

CHAPTER 4

DESCRIPTIVE STRATIGRAPHY

Field investigations in the Wagad area have revealed an interesting stratigraphic picture. The area is marked by a number of domes, anticlines and synclines and to measure the stratigraphic sections, in all twenty one traverses were taken across these structures (Fig.1.3). These traverses were so spaced as to give a regional coverage to the entire Wagad. Stratigraphic measurements were done upto one foot accuracy. Besides, in the entire study area behaviour of each stratigraphic unit both vertically and laterally was studied in detail. In this chapter an attempt has been made to present a coherent

picture of different stratigraphic units and their interrelationships, based mainly on the field observations.

GENERAL

As already stated, the present study is confined to the Mesozoic sediments which approximately comprise 90% of the outcropping area in Wagad, the rest being the younger Tertiary sediments.

The entire Mesozoic sequence of the area ranges from middle Jurassic to lower Cretaceous i.e. from Callovian to Neocomian. The 'Kanthkot Sandstones' which occur almost in the middle of the Wagad stratigraphic sequence have been observed as belonging to Argovian age (transversarius and bimammatus zones of Pascoe, 1959, p.1147). Below the 'Kanthkot Sandstones' a succession of about 800' thick sediments are exposed and could be assigned Oxfordian or Callovian age. The rocks above the Kanthkots, on the basis of the lamellibranch fauna have been correlated with the Umia series which comes at the top of the Jurassic sequence of Kutch. Smith (cf. Pascoe, 1959, p.1148) found the lamellibranch assemblage zone above the Kanthkots very similar to the one of the Umia series and thus this lamellibranch assemblage zone of the Wagad has been assigned the Tithonian or the uppermost

Jurassic age. According to the normal order of superposition the rocks above this lamellibranch zone have been assigned Neocomian or the Lower Cretaceous age. While investigating the Wagad area the author too has come across two lamellibranch horizons comparable to those of Smith, and these have been referred as Lower and Upper Astarte bands.

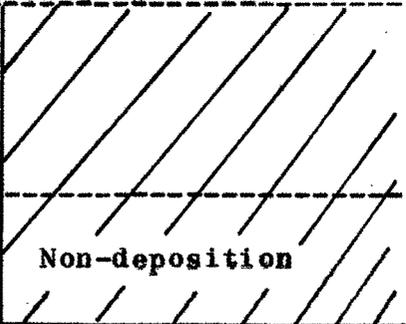
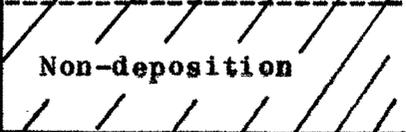
The typical fossil assemblage found in the Upper Astarte band is Astarte major and Trigonia Smeel. Cox (cf. Pascoe, 1959, p.1148), however, has assigned upper Argonian age to Barodia beds (Author's Upper Astarte bed) on the basis of oxytoma inaequivalve (sow). Lately, Biswas and Deshpande (1970) and Biswas (1971) have considered the Wagad rocks as ranging from Callovian to Neocomian. The oldest rocks of the Washtawa Formation according to them belong to Callovian age while the youngest rocks above the Upper Astarte band to be of lower Cretaceous age.

CLASSIFICATION AND DEFINITION OF STRATIGRAPHIC UNITS

The generalised stratigraphic sequence as worked out by the author is shown in Table 4.1.

TABLE 4.1

STRATIGRAPHIC CLASSIFICATION OF WAGAD GROUP OF ROCKS

Age	Group	Formation	Western Part Members & Lithology	Eastern Part Members & Lithology	
Tertiary		Lakadiya Formation	Variegated clays, shales and sand- stones	Variegated clays, shales and sand- stones	
-----Unconformity-----					
Lower Cretaceous	W A G A D G R O U P	Gandau Formation	Sst, grey to buff, massive with minor shales		
-----Disconformity-----					
Middle to Upper Jurassic		Kanthkot Formation	Adhoi Member Sst & sh alter- nations	Non-deposition 	
-----Disconformity-----					
			Fort Sandstone Member	Fort Sandstone Member Sst, massive, grey to pink	Fort Sandstone Member Sst, massive grey to br. & brick red
			Patasar Shale Member	Patasar Shale Member Shale, grey to dark grey, & khaki	Patasar Shale Member Shale, grey, khaki, silty
-----Disconformity-----					
		Washtawa Formation	Naras Shale Member Shale grey, khaki and silty	Chitrod Sandstone Member Sst, flaggy to bedded grey to brown	
			Kharol Member Shale and Sst alternations	Kharol Member Sst & shale alternations	
-----Base Not Exposed-----					

The Washtawa Formation

The name Washtawa Formation has been incorporated from the earlier published work of Biswas and Deshpande (1970). It forms the oldest stratigraphic unit of the area and is well exposed in the central and southern parts. The base of this formation is not exposed anywhere while the top is marked by a highly fossiliferous, ferruginous, cherry red conglomeratic mudstone band. In the western part of the area, this band shows abundant concentration of marine fauna including ammonites, lamellibranchs and brachiopods. Generally, the Washtawa Formation comprises shales, silty shales and sandstones. The author has taken the southern flank of the Washtawa dome in the south central part of Wagad (Fig. 1.4) as the type section of this formation.

The Washtawa Formation is further divisible into three members. The lower member all over comprises alternations of shales and sandstones. This has been designated by the author as Kharol Member. In the W, the Kharol Member is succeeded upward by a shale sequence, called Nara Shale Member; while in the E, the Kharol Member is overlain by sandstones and this has been called by the author as Chitrod Sandstone Member. The Nara

Shale Member of the W grades into Chitrod Sandstone Member in the E, the latter being a facies variant of Nara shales.

The Kanthkot Formation

The name 'Kanthkot Formation' has been proposed by the author. The Washtawa Formation is overlain by the rocks of the Kanthkot Formation with a minor disconformity. The stratigraphic sequence from the top of the ferruginous mudstone band (Washtawa top) upto the top of the Upper Astarte band has been included in the Kanthkot Formation. Rocks of this formation are widely exposed all over the Wagad and they mainly include sandstones and shales. The shales show a gradual increase of thickness from E to W.

The Kanthkot Formation is further divided as lower and upper. The Lower Kanthkot Formation includes two members - the Patasar Shale Member followed up by the Fort Sandstone Member. Patasar shales, deriving the name from the Patasar tank in western Wagad, have been described by Singh and Tripathi (1969, p.217). The author has given to these shales a members' status within regional stratigraphic framework of Wagad. The name Fort Sandstone Member is derived from the Kanthkot Fort which is situated

on the top of these sandstones. These sandstones have been described in a general way as Kanthkot sandstones by earlier workers, and are very widely exposed throughout the Wagad region. The top of the Fort Sandstone Member is marked by a highly fossiliferous, grey, conglomeratic hard band containing abundant lamellibranchs, mainly Astarte. This band termed as Lower Astarte band is traceable for long distances. The Upper Kanthkot Formation includes only one member called Adhoi Member. This name has also been proposed by the author, from the village Adhoi which is situated on the rocks of this member. It mainly consists of sandstones with occasional shale and siltstone beds.

The top of the Kanthkot Formation is again marked by a highly fossiliferous, calcareous, conglomeratic sandstone band called Upper Astarte band. The fauna includes mainly lamellibranchs of which Trigonina and Astarte are most prominent fossils. The look of this band is somewhat similar to the Lower Astarte band. The Kanthkot dome section (N flank) in the south western part of the area has been taken as the type section for the Lower Kanthkot Formation while the Adhoi anticline section (N flank) typically reveals the Upper Kanthkot Formation.

The Gamdau Formation

The rocks occupying the position above the Upper Astarte band have been included under the Gamdau Formation. The name Gamdau Formation has been proposed by the author from the village of that name around which good sections of this formation are exposed.

This formation is confined to the westernmost and south western parts of the area. The rocks are mainly arenaceous and include thickly bedded to massive sandstones with occasional thinly bedded shales and siltstones and constitute the uppermost formation of Wagad stratigraphy. Its top is encountered nowhere since the rocks gradually dip subsurface underneath the alluvial and the Rann cover.

Stratigraphic Relationships

The base of the Washtawa Formation is not exposed anywhere in the area. However, it is likely that the Washtawa rocks with additional unexposed thickness overlie the Precambrian crystalline basement rocks (Biswas and Deshpande, 1968, 1970). The top of the Washtawa Formation is marked by a fossiliferous mudstone band. This band, though changes its character along the strike from W to E is fairly continuous and has been

continuously traced in the area. This band is taken as a time parallel plane. Besides, the top of this band represents a minor time hiatus after which the rocks of the Kanthkot Formation were deposited. As already stated the Kanthkot Formation contains two fossiliferous horizons viz. the Lower and the Upper Astarte bands. The top of the Lower Astarte band which marks the boundary between the Lower and the Upper Kanthkot Formations also indicates a minor break in the sedimentation. The top of the Upper Astarte band that characterises the top of the Kanthkot Formation marks a similar disconformity. These two Lower and Upper Astarte bands are extensively developed in the area and mark two time parallel planes. The Gamdau Formation overlies the Kanthkot Formation with a disconformity.

STRATIGRAPHIC SUB-PROVINCES

The three physiographic divisions of Wagad hills namely the Northern Range, the Southern Range and the Kanthkot Range (Fig. 1.2) show distinct relationship with the structure and stratigraphy of the area, and accordingly, areally too the rocks could be divided into three stratigraphic sub-provinces.

The Northern Range Sub-province includes area N of Badargadh syncline (Fig. 1.4). It approximately coincides with that N of the Kidianagar-Badargadh-Sarasla-Chobari alignment. To the S of this axis are the remaining two sub-provinces.

In the south western area, the chain of domes and corresponding hills occur along the Kanthkot fault, to its N. This chain from the Manfara to Nara dome warrants a separate sub-province, and has been termed as the Kanthkot Range Sub-province.

Rest of the southern area from Mae in the W to Jadawas in the E has been described as Southern Range Sub-province. This area though smaller than the Northern Range Sub-province deserves a special attention as it comprises many complicated structures and appears to have undergone maximum sedimentation and also maximum degree of uplift. Thus the various structures of this area expose thick sections.

The detailed description of sediments including mode of occurrence, physical characters, lateral and vertical variations as observed in the field, of these three sub-provinces is presented in the following pages of this chapter.

I. NORTHERN RANGE SUB-PROVINCE

This sub-province extends from Chobari-Bharodia in the W to Hamirpur-Bhimasar in the E and includes structures like Chobari nose, Ramwao syncline, Tramau nose, Narada dome, Wagad anticline, Dabunda dome, Sonalwa dome, Hamirpur dome, Bhimasar anticline etc.

The Washtawa Formation

Rocks of this formation mainly occur in the areas which comprise the central region of the Northern Range and also roughly form geographically the central part of the Wagad. Since Wagad forms an arched shaped structure, the core part exposes the oldest Washtawa Formation.

Washtawa rocks are well exposed along the Wagad anticline, Dabunda dome, and Narada dome (Fig. 1.4). Except for the Narada dome which occurs as a separate oval shaped dome, other structures show good continuity with one another and as such areally a continuous outcrop of the Washtawa Formation is exposed.

The easternmost outcrops of the Washtawa Formation are encountered in the Dabunda dome and the Bachau-Rapar road that passes through this dome, exposes good section

of this formation. The Table 4.2 gives the detailed stratigraphic sequence exposed towards the eastern side of this N-S road.

The Washtawa Formation is divisible into three members - the Kharol Member and the Nara Shale/Chitrod Sandstone Member.

The Kharol Member: The total exposed thickness of this member in the Dabunda dome is 130'. It mainly consists of variety of sandstones particularly grey to pinkish grey and brown, massive, fine to medium grained, friable, along with dark grey to cherry red, hard, ferruginous and calcareous flaggy sandstone variety. The sandstones are usually of quartz-arenite type. Commonly khaki to brownish red, silty shales are associated with these sandstones.

On the other hand, within the Narada dome about 6 miles WNW of Dabunda dome, this member shows instead a better and thicker development of argillaceous facies. The shales are grey to bluish grey, soft, gypseous with interbanding of flaggy, yellowish grey, fine to medium grained sandstones and siltstones. The shale sequence is marked by a few, hard, blocky, calcareous, fine to medium grained sandstone beds. Obviously, the

TABLE 4.2

DAHUNDA DOME SECTION (N FLANK)

		Kanthkot Formation	Thickness in feet
-----Disconformity-----			
WASHTAWA FORMATION	Nara	Sandstone, grey to reddish brown, calcareous hard, conglomeratic and pebbly	... 5'
	Shale Member	Shale grey to brownish red, soft, gypseous, with occasional sandstone pinkish to grey, fine to medium grained, flaggy	... 100'
		Sandstone, bedded, pink to grey, fine to medium grained, micaceous and friable	... 15'
	Kharol Member	Shale, khaki to pinkish red, silty, with sandstone brownish red, ferruginous, flaggy, medium grained	... 35'
		Sandstone, massive grey to buff, medium grained, friable occasionally current bedded alongwith cherry red to dark reddish brown, fine grained, flaggy ferruginous sandstone alternations towards base	... 80'
-----Base Not Exposed-----			

predominantly arenaceous sequence of the Dabunda dome grades into argillaceous one in the Narada dome. In the Narada dome section, one highly fossiliferous, flaggy, calcareous, fine grained sandstone band occurs 143' stratigraphically below the top of this formation. Its fossils are mainly small lamellibranchs, commonly *Astarte*, *Pecten*, and occasionally tiny gastropods. This band has been correlated with the gastropod band of the Washtawa dome (to be described later). On going further W of the Narada dome, towards Tramau nose, Ramwau syncline and Wagad anticline, rocks of this member show a much dissected outcrop pattern due to minor faults and drainage system. Besides a change of facies from arenaceous to argillaceous, is also observed on traversing from E to W along the strike. There is also a general increase in the thicknesses of individual beds in that direction.

The Nara Shale Member: This member is also well exposed within the Dabunda and Narada domes. In the Dabunda dome it is mainly represented by grey to greenish grey and khaki shales along with alternations of grey to pink, flaggy fine to medium grained sandstones. In the Narada dome the constituent rocks of the Nara Shale Member are grey to bluish grey soft shales with

few hard, blocky, calcareous sandstone beds, forming good dip slopes. Further, similar sandstone bands occur continuously from Dabunda towards Lilpur in the W as well as along the southern flanks of Dabunda dome and along Wagad anticline. These bands could be well traced in these areas. However, further W, the exposures become discontinuous and these rocks are sporadically exposed from Tramau nose, through Ramwao syncline to western part of Wagad anticline. The beds in this area dip at very low angles from 3° to 4° due NNW. The shale country usually forming low gullies is often covered with a thin veneer of soil. The thickness of this unit considerably increases towards W.

Fossiliferous Mudstone Band: Though theoretically this bed is a part of the Nara Member, it is separately described because of its great importance as a marker horizon and a time parallel plane. It marks the top of the Washtawa Formation. It is almost continuously exposed from Dabunda in the E to Wandh Rabari in the W, and also in the southern areas N of Badargadh. In Dabunda dome, this band is more a ferruginous conglomeratic sandstone and is about 5' thick. In the Narada dome, it

is less conglomeratic. In Tramau anticlinal nose, it comprises fossiliferous conglomeratic mudstone. Good exposures of this band are encountered about 3 miles SSW of village Tramau. Further W, the band shows intermittent and sporadic outcrops but can be traced almost continuously through Ramwao low up to the western plunge part of the Wagad anticline in the northern part. This band shows similar characters in the southern part of the Wagad anticline as well. From about $1\frac{1}{2}$ miles NW of Badargadh, it is intermittently exposed through Sarasla, towards W. Near the western plunge of Wagad anticline, it is very well exposed and can be described as a cherry red to brick red flaggy to thickly bedded highly fossiliferous mudstone having smooth weathering surfaces. The band here is about 20' thick with intercalations of shales. Fossils include lamellibranchs, gastropods and ammonites. Its fossil content as well as thickness decrease towards E, and in Dabunda dome, it is totally unfossiliferous.

The Kanthkot Formation

In the Northern Range Sub-province, the rocks of this formation are well exposed and occupy much larger area than that of the Washtawa Formation. The

area from Hamirpur and Bhimasar in the E through Sonalwa, Rapar, Tramau, Ramwao to Bharodia in the W ideally exposes the Kanthkot Formation (Fig. 1.4).

The generalised stratigraphic sections encountered in the eastern Sonalwa dome and the westernmost Bharodia section are shown in Table 4.3

The details of the beds encountered in the various structures of the Northern Range e.g. Sonalwa dome, Dabunda dome, Narada dome, Tramau nose, Ramwao low, and Bharodia section and their correlation have been shown in Fig. 4.1

The Kanthkot Formation has been divided into two parts - Lower and Upper.

The Lower Kanthkot Formation

This lower part of the formation has been further subdivided into two members viz. the Patasar Shale Member and the Fort Sandstone Member.

The Patasar Shale Member: The shales occurring above the fossiliferous mudstone band (of the Washtawa Formation) and below the massive friable sandstones of Fort Sandstone Member have been described as Patasar Shale Member. This member shows good exposures in the

TABLE 4.3

BHARODIA AND SONALWA DOME SECTIONS

WEST

EAST

Bharodia Section

Sonalwa Dome Section

Thick-
ness

Thick-
ness

UPPER KANTHKOT FORMATION

Adhoi Member	Sandstone, grey to brown, buff, fine to medium grained flaggy to bedded with grey silty shale alternations, Top is marked by highly fossiliferous conglomeratic band (Upper Astarte band)	... 130'	Sandstone, brown to brick red, soft, bedded to massive, fine to medium grained with thin clay pockets	... 110'
Member	Sandstone, pinkish to yellowish, bedded to massive, fine to medium grained, occasionally cross bedded	... 290'	Shale, silty and sandy, grey to reddish brown, to ochrous red, with ferruginous flaggy, dark brown sandstone alternations	... 60'
	Shale, grey to dark grey, soft	... 45'		

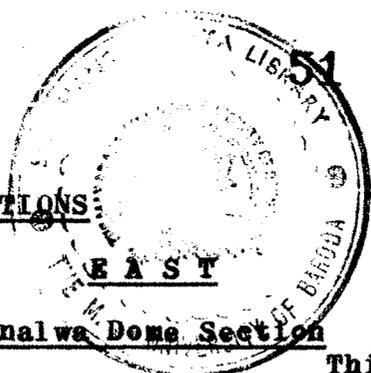
-----Disconformity-----

LOWER KANTHKOT FORMATION

Fort Sandstone Member	Sandstone, pink, yellow to grey and ochrous yellow, cross bedded, friable, fine to coarse grained occasionally pebbly. Top is highly fossiliferous - Lower Astarte band	... 175'	Sandstone bedded to massive, fine to coarse grained, pinkish, brick red and buff, friable	... 75'
Patasar Shale Member	Shale, grey to dark grey khaki, gypseous	... 100'	Shale grey to brown, with flaggy ferruginous, dark brown sandstone alternations	... 50'

-----Disconformity-----

Washtawa Formation



western half of the area. In the eastern part around Hamirpur and Bhimasar, its exposures are rather poor. A few scanty outcrops of silty grey to reddish brown shales occurring below the massive Fort Sandstone Member are the only recognisable outcrops. Westward, in the Sonalwa dome, the shales are somewhat better exposed and are seen fringing the core area of the dome, around Sonalwa tank. Here the shales are seen to be light grey and variegated in colour, silty with flaggy ferruginous sandstone alternations, their thickness being about 50'.

On going further west in the Dabunda dome, the shales are better exposed, and here the thickness is measured as 30'. The shale exposures near Dabunda village are fairly good and are seen overlying the conglomeratic mudstone band. Westward in the Narada dome, the thickness and nature of these shales is more or less as those in the Dabunda dome. In the Tramau and Ramwao area, the shales are grey to khaki in colour with occasional flaggy sandstone bands. The shales show very low dips and form wide low lying areas in this region. Often thin alluvium covers these shales.

In the westernmost area i.e. about 5 miles SE of Bharodia, these shales show comparatively darker shades and are grey to dark grey, soft, often nodular. There is a gradual increase of thickness of this member from E to W. The thickness which is only 30' in Dabunda is measured to be 55' in Tramau, 80' in Ramwao and 100' in Bharodia areas. This shale member rests over the top of the Washtawa Formation with a minor disconformity indicated by the conglomeratic fossiliferous mudstone band.

The Fort Sandstone Member: This member occupies not only the maximum area of the Northern Range but is also the most widely exposed unit of the entire Wagad region. The low dips of these sandstones, their characteristic massive nature, and resistance to erosion have resulted into their extensive outcrops. In the E, around Hamirpur-Bhimasar, the sandstones are massive, fine to coarse grained, pinkish to purple and buff coloured, commonly cross bedded and friable. Interbedded with this variety are sandstones cherry red, highly ferruginous, and hard. These ferruginous sandstone bands form good floors along their dip slopes. Around Bhutakia, these sandstones are grey to cream coloured, cross bedded,

and form ridges with hard ferruginous cappings. Further W, through Sonalwa, Tindalwa, Pragpur, Dabunda, Rapar upto Lilpur, the outcrops of this member are uniformly good and its several bands could be continuously traced for long distances. The Bachau-Rapar road passes through quite a few ridges of this sandstone between Lilpur and Rapar. The sandstones around Dabunda-Lilpur are grey, pink to yellowish in colour, friable massive, fine to medium grained, angular to subrounded, and cross bedded. Occasional pebbly layers are not uncommon. The change in overall nature and look of these sandstones is gradual from E to W. In the E, around Bhimasar-Bhutakia-Pragpur area this member contains numerous layers of hard ferruginous sandstone while there is a marked decrease in number of such layers in the W. Here the sandstones are mostly of pure quartzose type.

The entire area from Rapar to Bhimasar-Hamirpur is marked by a very high density of minor faults often associated with mafic dykes, which predominantly strike NNE-SSW and dip at high angles.

In the western parts of the area from Rapar through Tramau to Ramwao, the Fort sandstone member is fairly well exposed. The top of this member is marked by the

highly fossiliferous, conglomeratic, calcareous band referred to as Lower Astarte band. This band is very well exposed about $1\frac{1}{2}$ miles S of Tramau and about $\frac{1}{2}$ S of Ramwao. The fossils are mainly Astarte, Trigonina, Belemnites, Modiola etc. This band has been quite useful in recognising and tracing the top of this member. Between Ramwao and Kanthkot area, this fossiliferous band is highly pebbly, the pebbles consisting of milky and smoky quartz. This band could be continuously traced from Kanthkot through Ramwao and Tramau upto Narada. Further E of Narada though the band extends upto a little E of Rapar, it loses its typical fossiliferous and conglomeratic nature.

The thickness of this Fort Sandstone Member is seen to gradually increase from E to W. At Sonalwa in the E it is about 75' thick while westward its thickness increases such that at Dabunda, Narada, Tramau, Ramwao and Bharodia, it is 100', 125', 135', 130' and 175' respectively.

The Upper Kanthkot Formation

The Upper Kanthkot Formation comprises only one member both in the E as well as in the W, and has been referred as Adhoi Member.

The Adhoi Member: This is the uppermost member of the Kanthkot Formation and includes the column between the two Astarte bands. All over the area this member is marked by a basal shale unit. These shales are not well exposed in the eastern part. In Hamirpur-Bhimasar area, these show hardly any exposures, but between Sonalwa and Umaiya, on the flanks of the Sonalwa dome some outcrops of this member comprising flaggy, silty, shales and siltstones are encountered. In this area, the shales are light grey, brownish grey to reddish brown are seen overlain by flaggy to massive grey to buff and purplish, fine to medium grained, subangular to subrounded sandstones. Westward upto Rapar the outcrops of this member are sporadic. However in the eastern and the north eastern vicinity of Rapar a few sandstone bands of this member are recognised. Further west also, the outcrops show sporadic and intermittent occurrence. The basal shales are usually exposed in nala cuttings while the sandstones form occasional ridges. These basal shales are well exposed in a river cutting just N of Tramau village. A few fossiliferous horizons are also developed in these shales at this locality. Fossils are principally lamellibranchs.

In the westernmost part of the area this member is well developed and a good section is exposed in Bharodia nala extending from Bharodia to Ramwao. The upper part of this member comprises flaggy to bedded sandstones and shale alternations. These sandstones show at places development of giant size concretions measuring 8' to 10' in diameter. Ideal section showing these concretions is exposed in a nala about 1 mile S of Bharodia.

The topmost part of the Adhoi member is characterised by the highly fossiliferous conglomeratic, calcareous, hard, sandstone band referred to as Upper Astarte band. The fossils are mainly Astarte, Trigonina, Modiola etc. In Bharodia area this band forms a prominent and impressive N-S ridge with steep eastern side and a gentle westerly dip slope of 5° to 8° inclination. This band though highly fossiliferous and so prominent around Bharodia loses its fossiliferous character in the areas NE of the village.

The thickness of this member is also maximum in this area being 460', while it is only 160' in the Sonalwa dome in the E. The Adhoi Member overlies the Fort Sandstone Member with a minor hiatus, indicated by the Lower Astarte band. While the Upper Astarte band forming the top of this member again marks a minor

break in the sedimentation.

The Gamdau Formation

Sediments occurring above the Upper Astarte band have been termed as the Gamdau Formation. The top of this formation is not exposed anywhere since the rocks dip gently underneath the alluvial cover.

In the Northern Range sub-province, the Gamdau rocks occur only as a narrow strip striking roughly N-S, W of Bharodia, and their total exposed thickness measured W of Bharodia is about 300'.

The lower part of this formation includes fissile to flaggy, yellowish brown, slightly ferruginous, fine to medium grained sandstones with thin shale alternations. Occasionally in this, are interbedded massive pink, friable current bedded sandstones, and hard calcareous layers at places.

The upper part contains uniformly massive, friable, light yellow, grey to cream and buff coloured, subangular to subrounded, cross bedded sandstones with cherry red, hard, highly ferruginous fine to coarse grained sandstone layers. These massive sandstones show occasional pebbly horizons.

The strata all over the sub-province show very gentle dips varying on an average from 2° to 4° towards W. Nowhere in the entire area any fossiliferous zone is noted within the Gamdau Formation and this is in a marked contrast to the underlying Kanthkot Formation which contains several fossiliferous horizons.

II. KANTHKOT RANGE SUB-PROVINCE

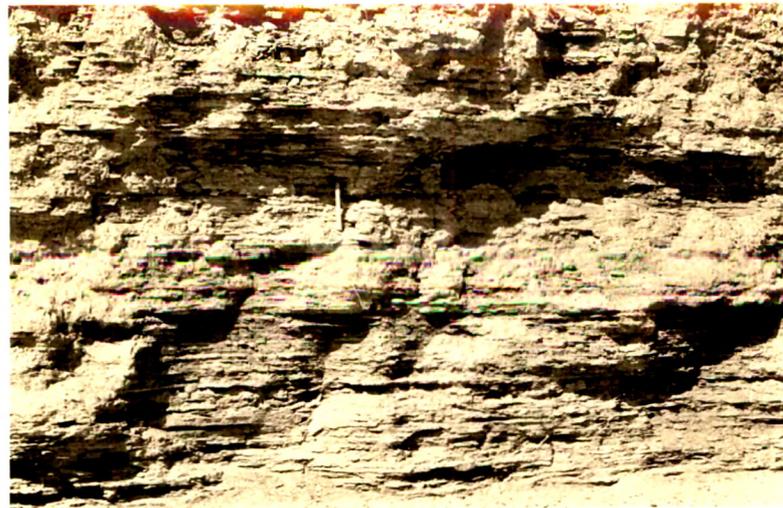
The Kanthkot fault striking roughly WNW-ESE, occurring in the south western part of Wagad has brought the Washtawa and the Lower Kanthkot Formations to the N in juxta-position with the Gamdau and Upper Kanthkot Formation to its S. A series of anticlines and domes occur along the northern side of this fault. The structures occurring from W to E have been named as the Manfara dome, the Kakarwa anticline, the Kanthkot domes, Meman Wandh synclines, and Nara dome (Fig. 1.4). This area as such forms a distinct structural and stratigraphic entity and thus has been described as a separate sub-province.

Figure 4.2 shows the details of the stratigraphic sequences exposed in these structures along with their correlation.

The Washtawa Formation

While this Formation in the Northern and Southern Range sub-provinces ideally exposes the two members viz. the Kharol and the Nara shale or Chitrod Sandstone Members, in the present sub-province the Kharol Member is not much exposed. In the Nara dome, which exposes the maximum stratigraphic column of this formation within the Kanthkot Range, a complete sequence of Nara Shale Member is exposed, and a few feet of sandy shales and siltstones below the Nara shales in this section appear to be equivalent of the Kharol Member.

The Nara Shale Member: This member has derived its name from the Nara dome which exposes its complete sequence. The lower part of this member consists of grey to dark grey thinly bedded and fissile shales with occasional yellowish grey flaggy sandstone alternations. In Nara dome one brick red to cherry red, flaggy concretionary mudstone band occurs within the shales about 120' stratigraphically below the Washtawa top. The upper part of this member is made up of light grey to greenish grey shales with more flaggy siltstone and sandstone alternations. In the western part in the Kanthkot dome, however, this member comprises more or less uniformly grey to dark grey soft shales. Obviously

PLATE 1

Shale and flaggy siltstone alternations,
Kharol Member. Locality: Nara dome.

PLATE 2

Nara Shales. Locality: Nara dome.

the flaggy siltstone interbanding seen in the Nara dome have graded into shales in the Kanthkot dome.

The total exposed thickness of this member is about 190' in the Nara dome and 140' in the Kanthkot dome, but in the Kanthkot dome its base is not exposed.

The top of this member in this sub-province also is marked by the ferruginous mudstone band. This band in the Kanthkot dome is about 35' thick and can be described as a cherry red to brick red, bedded ferruginous, clayey, highly fossiliferous mudstone. The fossils are ammonites, belemnites, lamellibranchs and branchiopods. The band changes its character to the E where in the Nara dome it is merely represented by a calcareous, grey, conglomeratic fossiliferous sandstone of about 10' thickness.

The Kanthkot Formation

This formation is well exposed around the Nara dome, Wandh Meman syncline, northern part of the Kanthkot dome, and around the Kakarwa anticline. To the S of the Kanthkot dome, the entire succession of this formation is thrown down by the Kanthkot fault.

The sequence encountered in the northern flank of the Kanthkot dome and Kakarwa anticline is shown in Table 4.4.

PLATE 3

Conglomeratic mudstone band, marking top of the Washtawa Formation. Locality: Nara dome, southern flank.

PLATE 4

Panoramic view of southern flank of the
Nara dome. Extreme left hill is the core.
Nara village is in the foreground.

TABLE 4.4

KANTHKOT DOME AND KAKARWA ANTICLINE SECTIONS

		Gamdau Formation	Thickness
-----Disconformity-----			
Kakarwa section	UPPER KANTHKOT FORMATION	(6) Sandstone, calcareous fine to coarse grained, and highly fossiliferous with Astarte, Trigonina etc. (Upper Astarte band)	... 5'
		Adhoi Member (5) Sandstone, yellowish to reddish brown, fine to coarse grained, highly fossiliferous with Astarte, Trigonina, Modiola, etc.	... 70'
		(4) Shale, khaki to grey, soft, gypseous	... 40'
		(3) Sandstone, flaggy to bedded, calcareous, yellowish brown, to grey with massive, soft, cross bedded sandstone at place with khaki, gypseous shale towards base and top	... 290'
-----Disconformity-----			
Kanthkot Section	LOWER KANTHKOT FORMATION	Fort Sandstone Member (2) Sandstone, reddish brown to pink massive, fine to coarse grained, cross bedded with highly fossiliferous, hard, calcareous top (Lower Astarte band)	... 210'
		Patasar Shale Member (1) Shale grey to dark grey, khaki, soft with occasional flaggy siltstone alternations	... 180'
-----Disconformity-----			
Washtawa Formation			

The Lower Kanthkot Formation

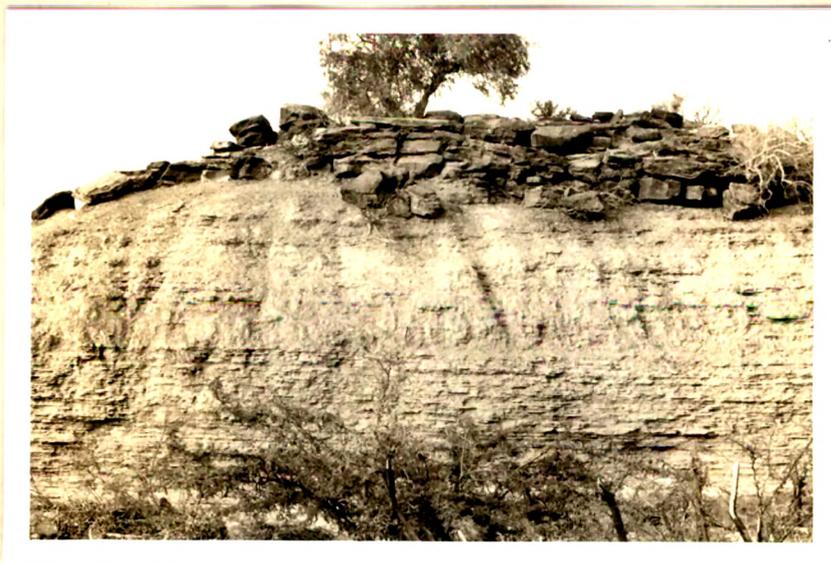
This Lower Kanthkot Formation has been divided into two members - the lower one mainly shaly designated as Patasar Shale Member, the Upper one being sandy and called Fort Sandstone Member.

The Patasar Shale Member: The shale section exposed around the Patasar tank near the Kanthkot dome area has been taken as the type area for this member. At Patasar proper these shales are grey to dark grey, soft gypseous in the lower part and greenish grey to grey and khaki, silty in the upper part. The upper part is often marked by flaggy yellowish brown siltstone alternations. These shales are continuously exposed eastward towards Nara, where it is seen that the upper part gradually grades into friable sandstones. At Nara, the shales are khaki to grey and silty. The thickness of this member at Kanthkot is as much as 180' while at Nara it decreases to 55'.

The Fort Sandstone Member: The sandstones that overlie the shales form a lofty hill marked by steep escarpments on all sides, on which the ancient fort of Kanthkot is situated. The Kanthkot hill forms the type section for this member. In addition the member is well exposed in

PLATE 5

Patasar Shales capped by Fort sandstones.
Locality: Patasar tank, representing type
section of the Patasar Shale Member.

PLATE 6

Shale and siltstone alternations of Patasar
Shale Member capped by bedded Fort sandstone.
Locality: about 1/2 mile west of Narada dome.

PLATE I

**Southern slope of the Fort hill representing
type section of the Fort Sandstone Member.**

the Nara dome, Meman Wandh syncline and in the core of Kakarwa anticline.

The sandstones are reddish brown, pinkish grey to buff coloured, fine to medium grained, subangular to subrounded, with occasional pebbly horizons and cross beddings. Usually these sandstones are friable and characteristically massive of quartz-arenite to quartz-wacke type. Here also the member is capped by the Lower Astarte band, marks the boundary between the Lower and Upper Kanthkot Formations.

The thickness of this member in the eastern part, (in the Nara dome) is about 300' while the same in the west (in the western Kanthkot dome) is about 210'. This decrease in the thickness westward is due to the fact that westward the sandstones in the lower part have graded into shales showing a facies change along the strike.

The Upper Kanthkot Formation

The Upper Kanthkot Formation comprises only one member viz. Adhoi Member.

The Adhoi Member: This member is exposed only in the Kakarwa anticline (Fig. 1.4). As shown in the Table 4.4,

the lower 290' of the strata of this member are mainly, composed of grey to reddish and pinkish grey friable, fine to medium grained, often cross bedded sandstones with occasional bands of blocky, calcareous, hard, gritty sandstone and highly ferruginous, cherry red to dark brown sandstone layers. This sandstone is overlain by khaki to grey silty shales with occasional flaggy yellowish grey sandstones and followed up by about 75' of highly fossiliferous silty sandstones of which the top is marked by the Upper Astarte band. This band forms a high ridge and makes very impressive westerly plunging nose of the Kakarwa anticline. In the eastern side of this anticline, its northern limb shows a distinct N-S swing from its original E-W strike. To the N, the band is traced upto Bharodia and beyond.

The Gandau Formation

The rocks of this formation are exposed only around Manfara dome and N of Kakarwa anticline. Its lower part consists of khaki to grey, silty, gypseous shales with flaggy, yellowish brown, fine to medium grained sandstone alternations. The upper part is mainly composed of thickly bedded to massive, cream to light grey and buff coloured, friable and concretionary, and cross bedded

sandstones. Often layers of hard, ferruginous, cherry red to brick red sandstones occur within the upper part of this formation.

The flaggy sandstones often show good asymmetrical ripple marks. Besides, at a few places, N of Manfara dome, good flute cast and slump structures are observed.

III. SOUTHERN RANGE SUB-PROVINCE

The Southern Range sub-province is by far the most important one, as it exposes the maximum stratigraphic column of Wagad. The area is marked by several complicated structures and has undergone high degree of uplift. The important structures include the Mae dome, the Wanka dome, the Halrae dome, the Adhoi anticline, the Washtawa dome, the Chitrod dome, the Dedarwa anticline and the Mewasa dome, the Sae dome, the Gamdau syncline, the Badargadh syncline and the Kidianagar structural basin. Most of the domal structures lie to the north of a high angled normal fault (South Wagad Fault).

The detail stratigraphic sequences exposed along these structures and their correlation is shown in Fig.4.3.

The Washtawa Formation

The area from Washtawa village in the central part to the Mewasa dome in the E, together with the core of

the Chitrod dome is occupied by the rocks of the Washtawa Formation. The Washtawa dome section exposes the maximum stratigraphic column. The base of this formation is not exposed anywhere. The stratigraphic sequence of the type section of Washtawa dome is shown in Table 4.5.

In this sub-province, both the members of this formation are developed and exposed. While the lower Kharol Member is seen all over, the upper member in the west is Nara Shale Member, and in the east it is the Chitrod Sandstone Member.

The Kharol Member: The shale and sandstone alternations comprising the lower part of the Washtawa Formation have been termed as Kharol Member. Rocks of this member are well exposed in the Washtawa dome and can be traced continuously towards E around Kharol and further in the core of Dedarwa anticline right upto the Mewasa domes. The sandstones towards the base and the top are usually thickly bedded and massive, pink, yellowish brown fine to medium grained and occasionally cross bedded. The central part includes mainly silty, khaki to grey, shales with flaggy, grey to yellowish grey sandstone alternations. The shale units are often capped by blocky, hard, gritty, calcareous sandstone bands which could be

TABLE 4.5
WASHTAWA DOME SECTION (S FLANK)

Kanthkot Formation		Thickness	
-----Disconformity-----			
WASHTAWA FORMATION	Nara Shale Member	<p>(3) Shales, grey to khaki, silty, soft, with flaggy siltstone beds at places. Top is marked by highly fossiliferous conglomeratic mudstone band</p>	... 125'
	Kharol Member	<p>(2) Sandstone, grey, pink, and brown, massive, fine to medium grained, cross bedded</p>	... 105'
		<p>(1) Shale, grey to dark grey, khaki, with flaggy to thickly bedded, pinkish to grey sandstone alternations</p>	... 410'
-----Base not exposed-----			

traced in the field almost continuously from Washtawa to Mewasa area.

A highly fossiliferous, mudstone band occurs in the core of the Washtawa dome about 520' stratigraphically below the top of the Washtawa Formation. The same band is also recognised in the core of the Mewasa dome about 500' below the top of the formation. It is a dark reddish brown to brick red, ferruginous flaggy, highly fossiliferous, mudstone grading into calcareous sandstone at places. The fossils are mainly lamellibranchs, gastropods and some ammonites. Gastropods are characteristically tiny and form a distinguishing feature of this band.

The central part of this member is more arenaceous in the Mewasa dome as compared to the Washtawa dome. In the Mewasa dome, an occurrence of a doleritic sill of 20' thickness is noted.

The Nara Shale/Chitrod Sandstone Member: The Nara Shale Member in the W and the Chitrod Sandstone Member in the E lie over the Kharol Member, the two being the facies variant of each other. The two younger members are well exposed ⁱⁿ the Washtawa dome, and the Mewasa and Chitrod domes respectively.

In the Washtawa dome, the shale unit occurring below the fossiliferous mudstone band that marks the top of the Washtawa Formation, is considered as Nara Shale Member. These shales gradually grade into fissile to flaggy sandstones towards E through Kharol, Dedarwa and Mewasa domes. This change from shales to sandstones is clearly noticed in the eastern part of the Washtawa dome and thus in the eastern part these sandstones which are the facies variant of Nara shales form a separate entity termed as the Chitrod Sandstone Member. Good section of the Chitrod Sandstone Member is exposed in the Chitrod dome.

The Nara shales which occur only in the central and western parts of the Washtawa dome are grey to greenish grey, soft, gypseous with fissile siltstone alternations. The Chitrod sandstones which occur in the rest of the eastern part are yellowish brown to grey, micaceous, flaggy in nature. There is a gradual increase of thickness of this member from E to W; about 100' in Mewasa dome to about 125' in the Washtawa dome.

Within the Washtawa dome, the Formation is marked by fossiliferous, conglomeratic band which forms the top of the Washtawa Formation ^{and} is about 5' thick. The fossils

are mainly lamellibranchs and a few ammonites. Obviously this band is a facies variant of the thicker (35') mudstone band developed in the Kanthkot dome. As mentioned earlier, it has been laterally traced from Kanthkot area in the W towards Nara in the central part, and is seen that it changes its nature around Nara. From Washtawa as it is further traced eastward it becomes completely unfossiliferous and grades into a coarse grained ferruginous and locally conglomeratic sandstone band, ideally seen in the Chitrod and the Mewasa domes.

The Kanthkot Formation

The Kanthkot Formation is well exposed along the southern chain of domes. In the Mae, Wamka, Halrae and Adhoi structures it occupies the cores. It also outcrops on the flanks of the Washtawa, Chitrod, Dedarwa and Mewasa domes and within the Gamdau and Badargadh synclines and Kidianagar structural basin. As compared to the Washtawa Formation, areally it is much more extensive. The base and the top of this formation are nowhere exposed together in a single locality. However, the lower Patasar and the Fort Sandstones Members are well exposed within the Washtawa dome while the Adhoi Member is well represented in the Adhoi anticline. The

two structures are quite closeby and thus the Washtawa and the Adhei exposures taken together have provided a complete and representative section of this formation. The generalised sequence of strata is shown in Table 4.6.

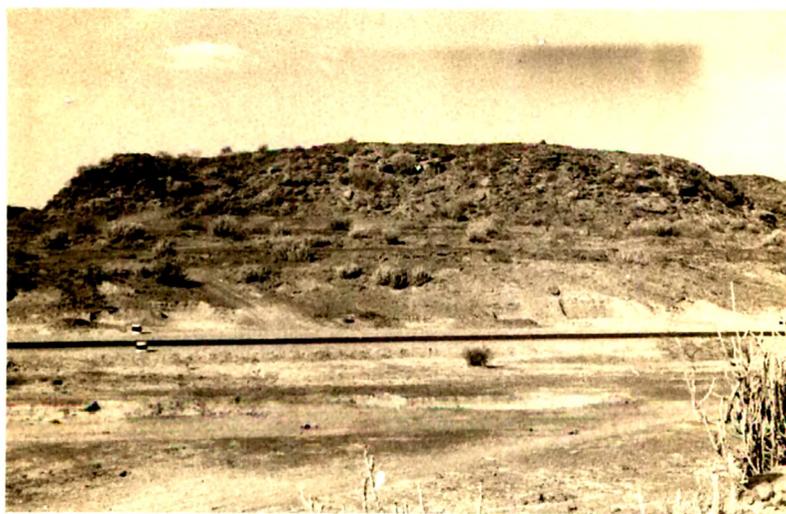
The Lower Kanthkot Formation

The Patasar Shale Member: The Patasar shales are exposed only in the eastern half of this subprovince. They are continuously exposed along the Washtawa, Dedarwa and the Mewasa domes, as well as within the Chitrod dome. Within the Washtawa dome, these shales are seen to be grey to greenish grey, dark grey and khaki, while in the Chitrod dome, the colours are light olive green to grey. In the Dedarwa and the Mewasa domes, the colour changes to grey, khaki, occasionally reddish brown and variegated. The shales in the eastern parts show more flaggy siltstone and sandstone bands. The thickness of this member is more or less constant.

These shales which are overlain by the massive Fort Sandstone Member provide a very good marker, as the two members are always seen to occur together and could be laterally traced over large areas. The shales and the overlying sandstones form impressive and lofty

TABLE 4.6
WASHTAWA DOME (S FLANK) AND ADHOI ANTICLINE
(N FLANK) SECTIONS

Gambau Formation		Thickness
-----Disconformity-----		
Adhoi anticline section UPPER KANTHKOT FORMATION	Adhoi Member	(4) Sandstone, flaggy to massive, reddish to yellowish brown, fine to coarse grained, soft, with occasional hard calcareous layers with grey, soft, shale alternations. The top is marked by fossiliferous, calcareous conglomeratic band - Upper Astarte band ... 145'
		(3) Sandstone, flaggy to bedded, yellowish brown with massive cross bedded sandstone in the lower parts with silty shales at the base ... 190'
-----Disconformity-----		
Washtawa dome section LOWER KANTHKOT FORMATION	Fort Sandstone Member	(2) Sandstone bedded to massive, ochrous yellow to brown, fine to coarse grained, at places pebbly with thin silty shales in the middle. The top is highly fossiliferous, hard calcareous band (Lower Astarte band) ... 315'
	Patasar Shale Member	(1) Shale, grey to greenish grey, fissile, bedded ... 35'
-----Disconformity-----		
Washtawa Formation		

PLATE 8

Khirai hill - Patasar shales capped by Fort sandstones.

scarps N of the Washtawa dome. Good shale outcrops also occur along the main Bhuj-Radhanpur highway just S of Chitrod village.

The Fort Sandstone Member: This member occurs along the axial zone of the Adhoi anticline, and on the flanks of the Washtawa, Chitrod and the Mewasa domes, and within the Badargadh syncline and the Kidianagar structural basin.

In the Adhoi anticline, the sandstones are ochrous yellow to grey, soft fine to medium grained with flaggy to bedded, calcareous, hard variety in the upper part. At places, they are interbedded with shales. The sandstones often show ripple mark development. A couple of such bands are quite prominent in the Adhoi anticline. In the Washtawa dome and the Badargadh syncline also, the sandstones show similar characters. However, in the Badargadh syncline, the sandstones are more massive and form high E-W striking ridges. Good outcrops of these sandstones occur along the Bachau-Rapar road, 1 mile N of village Khirai. This road passes through the Badargadh syncline and many good road cuttings ideally expose the sandstones. On the northern flank of the Chitrod dome, these sandstones form a very prominent hill with steep

PLATE 9

Panoramic view of the northern flank of
Mewasa dome.

southerly cliffs. Chitrod village is situated on this hill. In the east, on the flanks of the Dedarwa anticline and the Mewasa dome, these sandstones form a chain of narrow elongated E-W striking hills. It is observed that sandstones in the eastern areas are coarser and often pebbly, and are of quartz-arenite to quartz-wacke type.

The top of this sandstone member is recognised only within the Adhoi anticline and in the Washtawa and Chitrod domes.

The thickness of this member in the Mewasa, Chitrod and the Washtawa domes are 285', 510', and 500' respectively. The exposed thickness in the Adhoi anticline is 350'. Along the southern flanks of the Chitrod and Dedarwa-Mewasa structures, this member is seen truncated by the South Wagad Fault.

The Upper Kanthkot Formation

The Adhoi Member: A complete succession of the Adhoi Member (i.e. from the top of the Lower Astarte band to the top of the Upper Astarte band) is exposed in the western parts of the sub-province within the Mae, Wanka, Halrae domes and the Adhoi anticline. Lower parts of the succession is also exposed on the flanks of the Washtawa

and Chitrod domes. The type section of the Adhoi anticline is shown in Table 4.7. The basal shale unit exposed in the Adhoi anticline also occurs in the western part within the Halrae, Wamka and the Mae domes. The shales are grey to greenish grey and occasionally bluish grey. In the Washtawa dome, itself, these tend to become more silty and interbedded with sandstones eastward and further east in the Chitrod dome this shale unit is completely replaced by flaggy to bedded yellowish brown sandstones. In the middle parts of the succession, which is about 210' thick in the Adhoi area, within the Halrae, Wamka and the Mae domes, the sandstones show good development of cross bedding.

The shales overlying these sandstones are uniformly present from Adhoi westward. The shales are grey to dark grey and greenish grey. Flaggy to massive sandstone unit of 35' thickness is developed within these shales in the Adhoi anticline. The shales are overlain by flaggy to bedded, calcareous, silty sandstones, over which comes the highly fossiliferous, conglomeratic Upper Astarte band. The fossils are mainly Astarte, Trigonina, Modiola etc. This band forms separate closures around the Mae and the Wamka domes, besides it encircles

TABLE 4.7
ADHOI ANTICLINE SECTION

Gamdau Formation		Thickness
-----Disconformity-----		
UPPER KANTHOK FORMATION	Adhoi Member	(5) Shale, light grey to grey, soft, clayey, with highly fossiliferous calcareous sandstone top (Upper Astarte band) ... 20'
		(4) Sandstone, yellowish brown, soft, massive, micaceous, cross bedded ... 35'
		(3) Shale, grey to dark grey, with thin flaggy siltstone alternations ... 35'
		(2) Sandstone, ochrous yellow to buff, massive, friable, with ferruginous, flaggy, silty sandstones in the upper part ... 210'
		(1) Shales, silty, grey to greenish grey, with flaggy siltstone alternations ... 25'
-----Disconformity-----		
Fort Sandstone Member		

PLATE 10

View of the northern flank of Adhoi anticline representing the entire Adhoi Member. Ridge on right is Lower Astarte band while extreme left hill belongs to the Gamdau Formation.

the Adhoi anticline. This band which gently dips along the northern limb of the Adhoi anticline makes a sharp swing towards W about 4 miles NE of Adhoi, and S of Kanthkot fault, and forms a prominent synclinal structure. It gently dips towards S in this area and finally abuts against the Kanthkot fault about 2 miles NW of village Torania. The area between this band and the Kanthkot fault is occupied by upper shale and sandstone units which gently dip towards SSW.

The Gamdau Formation

The rocks of the Gamdau Formation occupy the area between the Kanthkot fault and the southern chain of structures, marked by a syncline with approximately WNW-ESE axis. This syncline runs westward from the Washtawa dome and opens out further W of the Mae dome.

Hills around village Gamdau as well as those about $1\frac{1}{2}$ miles N of the Wanka dome provide good sections of this formation. The hills expose massive, friable, light grey sandstones overlying thinly bedded siltstones and silty shales. Scattered outcrops of the Gamdau rocks are also seen upto a little E of village Kharoi.

The rocks are mainly flaggy silty sandstones and grey to brownish grey shales in the lower part, followed

PLATE 11

Highly fossiliferous nature of the Upper Astarte band. Locality: Manfara dome.

PLATE 12

Massive sandstones belonging to upper part of the Gamdau Formation. Locality: 1 mile N of Wamka dome.

upward by thickly bedded to massive, grey to white and pink, friable and often cross bedded sandstones. A few horizons of hard, ferruginous, cherry red sandstone bands are seen developed within this formation. Several such units, each comprising flaggy to massive sandstones, capped by hard, ferruginous, hematitic layers, are noted within the Gamdau syncline and this probably indicates a cyclic nature of deposition. These hard bands could be easily recognised and traced in this area.

Several sedimentary structures like load casts, 'scour and fill' structures, flute casts are noted in these sandstones. Giant ripple marks, measuring about $2\frac{1}{2}$ ' - 3' across the crests are noted at about 2 miles SE of village Torania. Besides, several localities show good development of asymmetrical ripple marks and ripple drift structures. Cross bedding both of trough and tabular type, is quite common.

The total thickness of this formation is about 220' in the Adhoi area, 310' in the Halrae and 170' in the Wanka area. In the Mae area where the syncline opens out, the thickness of this formation is as much as 550'.

The deposition of the Gamdau Formation appears to have been confined only to the western part of the area.