CHAPTER 5

STRATIGRAPHIC ANALYSIS

In the preceding chapter, an account of the stratigraphy as exposed in the field has been given. Now in this chapter, an attempt has been made to analyse the various data, synthesise the conclusions and represent them in the form a number of stratigraphic maps.

The scope of this chapter is limited to the description of the stratigraphic maps only and the sedimentological and different vector properties of the strata have been discussed in subsequent chapters.

Krumbein and Sloss (1963, p.512) have very rightly pointed out that stratigraphic mapping is a more refined procedure of integration of data and some of the most significant attributes of sedimentary rocks are revealed only through such mapping.

Several stratigraphic maps alongwith three stratigraphic sections (partly restored) have been constructed. The main purpose of these maps is to present the thickness and lithologic variations, both lateral and vertical, within selected stratigraphic intervals, and also to reveal the geometry of the sand bodies. The maps present a three dimentional picture of the different rock units referable to 'response models' of Krumbein and Sloss (1963, p.502-503). A response model is a structuring of the resultant deposits within the framework of the causative factors that are included in the 'process model'.

SELECTION OF STRATIGRAPHIC UNITS

In the preparation of stratigraphic maps the author has taken help of four characteristic horizons represented by (1) The gastropod band towards the base of the Washtawa Formation, (2) the ferruginous conglomeratic mudstone band that tops the Washtawa

Formation, (3) the Lower Astarte band that forms the top of the Lower Kanthkot Formation and (4) the Upper Astarte band that marks the top of the Upper Kanthkot Formation. The tops of these bands characterise synchronous surfaces, i.e. surfaces on which every point has the same geological age (Krumbein and Sloss (1963, p.364-65). As these bands are easily recorded all over the study area, the author has utilised them for classifying stratigraphic successions. Krumbein and Sloss (1963, p.433) have stated that lithologic key beds are most commonly used because of their relative ease of identification in outcrop section.

Separate stratigraphic maps have been constructed for (1) the Washtawa Formation, (2) the Lower Kanthkot Formation, (3) the Upper Kanthkot Formation and (4) the Gamdau Formation. Since the top of the Gamdau Formation is nowhere exposed the isopach map for this formation show only the present day distribution of the rock types. As the object of the author was to decipher and present important attributes of these sedimentary strata clearly, he has prepared only individual stratigraphic maps with either single or double components instead of composite maps. Forgotson Jr. (1960, p.85) has aptly suggested that "It is better to prepare several maps each designed for a specific purpose, than to combine so much information on a single map that the pattern clouds the interpretation".

PREPARATION OF STRATIGRAPHIC MAPS

Forgotson Jr. (1960, p.84, 85) has said 'facies maps are designed to show the areal variation of selected components within a defined stratigraphic interval. A series of isopach and facies maps can present a three dimensional picture of a rock unit'. Further, he has classified such maps into five types depending on the nature of information they display.

On the basis of the available data and the variations within the different mappable attributes, the author has constructed following stratigraphic maps:

(1) Isopach Maps: These maps have been prepared for all the formations. The observed thickness is plotted at each control point for all formations and lines of equal thickness are drawn through the points. The maps for the Washtawa and the Gamdau Formations

represent the present day observed thickness of the unit. The Kanthkot Formation, however, shows two sets of contours one showing factual picture of the present day distribution of the stratigraphic unit and other representing the inferred thicknesses just after the deposition.

(2) Sand-Shale Ratio Maps: To display the inter-relations between two lithologic components - sandstones and shales, with single set of contours, thickness ratio maps have been prepared. The thicknesses of sandstones and shales are calculated at each control section and the ratio is computed as:

$$\text{Sand-Shale Ratio} = \frac{\text{Sandstone + Conglomerate}}{\text{Shale + Silt}}$$

The ratio is plotted at every control point and lines of equal ratio in geometric progression have been drawn. The ratio maps are prepared for the Washtawa, the Lower and the Upper Kanthkot Formations.

(3) Sandstone Isolith Maps: The total thickness of sandstone in the various stratigraphic units, were recorded at each control point and lines of equal sandstone thickness were drawn, to form a 'net thickness" or 'isolith' map of sandstone. These maps have been

constructed for the Lower and Upper Kanthkot Formations only.

(4) Sandstone Percentage Maps: The percentage of sandstone at a control point in a unit is computed by dividing sand thickness by total thickness and lines of equal percentage are drawn. Such maps were prepared for the Lower and Upper Kanthkot Formations.

(5) Shale Isolith and Colour Map: Isolith map displaying net shale thickness of a unit, has been prepared only for the Kanthkot Formation. On this the gross shale colour data has been superimposed.

THE WASHTAWA FORMATION

Isopach Map

The isopach map of the Washtawa Formation (Fig.5.1) shows gross thickness variations. The contours have been drawn at 100' interval.

The Washtawa Formation is well exposed in the central and southern parts of the area and as such affords a good control for construction of isopach map. Contours in the north western and north eastern parts have been extrapolated, keeping in view the regional trend of thickness change of this formation.

The zero isopach contour represents the exposed base of this formation. The map shows six closures of contours one each in the central and northern parts and four in the southern part. These closures or 'highs' are results of individual uplifts along the structures occurring in the area. Within these closures the difference between the lowest and the highest values of conteurs marks the degree of upliftment. The low values of contours in these areas is a phenomenon of erosion, and it has no depositional significance.

The isopach contours show a regional WNW-ESE trend. In the north western parts, their strike becomes NW-SE. The least thickness is indicated by the 300' contour, in the north eastern part around Bhutakia. The thickness of this formation gradually increases towards S and SW. The exposed thickness around Washtawa is almost 700'. As such the southern areas around Nara-Washtawa-Mewasa axis, as well as around Chitrod represent a greater thickness upto 700'-800'. The increase in thickness southward is rather rapid. It is obvious that this abrupt increase in thickness is a result of marked subsidence and correspondingly larger accumulation of sediments.

Sand-Shale Ratio Map

Though the upper part of the Washtawa Formation is well exposed all throughout the area, its lower part is encountered only in three localities viz., the Washtawa dome, Mewasa dome, and the Narada dome. The sand-shale ratio in these three areas represent the entire Washtawa column, whereas in the other areas, the ratio has been calculated on the basis of exposed columns only. The sand-shale contours drawn are in the geometric progression that brings out exponential rate of change.

The contours broadly show a NNE-SSW to NE-SW strike (Fig. 5.2). Higher sand-shale ratio is seen in the south central and the north eastern parts. The ratio is greater than 8 around Chitrod while in Bhimasar-Bhutakia-Hamirpur area in the E it is between 8 and 4. The predominence of sandstones in the eastern and southern parts is clearly demonstrated by the map. From E to W again there is a gradual decrease in the ratio. In Dabunda-Washtawa area it varies between 4 to 2, and 2 to 1. Along the Kanthkot-Narada axis and to its W, the value is still lower, less than 1/2. Thus there is more or less a gradual increase in the finer clastics from E to W.

THE KANTHKOT FORMATION

Isopach Map

The isopach map of the Kanthkot Formation contains two types of contours (Fig. 5.3), one representing the actual present day thicknesses as exposed in the field while the other representing the thicknesses prior to erosion effect. The former set is shown as thin contours while the latter one with thicker lines. The contour interval is 100'.

The contours representing the present day factual thickness data indicate that the base of the Kanthkot Formation is exposed in the central and south central parts of the area, and is indicated by the zero isopach line. There is a gradual increase in the thickness to the N and S of this zero isopach line. The contours show a regional E-W strike, which becomes roughly WNW-ESE in the south western part and NE-SW in the north western part. The southern part is also marked by a few closures of the contours. It is obvious that these contours show strong influence of the structural pattern and the post depositional erosion of the area.

The minimum isopach value of 200' is in the north eastern area, around Bhimasar-Hamirpur. The value gradually increases towards SW and the maximum thickness of over 800' is in the SW near Wamka-Mae. The low values around the closures in the southern area indicate removal of the sediments due to erosion.

The other set of contours shown as thick lines also roughly shows an arcuate pattern with strike varying from NW-SE to NNE-SSW. The contours point to a gradual increase in the thickness of this formation from NE to SW. The values indicate a thickness increase from around 200' in the north eastern part to over 800' in the south western part.

Sand-Shale Ratio Maps

Two generalised sand-shale ratio maps have been prepared one each for the Lower and the Upper Kanthkot Formations (Figs. 5.4 and 5.5). The author has also put on the maps inferred ratio values for the areas where the formation has been stripped off due to erosion.

The Lower Kanthkot Formation:

The Lower Kanthkot Formation comprising the succession between the fossiliferous mudstone band and the Lower Astarte band shows an interesting pattern of sand-shale ratio (Fig. 5.4). A major portion of the central and the northern parts show a ratio between 2 and 4, while the north western parts have the ratio less than 2. Two isolated areas in the E around Sonalwa and Kidianagar also show ratio less than 2. The southern Washtawa-Chitrod-Mewasa area is showing a ratio more than 4.

The Lower Kanthkot Formation is not exposed in the south western parts of the area while the same shows poor outcrops in the NE.

The Upper Kanthkot Formation:

The sand-shale ratio map (Fig. 5.5) for the Upper Kanthkot Formation representing the stratigraphic interval from the Lower Astarte to the Upper Astarte bands shows a broad similarity in the variation pattern with that of the Lower Kanthkot Formation.

A major part of the central, western and south western area shows the ratio between 2 and 4. A narrow strip in the N along Rapar-Tramau and the area around Kakarwa in the W, as well as the area along the Washtawa-Chitrod axis in the S show higher ratio, more than 4. Small areas around Washtawa and Chitrod proper show a ratio even more than 8. Thus the northern and the southern parts are dominated by sandstones, the Washtawa-Chitrod area being the site of maximum sand deposition.

It is interesting to note that both the Lower and the Upper Kanthkot Formations show high sand-shale ratio in the Washtawa-Chitrod area.

<u>Sandstone Isolith Maps</u>

'Net sandstone thickness maps' or 'sandstone isolith maps' have been prepared for the Lower and Upper Kanthkot Formations (Figs. 5.6 and 5.7). The maps present the areal variation of sandstone thickness of these two stratigraphic intervals. The contours over areas where rocks are either eroded off or are sub-surface have been interpolated and shown in dashed lines.

<u>The Lower Kanthkot Formation</u>:

The sandstone isolith lines for the Lower Kanthkot Formation show an approximately elongate regional trend with WSW-ENE axis. The contour interval is 100' (Fig.5.6).

The north eastern part around Bhimasar and Sonalwa shows low sandstone thickness around 100'-150' and indicates a somewhat linear pattern of sand body.

Two distinct sites of thicker sands accumulation are the areas around Washtawa-Chitrod and S of Kidianagar. The maximum sand thickness is about 500' around Washtawa while a thickness of about 350' is encountered S of Kidianagar. These two areas appear like oval shaped sites of sand accumulation with NE-SW axes.

The northern part of the area shows thin deposition of sandstones, and the thickness varies from 100' to 150'. In the western part, S of Bharodia, over 200' of sandstone thickness is measured.

In a broad way, the total sandstone distribution in the area comprises an elongate sand body in the north eastern part having NE-SW axis which tends to open out in the SW, with a gradual increase of thickness in that direction.

Upper Kanthkot Formation

Figure 5.7 represents the sandstone isolith map for the Upper Kanthkot Formation. In the eastern and north eastern area i.e. around Bhutakia-Bhimasar and Rapar-Sonalwa, the sandstone thickness is much less and of the order of 100' or even less. A few sandstone bodies in this area occur as 'pods' (Potter,1962,p.1893) having thickness of over 100', with roughly WSW-ENE axes. The Badargadh-Washtawa-Chitrod area in the central and south central part also shows a linear WSW-ENE pattern but with higher thicknesses. Around Marada-Washtawa axis there is a swing in trend of the contour lines and W of it, they show roughly N-S trend. In this western area there is a gradual increase in the thickness to as much as 400'.

It is a noteworthy feature that sand body which has an elongate trend in the eastern, opens out in the western half of the area. However, in the eastern half of the area, only lower part of the Upper Kanthkot Formation is represented. The non-occurrence of the upper part is partly due to erosion and partly due to non-deposition.

Kanthkot Formation as a whole:

The sandstone isolith contours in both the maps show a broad similarity in the geometry. Besides, there is a much conformity with the pre-erosion isopach contours of the formation. Both maps show elongate type sand bodies in the E, though this pattern is more pronounced in case of the Upper Kanthkot Formation. There is also a general increase in the sandstone thickness towards SW.

Sand Percentage Maps

The sandstone percentage maps (Figs. 5.8 and 5.9) for both the parts of the Kanthkot Formation have been prepared with a view to compare them with the sandstone isolith and sand-shale ratio maps. The contours over the areas where the respective formation has either been eroded off or is subsurface have been shown by dashing.

The Lower Kanthkot Formation:

The Lower Kanthkot Formation shows a high percentage of sandstones in the eastern, northern, and the southern parts while in the central and western parts the sandstone percentage decreases (Fig.5.8). The contours roughly show a 'V' shaped pattern with an approximate E-W axis. The central axial part is marked by comparately less sandstone percentages.

In the southern parts of the area, along the Adhoi-Washtawa-Chitrod axis, the sandstones show high percentages, from 80 to over 90. Though the outcrop conditions in the E around Kidianagar-Bhutakia-Bhimasar are not very good, the exposed sections show similar high percentage values. In the W, around Kanthkot-Ramwao-Bharodia, the sandstone percentage is comparatively less ranging between 50 and 70.

The sandstone percentage map is broadly comparable with the sand-shale ratio map in the sense that southern parts shows both a high sandstone percentage as well as a high sand-shale ratio. However the eastern parts around Sonalwa and Kidianagar are the only two areas where the relationship between sandstone percentage and the sand-shale ratio is not in conformity.

The sandstone isolith map also show high values for net sandstone thickness along the southern Washtawa-Chitrod-Mewasa axis and this matches very well with the high sands percentage value for this area.

It is observed in the field that the increase in the sandstone percentage as well as in the net sandstone thickness in the southern area is more due to increase in the thickness of individual beds rather than due to increase in the number of discrete sandstone beds.

In general, the percentage contours show a semioval pattern with E-W axis in the central and the eastern parts with a tendency to open out to the W.

The Upper Kanthkot Formation:

A major part of the sequence of this unit is not present in the eastern half of the area. The exposed lower part of this unit, E of Rapar-Chitrod, show a high sandstone percentage between 90 and 100 (Fig.5.9).

The percentage contours show roughly a NNE-SSW trend and are marked by an E-W swing in the northern part. The contours further W, show a swing towards SW making a sort of semioval pattern with an approximate NE-SW axis. Thus the south western area around Adhoi-Wamka is marked by comparately less sandstone percentage of about 70 to 75. The change in the percentage values is more rapid in the southern area as compared to the northern area.

The sandstone percentage map is grossly comparable with the sand-shale ratio map which shows higher values for northern and southern areas. Besides the general trend of sand isolith map is also comparable with the NE-SW strike of percentage contours.

Shale Isolith and Colour Map

The shale content in the eastern part of the area is quite low (Fig. 5.10), and the total thickness is less than 50'. The shale thickness gradually increases towards W. In the westernmost part around Kakarwa and Mae, it is measured to be around 250'. The change in the isolith values is quite uniform.

The shale isolith contours show somewhat an arcuate pattern, probably parallel to the depositional strike. In the northern half they show roughly NNW-SSE strike which swings towards SSW in the southern areas. The increase in the net thickness of shale from E to W is quite in conformity with increase in the isopach values (pre-erosion) of the Kanthkot Formation, besides contours of both the maps show good regional parallelism.

Change in the gross colour characters of shales from E to W are also noted.

The author has found the colours to be a good supporting evidence for depositional conditions. The shale colour map brings out this relationship well. Broad relationship between the colour and depositional conditions have been suggested by Forgotson Jr. (1954, p.2484).

It is seen that the shale colour becomes uniformly grey to dark grey with greater thickness in the W, while smaller thickness of shale in the eastern parts is marked by reddish brown, variegated and khaki colours.

THE GAMDAU FORMATION

Isopach Map

The Gamdau rocks occupy only a small portion, in the south western and western parts of the area. As these mainly comprise sandstones with minor amounts of siltstones and shales, only isopach map of the Gamdau Formation could be prepared (Fig. 5.11).

Zero isopach line presents the base of this formation, and the isopach contours represent the actual present-day thicknesses only. The Gamdau rocks occur only along the valley between the Kanthkot Range and the Southern Range (Fig. 1.2) and as a narrow N-S strip fringing the older rocks in the western part.

In the southern valley region, the thickness varies from zero to over 300' in the area around Torania. The isopach contours in this area show an ESE-WNW strike, while in the western part they show N-S trend. As such the southern area forms a narrow elongate sand body with thicker central axial region.

The contours open out towards W where the thickness gradually increases to about 600' around

Kharoi. Further W, the Gamdau rocks go below the alluvial cover and as such the top of this formation is not exposed. About 300' of thickness is measured around Bharodia-Khankoi region in the N. In the southern region, rocks of this formation encircle the 'highs' of the Mae and Wamka domes forming 'holes' in the isopach maps.

The rate of thickness change is fairly uniform both in the southern as well as in the western areas.

STRATIGRAPHIC CROSS SECTIONS

Close spaced stratigraphic cross sections, across or parallel to the regional strike of the strata are very useful in the study of sedimentation. Accordingly, with a view to portray the vertical and lateral relationships of the different formations of the entire Wagad Group, the author constructed three representative stratigraphic sections.

The three cross sections prepared represent two E-W strike sections along the Northern and Southern Ranges, and the third N-S cross section across the regional strike (Figs. 5.12, 5.13, and 5.14).

<u>Northern Range Cross Section</u>

Figure 5.12 represents the generalised stratigraphic cross section along the section line AA' (Fig.1.3), in the Northern Range. It is an E-W section roughly parallel to the regional strike of the area.

Base of the oldest Washtawa Formation is not exposed, and the oldest bed encountered in the Narada and the Dabunda domes has been extrapolated in the Section. The oldest sandstone sequence of Washtawa Formation shows a tendency to thicken towards E. Part of these sandstones have been replaced by Nara shales in the western part. A few thin sandstone bodies occur in the central area. There is a slight increase in the thickness of Washtawa Formation in the W.

The basal shales belonging to Patasar Member of the Kanthkot Formation are continuous from Sonalwa in the east to Bharodia in the west. These shales thicken towards west and are typically marine in the western part. The overlying Fort Sandstone Member is more thick in the eastern region. Towards W, a part of these sandstones is replaced by Patasar Shale Member. There is an overall increase in the thickness of Lower Kanthkot Formation towards west. The top of Lower

Kanthkot Formation i.e. the Lower Astarte band or its equivalent horizon is not easily identifiable in the eastern parts.

The basal shale part of the overlying Adhoi Member also shows good continuity from E to W with a gradual increase in its thickness towards W. The overlying sand-silstone sequence also shows thickening towards W. It appears that the upper part of this sequence is stripped off due to erosion in the central region. One more shale lithosome is developed within Adhoi member in the western region.

The top of the Kanthkot Formation is exposed only in the western region, where a thin sequence of Gamdau sandstones overlies this Formation.

In general, the entire stratigraphic sequence appears like a wedge shaped body with a progressive thinning of sequence towards east. Besides the general increase of thickness towards W, there is also an increase in shale content of the sequence as well as increase in the number of discrete shale bodies, in this area. The total exposed sedimentary thickness varies from about 300' in the east to over 1200' in the west.

Southern Range Cross Section

The stratigraphic cross section (Fig. 5.13) along the Southern Range (section line BB' in Fig. 1.3), roughly parallel to the regional strike reveals an interrelationship pattern identical to that of the Northern Range cross section.

The gastropod band occurring towards the base of the Washtawa Formation is exposed in the Mewasa and Washtawa domes, and hence the lower part of the section could be continuously constructed in the eastern part. W of Nara proper, the area does not expose the Washtawa Formation, and hence some extrapolation had to be made to visualise the older sequence in the western part.

The lower sandstone-shale sequence belonging to the Kharol Member shows a gradual thinning towards E. Besides, in general the shale units also become thin towards E. The lower shale units partly replace the intervening sandstone beds and show increase in thickness towards W. The upper shales of the Nara Member of the upper part of the Washtawa Formation which are well exposed in the Washtawa and Nara area i.e. in the central part, are completely replaced by Chitrod Sandstone Member in the eastern part.

The Patasar Shale Member occurring towards the base of the Kanthkot Formation is exposed throughout the area. The lower part of the Fort Sandstone Member which is thickest around Washtawa in the central region gradually thins out westward and finally pinches out near Wamka where it is replaced by shales of the Patasar Member. The Patasar shales which occur as a single continuous shale sequence in the western part are partly replaced by the Fort sandstones in the central part and further E, they occur as two discrete shale units. Though for operational purpose the upper unit has been included in the Fort Sandstone Member in the eastern part, the two shale units form only one lithosome. Within the Fort Sandstone Member one more shale unit is developed in the western part. The total shale content of the Lower Kanthkot Formation is much more in the western parts as compared to the eastern part.

Thin basal shales of Adhoi Member of the Upper Kanthkot Formation overlie the Fort Sandstones in the central and western parts. However, this shale unit is not encountered in the easternmost parts. Two discrete shale units are developed in the western part within the Adhoi Member. The shale content as well as the number of individual shale units of the Upper Kanthkot Formation also increase towards W.

The total thickness of the Kanthkot Formation occurring in the eastern parts of the area is only about 250' while the same is over 800' in the west.

The Gamdau Formation occurs only in the western part of the area. It is principally composed of only sandstones. However, thin sequences of shales and flaggy siltstones are noted in the basal and middle parts of the formation. The thickness of this formation gradually increases towards W. Around Gamdau proper it is about 250' while in the westernmost Kharoi area it is over 500'.

Both the northern and southern range cross sections show a wedge shaped mass, with the tapering end towards the eastern side. Gradual thickening as well as subsequent occurrence of younger strata is seen to take place as one traverses westward. In the core of Mewasa dome in the east, almost the basal part of Washtawa Formation is exposed (gastrapod band). However, in the west in the Mae and Wamka domes, the base of Upper Kanthkot Formation is only exposed. The Washtawa

Formation as well as the Lower Kanthkot Formation is not exposed in the western parts.

The total exposed sedimentary thickness in the eastern parts of Wagad is of the order 800'-900', while the minimum thickness of the total stratigraphic column occurring in the western parts, is as much as of 2000'. The increase in total shale content as well as in the number of discrete shale beds, also takes places from east to west.

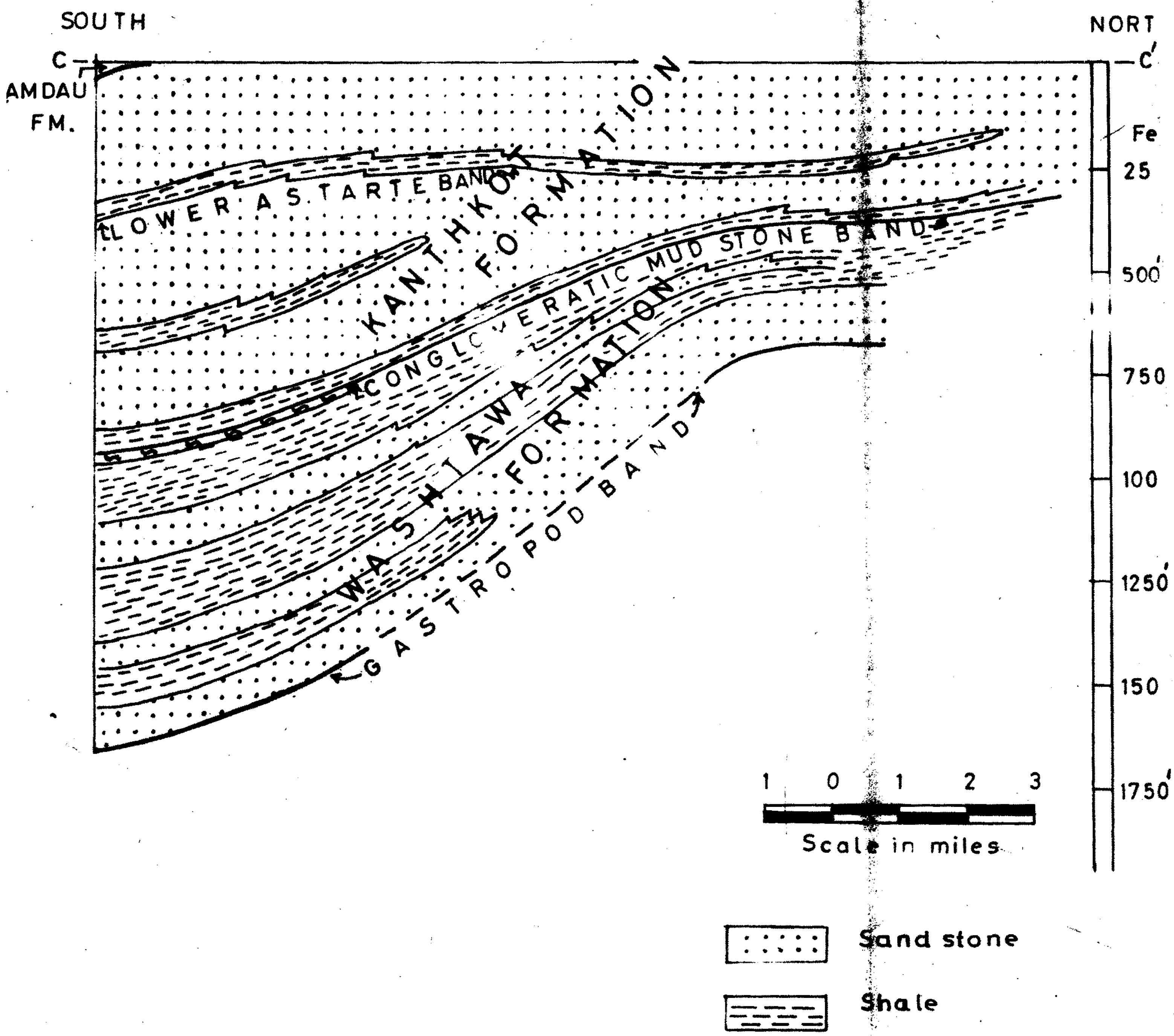
<u>North-South Cross Section:</u>

Figure 5.14 represents an approximate N-S stratigraphic cross section along Narada-Washtawa alignment (section line CC', Fig. 1.3).

The basal gastropod band occurring in the Washtawa dome has been correlated with the similar band in the Narada dome. Both the Kharol Member and the Nara Shale Member of the Washtawa Formation become appreciably thicker in the southern parts of the area. Also an increase in number of discrete shale bands is noted in the southern area.

The Lower Kanthkot Formation also thickens considerably in the southern area, along with a

TRANSVERSE STRATIGRAPHIC CROSS SECTION OF THE WAGAD GROUP (NORTH-SOUTH)



development of some shale sequences within the Fort Sandstone Member. The total exposed thickness of the Upper Kanthkot Formation remains more or less the same all along the section. The Gamdau rocks are present only along the southernmost fringe of the section.

The section comprises a very wedge shaped body with a tapering northern end. The total thickness varies between 500' to 600' in the N to over 1500' in the S. Though, there is a sharp increase in total sedimentary thickness towards S, it is interesting to note that the thickness of the Upper Kanthkot Formation does not appreciably increase.

FENCE DIAGRAM

A generalised fence diagram for the entire Wagad area (Fig. 5.15) ideally displays the regional interrelationship of various stratigraphic units. The top and bottom of the fence represents respectively the tops and bottoms of the actual stratigraphic columns exposed in the different area. As such the diagram represents the present day factual picture as has emerged out from field observations.