoslope in the eastern deltaic area as well as in the western marine area. The total section expands to the S and W such that two thin shale lithesomes occurring in the E increasingly replace the intervening sandstone lithesomes giving rise to a thick shale body in the W. Besides, one more shale lithosome appears in the W. Thus the gradual increase in the finer clastics in the W is a characteristic feature.

The transverse cross section (Fig. 5.14) shows a sharp increase in the thickness of the Lower Kanthket Formation to the S. It is significant that this filling was brought about least by the transverse dispersal pattern and was mostly a result of longitudinal filling only. The source area was obviously towards NE and ENE.

The Lower Kanthket Formation also shows a wedge shaped body with pronounced thickening in the south western parts.

Tectonic Setting

The eastern part of the area predominantly consists of pure quartz sandstones or quartz arenites along with laminated shales and claystone pockets and lenses. Generally clays are light grey, and shales show variegated colours. The sandstones often show ferruginous brick red colour. These facts indicate a stable shelf depositional conditions for the majority of the eastern half of area during the Lower Kanthkot time (Dapples, Krumbein and Sloss, 1948, p.1943). This is further supported by occurrence of thin stratigraphic thickness indicating a mild rate of subsidence in this part of the area. The sporadic occurrence of carbonaceous shales along with dominantly current bedded sandstone (e.g. in a nala N of Kidianagar) supports the transitional environments under stable shelf conditions (Krumbein, Sloss and Dapples, 1949, p.1876).

The south central and south western parts of the area around Chitrod-Washtawa and Nara-Adhoi are marked by a mildly unstable tectonic setting. This is evidenced by frequent occurrence of quartz wacke type micaceous sandstones, flaggy siltstones and silty shales (Dapples, Krumbein and Sloss, 1948, p.1943). The occurrence of cross bedded and rippled quartz arenite to quartz wackes, and their calcareous nature along with silty shales and siltstones indicate epineritic environment under unstable shelf conditions (Krumbein, Sloss and Dapples, 1949, p.1876). Further the high sand-shale ratio around the Chitrod-Washtawa area along with greater formational thickness characterises higher rate of subsidence in this area. Potter (1962, p.1903) has assigned high sand-shale ratio as a result of rapid subsidence. The transverse cross section (Fig. 5.14) clearly reveals this fact. The lower datum plane shows a sharp downwarp indicating a contemporaneous subsidence with reference to the northern part during the Lower Kanthkot deposition.

The structures, occurring in the southern parts uniformly expose older rocks as compared to their counterparts in the north. This phenomenon is a result of higher degree of uplift of the southern and south western parts.

This tectonic setting of the Lower Kanthkot basin corresponds fairly well with that of the Washtawa time. It may however be pointed out that though subsidence was contemperaneous with the deposition, uplift phase was probably one single event during the post Upper Kanthkot time.

THE UPPER KANTHKOT FORMATION

Environments of Deposition

In general, this formation also shows that the area west of Narada-Washtawa axis experienced marine deposition, while deltaic environments prevailed in the area east of it (Fig. 10.3).

The author uniformly encountered marine fossils in the western parts of this formation. The fossil-bearing occurrence do not extend eastward beyond Tramau nala and the southern flanks of the Washtawa dome. This fact coupled with the decrease in the sand-shale ratio values in the W indicates marine depositional environment in the western part.

The sandstone isolith map (Fig. 5.7) of the Upper Kanthkot Formation shows strong elongate pattern of sand bodies E of Narada-Chitrod axis. These sand bodies are of dendroid and pod shaped, and typically represent delta channel or fluvial environments of deposition. The sandstone isolith map broadly resembles with the similar map for Schular Formation of Cotton Valley Group of eastern Lousiana and western Mississippi of Forgotson Jr. (1954, p.248 to 293) who has suggested such isolith pattern to represent a typical delta deposit. Potter (1962, p.1894) has suggested similar environment for elongate sand bodies of Illinois basin.

The cross bedding data from the western half of the area, shows bimodal rose diagram. Such bimodal current pattern typically develops under estuary, beach or shallow marine environments (Klein, 1965, p.373, Table I; Selley, 1968 cf. Barrett, 1970, p.410; McCave, 1968, p.84-85).

The prevalance of shallow marine or marginal environment in the western part is also clearly indicated by common occurrence of symmetrical ripple marks. Together with occasional development of graded bedding within Adhoi and Kakarwa anticline (Heckel, 1970, p.243, fig. 6; Coleman and Gagliano, 1965, p.147, Table I).

As stated before in Chapter 7, the frequency curves of the individual samples from the Mae, Kakarwa and Adhoi domes of the Upper Kanthkot Formation in W, indicate a marine origin. The curve of the sample from the Kakarwa anticline in the extreme west, resembles to that of sediments from Altamaha river estuary belonging to a wave zone area.

The vertical sections of the Kakarwa and Adhoi anticlines show a good fining up pattern of the mean grain size, indicative of marine transgressive model (Visher, 1965, p.54-56; Selley, 1972, p.16, fig. 1.1).

Thus summarising the above interpretations, the author has derived the following environmental analysis for the Upper Kanthkot deposition. The eastern-most part(east of Hamirpur and Bhimasar) was the area of non deposition at the start of the Upper Kanthkot deposition. The area between this, and Narada-Chitrod in the central part, probably experienced a deltaic environments. As the outcrop conditions of this formation in these parts are too scanty, determination of further characteristics of this delta model (e.g. prograding seaward or landward etc. in a course of time) is not possible.

On the other hand, the western half of the area which forms the best exposed portion of this formation was deposited under transgressive marine environments (Fig. 10.3).

Basin Geometry

During the Upper Kanthkot deposition the paleoslope continued to be towards SW and WSW. Thus the basin retained its pre-existing shape, the axis being WSW-ENE with the depositional strike perpendicular to it. The greater thicknesses in the southern parts indicate the asymmetrical nature of the basin with deeper areas of deposition in the S and W.

The general arcuate pattern of the basin is apparent from the orientation of the inferred shore line (Fig. 10.3).

Directional Structures

The Upper Kanthkot rocks are characterised by medium to small scale cross bedding of both tabular and trough types, along with symmetrical ripple marks. The thickness of the cross bedded sets generally decreases along the direction of the current. At a few localities sole marks showing conformity with the cross bedding directions are also encountered.

The cross bedding data corresponds with the basinal paleoslope and the strikes of the symmetrical ripple marks broadly tally with the depositional strike.

Lithic Fill

The depth of the depositional basin is reflected in the lithic fill also. The eastern and the south central parts of the area show high sandstone percentage upto 80% or even upto 90% around Washtawa proper. The sandstones are principally of quartz arenite to quartz wacke type, and show light grey to brown grey and buff to orange colours. Calcareous sandstones are frequently met with in the western parts.

The shales which are about 20% in the south central and eastern areas progressively show increase in volume towards W. Where these are typically marine of light grey to grey in colour, silty and fossiliferous.

Lithic Arrangement

The lithic arrangement shows good conformity with the directional structures, and is similar to those of the older stratigraphic intervals.

The direction of sediment transport towards WSW and SW is longitudinal to the basin. The formation thickness also increases in this direction. The longitudinal stratigraphic cross sections (Fig. 5.13) depicting increase in the thickness show a concomitant increase in the shale lithosomes. The transverse cross section (Fig. 5.14) also displays an increase in the formational thickness towards S. Of course this increase is not as pronounced as that in the older formations.

The sediments continued to come from NE and ENE.

Tectonic Setting

The north western part of the Upper Kanthkot Formation is characterised by the occurrence of cross bedded, quartzose sandstones along with pure shales and siltstones. The sandstones show good parallel bedding and occasionally grade into highly calcareous varieties. These facts indicate a stable shelf tectonic framework probably with epineritic environments (Dapples, Krumbein and Sloss, 1948,p.1943, and Krumbein, Sloss and Dapples, 1949, p.1876).

The south western area shows thicker sedimentation. This fact coupled with the common occurrence of siltstones and silty shales, along with quartz wacke type sandstone, indicates unstable shelf tectonic setting (Dapples, Krumbein and Sloss, 1948, p. 1943; Krumbein, Sloss and Dapples, 1949, p.1876). The high sand-shale ratio in the Kakarwa area in the W and around Washtawa in the south central part is indicative of a greater rate of subsidence.

Thus, the area experienced stable shelf conditions in the northern parts and mildly unstable to stable shelf conditions in the southern parts which is in conformity with the tectonic conditions that prevailed during the deposition of older formations. Similarly the southern area underwent higher degree of uplift than its counterpart in the N. The outcrops in the eastern half of the area are too meagre to derive any conclusion.

THE GAMBAU FORMATION

Environments of Deposition

These rocks are completely devoid of any fossil assemblage. It is significant to note that the Upper Kanthkot rocks which just underlie these Gamdau rocks contain rich marine fauna.

The geometry of the Gamdau formation which is essentially elongate and is restricted in between the two hill ranges in the south western parts shows a dounwarped basal section. These facts indicate a probably fluvial or valley fill environment of deposition (Visher, 1965, p.49; Potter, 1962, p.1894).

The cross bedding pattern shows a unidirectional dispersal system. Further the cross bedding azimuths are seen always oriented towards the synclinal axis which probably formed the deepest part. Such cross bedding pattern develops as a result of fluvial deposition (Klein, 1967; p.373, table I; Selley, 1968, cf. Barrett, 1970, p.410, table 8). The western Chebari plain shows a somewhat fanning pattern of the cross bedding data. The frequent occurrence of asymmetrical ripple marks along with ripple drift structures also suggests fluvial deposition.

The Gamdau hill section shows fining up pattern of mean grain size (Fig. 7.7). Such grain size variation is a result of currents which waxed quickly and waned slowly in velocity through time (Selley, 1972, p.41-42). Besides Allen (1965, cf. Selley, 1972, p.41-42) has stated that the fining upward cycle occurs in many ancient alluvial deposits. Visher (1965, p.49) has supported similar upward fining patterns for fluvial or valley fill model.

The cumulative weight percentage distribution curves of the individual samples of the Gamdau Formation further support their fluvial origin. The curves for samples from the Gamdau hill, Adhoi dome and the Mae dome resemble those of Atlamaha river main channel, fluvial Degonia sandstone, Illinois and Brazos river Texas, respectively.

Basin Geometry

It is apparent from the earlier discussion that the Gamdau deposition took place only in the south western and western parts of Wagad. The central and the eastern parts had already become areas of non-deposition. The zero isopach line of this formation probably marks the edge of the basin during Gamdau time.

The Gamdau valley and the western Chobari plain where the Gamdau sedimentation took place indicate westerly and west north westerly paleoslope.

Thus, though slowly the basin got filled up in the course of time, the paleoslope continued to be more or less in the same directions from the start to the end of sedimentation.

Directional Structures

Medium to small scale cross bedding, asymmetrical ripple marks both small and big size, and ripple drift are the most prevalent vector structures of this formation.

The cross bedding directions match well with the paleoslope and show preferred orientation towards the Gamdau syncline which in turn coincides with the basin axis during the deposition of Gamdau Formation. The ripple marks broadly tally with the depositional strike.

Lithic Fill

The Gamdau Formation contains mainly sandstones with minor amounts of shales and siltstones. The sandstones constitute over 90% of the lithic fill.

The sandstones are mainly of quartz arenite to quartz wacke type occasionally micaceous. They are mainly light grey to grey and cream coloured with occasional dark ferruginous hematitic bands. The grain size often varies from very fine to coarse.

Lithic Arrangement

The total section of this formation expands westwards along the direction of the paleoslope. The thickness increases from zero to over 600' in the west in areas around Mae and Kharei. This indicates a longitudinal filling sub-parallel to the basin axis. This westerly increase in the formational thickness corresponds very well with the regional distribution pattern of the entire Wagad basin comprising all formations.

Tectonic Setting

The Gamdau synclinal area commonly contains quartz wacke and micaceous sandstones along with flaggy to bedded siltstone beds. The sandstones show bedded to massive nature. These observations probably indicate a mildly unstable shelf tectonic setting (Dapples, Krumbein and Sloss, 1948, p.1943; Krumbein, Sloss and Dapples, 1949, p.1876). Further, somewhat quick increase in the formation thickness in the south western part indicates rapid subsidence of this south western area. The northern part of the area (west of Bharodia) shows poor exposures of the Gamdau Formation. However, on the basis of a few outcrops studied, it appears that somewhat stable shelf condition prevailed in this area. The lithologic association here is bedded sandstone with laminated shales at places. Sandstones are principally of quartz arenite type.

ENVIRONMENTAL SEQUENCE AND TECTONIC SIGNIFICANCE

From the above account, it is obvious that the Wagad area could be divided into two along Rapar-Chitrod axis - each characterised by distinct environments in a single basin.

The eastern part (E of Rapar-Chitrod axis), underwent two distinct successive cycles of marine regression, each followed upward by delta channel environments on the top. These two marine regression cum delta channel cycles roughly correspond with the Washtawa and the Lower Kanthkot deposition. The delta channel environment of the younger cycle probably continued at least during the deposition of the lower part of the Upper Kanthkot Formation as well. It appears that this eastern half of the area became positive towards the end of Upper Kanthkot time.

The western half of the area (west of Rapar-Chitrod axis) on the other hand experienced two cycles of marine regression, without any deltaic sequence. Except for the Nara shale member, the two lower and upper marine regression cycles - roughly correspond with the deposition of the Washtawa and the Lower

Kanthkot sediments. The Nara shale deposition probably belongs to the upper phase of marine regression cycle. The Upper Kanthkot deposition probably represents marine transgressive phase, restricted to the western parts only. The Gamdau rocks occurring in the extreme south western and western parts were deposited under fluvial conditions, directly over the marine transgression rocks.

The author could not establish any regional correlation of the environments for the Upper Kanthkot and the Gamdau Formations for want of sufficient geologic record in the field. However, a possible explanation seems to be that while the eastern half of the area typically represents rocks characterising upper part of a delta sequence and shows a gradual tendency of becoming positive, the western half of the area experienced a contemporaneous subsidence resulting in a local marine transgression. Further it appears that during Post-Upper Kanthkot time the entire area became positive and there was some time lapse, resulting into stripping of the strata due to erosion. Later on the Gamdau sedimentation took place.

The isopach and the facies strikes of the Washtawa, Lower and the Upper Kanthkot Formations vary mostly between the NW-SE to NE-SW directions. These strikes are quite discordant with the regional structural trend of the area which is principally E-W. Thus, it is clear that the structural disturbances took place at a later date, after the initial subsidence which is reflected in the thickness and facies distribution (Krubein and Sloss, 1963, p.490). Thus the main tectonic episode or the uplift of Wagad area took place during post-Upper Kanthkot time.

The isopach contours of the Gamdau Formation show very good parallelism with the structural pattern of the area. This fact denotes that no major structural disturbances took place during post Gamdau deposition.

Thus the main tectonic events of the Wagad basin took place during post-Upper Kanthkot and pre-Gamdau times.