CHAPTER III

G E O L O G I C A L S E T T I N G

As has been mentioned in the introductory chapter, the area under investigation contains an important assemblage of Mesozoic rocks. A variety of lithological types ranging from arenaceous to argillaceous and calcareous in composition are abundantly developed. The sedimentary rocks mainly comprising varieties of sandstones, siltstones and limestones are intruded by the dykes of dolerites and overlain by basalts of Deccan Trap. The various

formations as mapped in the field show the following succession:-

Alluvium, Coastal sands, Blown sands, etc.		Recent	
Sandy oolitic limestones	+20 m.	Sub-Recent()	
Green sandstones	5 to 7 m.	Supra-Trappean	(?)PALAEOCENE
Intrusive dolerites and basalt flows	3 to 15 m.	Deccan-Trap	CRETACEO - EOCENE
Sandstones, ferruginous sandstones, silty shales	274 m.	Bhuj Series	LOWER TO MIDDLE CRETACEOUS
Sandstones, siltstones, shales	82 m.	Umia Series	
Shales, sandstones, calcareous sandstones and siltstones	329 m.	Katrol Series	JURASSIC
Shales, sandstones, oolitic limestones	122 m.	Chari Series	

---------- Katrol Fault ----------

Sandstones, ferruginous sandstones, silty shales	+140 m.	Bhuj Series	LOWER TO MIDDLE CRETACEOUS
Sandstones, siltstones, shales	+15 m.	Umia Series	

The Cretaceous rocks are repeated on account of the Katrol fault. This fault runs almost E-W and dips rather steeply due south, thus being more of

the nature of a reverse fault. Though the dips of the strata in general are due south, the most striking structural feature of the rocks is the existence of elongated domes and flexures in the vicinity of the fault to its south (Fig. 2).

On the whole, the rocks in the central part of the area are better exposed. The degree and extent of exposures is very good and individual beds can be easily traced for considerable distances. Comparatively, the area to the north of Katrol fault is poorly exposed. Similarly the areas in the south fringing the basaltic hills of Deccan Trap, are also not well exposed. The general trend of the strike is east-west and the various beds are seen gently dipping (5^{o} - 10^{o}) due south. However, in the vicinity of the faults high dips - as much as 30^{o} to 60^{o} are noted (Fig. 1).

In the following pages of this chapter, the author has systematically described the various field characters both lithological and structural recorded by him. The whole account has been divided into two main sections. The first one deals with the

areal distribution and field characters of the rocks belonging to the different formations, while in the second section, is included a description of the various characteristic sedimentary structures whose study was found useful in deciphering the prevalent depositional conditions.

Section A

Areal Distribution And Field Characters

ROCK FORMATIONS TO THE NORTH OF KATROL FAULT

To the north of the Katrol fault are exposed Cretaceous rocks - parts of both Umia and Bhuj Series (Fig. 1).

Umia Series:-

Umia series consists of a group of inter-stratified beds (0.35 to 0.45 m. thick) of following lithological types:-

(1) Purple, medium to fine grained, silty, sometimes micaceous sandstones and siltstones.

(2) Red, brown and variegated, coarse grained, ferruginous sandstones.

(3) Greyish black, silty, carbonaceous shales.

These three lithological types do not show any succession and are interbedded rather haphazardly.

The total width of the outcrop of this series in the eastern part of the area is about 500 metres. While on being traced to the westward, towards the extremity of the area, its width is reduced to about 300 metres or even less.

The various beds of this series can more or less be continuously traced from the easternmost boundary of the area upto as far as 400 metres west of Bhuj-Mandvi road. Good exposures are recorded just south of Bhuj on the Bhuj-Mundra road, and these are seen continuing westward. Just near the road to its west a carbonaceous shale band has yielded some plant fossils. Very poorly preserved, these fossils - plant impressions - look like small leaves. The strata are gently dipping (2° - 3°) due south. Further west of Bhuj-Mandvi road, after a gap of about 2 km., Umias are again encountered north of Sukhpur. Here these rocks form nearly 300 metres wide outcrop ideally exposed in a nala. This outcrop can be traced further west even beyond Kalyanpur, but here all the above described rock units of Umia series are not seen. Only some purple, fine grained,

laminated sandstones, siltstones and occasional ferruginous sandstones are recorded and that too, the outcrops are discontinuous. Further west of Kalyanpur another set of good exposures are noted in small hills, 2.5 km., NNW of Mankuwa. Fine grained sandstones here, show a typical columnar jointing. To the south and the west of this hill are seen doleritic dykes running WNW-ESE and NNE-SSW respectively. These dykes are highly weathered, friable and of purple colour. The columnar jointing in the sandstones appears to be due to the effect of these intrusions.

Further, on going west of these hills, the exposures of Umia rocks get sparse within the limits of the area. (Of course to the north of this hill good outcrops are present). About 2 km. north of Nangiari, a few isolated patches of poorly exposed Umias are noted. Here the rock is mainly a purple, fine grained, micaceous sandstone. In these exposures, the Umia beds show a slight change in the dip direction, and are seen dipping very gently (about 2° - 4°) due S.E.

Bhuj Series:-

The Umia series is succeeded by the rocks of Bhuj series which for the most part consist of massive sandstones. The entire series is seen to be made up of a number of repetitious identical sedimentary units - each comprising (in ascending order) the following:-

(1) A discontinuous thin basal layer of white to grey, silty claystone - shale (sometimes present, sometimes absent).

(2) Yellow, brown and pink, coarse to medium grained, massive friable, cross bedded, felspathic sandstone forming the main bulk of the unit.

(3) Thinly bedded limonitic gritty sandstone layer.

(4) Highly ferruginous, hard and compact, brown, coarse-grained sandstones - marking the top of the unit.

The main bulk of the Bhuj rocks is seen to show several of the above mentioned units, and the entire formation is made up of several such units or cycles.

It is obvious that a sort of cyclic fluctuation in the nature of sedimentary environment gave rise to this repetition.

The massive sandstones show very poor stratification and it is difficult to take accurate dip measurements in these rocks, except where the ironstone bands and claystone or shale bands are present. The strata dip gently (2° - 3°) due south. These sandstones show cross-bedding. Near their contacts with doleritic dykes and along faults zones these are seen to be quite hard, almost quartzitic with a glimmering lustre.

Rocks of Bhuj series form conspicuous and good outcrops all along the northern part of the area, north of the Katrol fault. Overlying the Umias in the north, these Bhuj rocks are cut by the Katrol fault to the south. Almost continuous exposures are recorded and can be traced from east to west around Mirzapur, Sukhpur, Mankuwa and Samatra.

In the east, Bhuj rocks are seen occurring in force in the hills just to the northeast of Mirzapur.

Isolated patches forming small hillocks are also noted to the south and southeast of the village. The rocks are exposed on the surface as well as are seen in a number of sections and cuttings. The cyclic nature of sedimentation giving rise to a repetition of the above mentioned layers is conspicuous and in all, five cycles are clearly revealed in these outcrops. It is noted that the lowermost claystone or shale layer which underlies the massive sandstones is not developed prominently in this part and only the upper three varieties are repeated again and again. A conspicuous transverse fault, north of Dharamsala cutting the Bhuj rocks, is noted for 400 metres, its strike being 130° - 310°.

West of Mirzapur and to the west of Bhuj-Mandvi road, a few outcrops of these sandstones are recorded around Sukhpur. Only the yellowish brown, coarse, friable sandstones are seen to occur, the other two varieties are not clearly developed. One and half kilometre southwest of Sukhpur in the nala,

white, grey, laminated claystone or shale, which is the characteristic bed underlying the massive sandstone, is exposed. In this claystone band clear plant impressions are seen preserved. Rajnath (1942,p.11) has also reported similar occurrences of the plant fossil from Bhuj series, perhaps the only plant fossil to be reported, and has identified it as Ptilophyllum cutchense.

On going further west, beyond Sukhpur upto Mankuwa, very few exposures of the sandstones of this series are noted. Two and half km. east of Mankuwa, there is a basic intrusion forming a small hillock, and it is obvious that the intrusion is cutting the Bhuj rocks. This intrusion continues northwards as a dyke. Perhaps this dyke extends southward also-somewhat intermittently for about 2 km. and abuts against the Katrol fault. All along the contact of the dyke, the sandstones have altered into quartzites. About 750 metres southeast of Mankuwa in a nala, again the bed of white claystone that underlies the massive sandstones, is exposed. Perhaps it is the same bed which is seen near Sukhpur. As usual a few ill-defined plant impressions are present.

South of Mankuwa village these sandstones are seen forming gentle E-W folds - a northern syncline and a southern anticline. The folds are very gentle and the dips of the limbs hardly exceed 6°. These flexures flatten to the east and west.

In the area to the southwest of Mankuwa, towards and around the village Bharasar, the Bhuj sandstones with all the accompanying variations form ideal exposures in the three southwest flowing nalas. Almost continuous exposures are met with right upto the Katrol fault in the south. Varieties of sandstones, - massive as well as variegated, gritty and ferruginous, are well exposed in nala sections. In all five units of deposition, each beginning with massive sandstone, succeeded by variegated gritty layer and finally by ironstone bed are recognised. The claystones are not significantly developed. A maximum thickness of approximately 150 m. is measured. Along the easternmost nala, a doleritic dyke trending NNE-SSW is encountered. This dyke shows alteration into a purple friable rock. The same dyke is seen exposed to north about 500 m. south of Mankuwa. Here the alteration and weathering

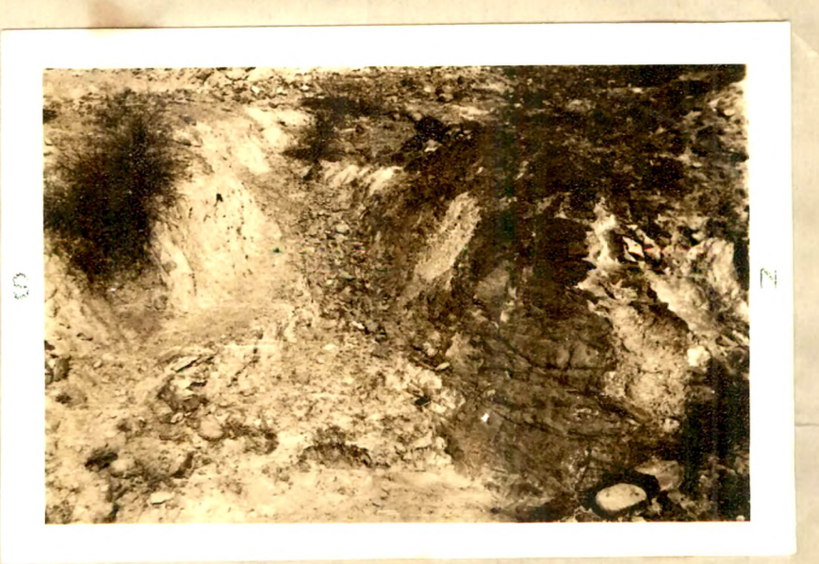
of the basic dyke is ideally seen. This dyke is seen abutting against the Katrol fault in the south.

Apart from the nala sections, the exposures in this area (i.e. to the west of Bharasar) are rather scanty. Only a few scattered hillocks of poorly exposed sandstones are seen occurring sporadically. Here again, is recorded an N-S transverse fault cutting the Bhuj rocks. This fault is seen truncated by another NE-SW fault in the north, while in the south it, as usual, abuts against Katrol fault.

Further west, there are small hillocks formed of friable, massive sandstones. The outcrops as such are poor and invariably capped by a ferruginous, compact rock (ironstone) which appear to have been derived by the weathering of the underlying massive sandstones. This ferrugination of the sandstones indicates a longer duration of exposure to oxidising agents. Through these rocks intrudes a NNE-SSW doleritic dyke.

Around Samatra in the west, massive sandstones are again very well exposed. But here the repetition

PLATE I



A. Katrol Fault.

B. Katrol fault showing drag effect.

of various units as seen in the east, is not so clear. A minor but conspicuous transverse fault cutting these rocks east of Nangiari is seen continuing southward and abutting against Katrol fault.

KATROL FAULT:

Katrol fault is an almost east-west regional fault and is inclined steeply (about 60° to 80°) to the south (Fig. 1), It is clear from the field evidence that the older rocks to the south (Chari and Katrols) have been brought over younger (Bhuj) ones and thus in its present state, the dislocation is of the nature of a reverse fault. Broadly speaking the trend of the fault runs parallel to the strike of the strata. Except at a few places where the fault-zone is covered by recent soil, throughout the area good sections of the fault-zone are exposed (Plate IA & B). Though for the most part, the fault is seen extending E-W, at many places its course has been somewhat sinuous. When traced from east upto Bhuj-Mandvi road, the trend of the fault is east-west. West of Bhuj-Mandvi road near Wandh its strike becomes almost NE-SW.

South of Bharasar and further west it is somewhat zigzag. South of Samatra, however, its trend again becomes east-west (Fig. 2).

In the immediate vicinity of this fault, to the south, considerable drag effect is noticed in the dips of the strata. On crossing the fault at a number of places, strata to the south show overfolding due to the drag movement. When traced southward just along the fault plane, the dips are fairly steep due south, and within a distance of a few metres, they become almost vertical, then start dipping due north and ultimately on crossing the crest of the flexures, start dipping gently due south (Fig. 5). Field evidences clearly point to a possibility that this folding, and perhaps the dome structures are connected with the reverse movement along the fault plane.

Fault-breccias are scarce but not absent. At a number of places they have been recorded e.g. south of Mirzapur, Bharasar and south of Samatra.

ROCK FORMATIONS TO THE SOUTH OF KATROL FAULT:

In the area to the south of Katrol fault, a complete succession of all the rock formations can be

traced from north to south; the oldest being the Charis and the youngest being the Deccan Trap (Fig.1). Immediately to the south of the fault, all along the dislocation, north-dipping Katrols are seen forming a narrow discontinuous band. The fact that this formation is occurring in contact with the fault, and not the Chari, is evidently on account of the formation of drag folds (resulting into domes) in the vicinity of the thrust. Wherever the domes have been dissected by the fault, the Katrols have been eroded away, and the Chari rocks are seen abutting against the fault. Further south, after the zone of domes, the dips again uniformly start dipping due south (about 10°-12°) and the Katrols are seen successively overlain by Umia and Bhuj series and finally by the lavas of the Deccan Trap right near the southern extremity of the area.

Chari Series:

South of Katrol fault, in all eight domes have been recorded in the area (Fig.2). While some of the domes are rather complete, others are only

partly developed. A study of the various domes has revealed the following succession of Chari rocks in the area:

Yellow and brown, silty and clayey, oolitic limestone; in portions ferruginous, highly fossiliferous with belemnites, ammonites and brachiopods (Dhosa Oolite).	
Greenish yellow, sandy limestone.	MEMBER C
Grey, yellow, khaki, gypsiferous and calcareous shales with intercalated calcareous and ferruginous siltstones at times fossiliferous.	(47 m.)
Brown, red, grey, gritty, hard, calcareous and ferruginous sandstone; mostly fossiliferous with lamellibranchs, brachiopods and ammonites; on weathering stands out prominently.	
Yellow, greenish grey, shales; alternating with ferruginous sandstones and calcareous siltstones.	MEMBER B
Grey, brown, gritty, compact, calcareous and ferruginous sandstone (similar to above mentioned but less fossiliferous).	(46 m.)
Grey, yellow, purple, medium to fine grained, friable sandstone; occasionally hard and calcareous.	

Yellow, reddish brown, conglomerate; calcareous and ferruginous, fossiliferous with belemnites and gastropodes etc.	
Yellow, grey, khaki, calcareous shales; intercalated with ferruginous and calcareous siltstones.	MEMBER A (29 m.)
Yellow, purple, fine grained calcareous sandstones.	

Base Not Exposed

Top of the Chari series is marked by a boundary, yellow, brown oolitic fossiliferous limestone band commonly known as Dhosa Oolite. This band of 0.5 to 0.6 m. thickness outcrops prominently and is very useful in tracing the Chari rocks.

From east to west, as stated above, the Chari rocks are exposed all along, to the south of Katrol fault forming a number of domes. The northern limbs of these domes at several places cut up by the Katrol fault, and whenever traceable, are always steeply, dipping due north, and abutting against Katrol fault. Sometimes these northern limbs are seen even overturned. and dipping steeply due south. The southern limbs of the domes are somewhat continuous, gentler, dipping due south. The Dhosa Oolite band on the southern limbs, is very often seen shifted by a metre or two to the

north or south on account of N-S transverse faults. This shift is very characteristic in the field and has proved very useful in delineating the southern limits of these domes (Fig.2).

In the easternmost part of the area, Chari rocks form a conspicuous, elliptical dome about 500 metres long (Fig.2). The Bhuj-Mundra road almost cuts across this dome. Its existence is made very conspicuous by the easily recognisable Dhosa Oolite band, which forms rather an arcuate exposure. The southern flank of the dome almost strikes E-W and dips 20° due south, while in the north it is truncated by the Katrol fault. In the northwestern part of the dome, where Katrol fault cuts it, a small outcrop of Dhosa Oolite dipping due north is recorded and obviously represents a fragment of the north dipping limb. To the east, this dome, at about 800 metres east of the Bhuj-Mundra road, is seen abruptly truncated by a NNE-SSW fault.

Rocks which underlie the Dhosa Oolite, are ideally exposed in the core of the truncated dome and form good exposures in the tract between Katrol fault and Dhosa Oolite band. Immediately to the south of

Katrol fault, to the east and west of the road, grey, yellow, gypsiferous, calcareous shales with ferruginous nodular siltstone bands (Member B) are recorded. They show inverted dips (i.e. steep southerly). These shales are overlain by reddish brown, gritty, hard, ferruginous and calcareous, fossiliferous, sandstone band (Member B). This band follows the trend of Dhosa Oolite and to the west, it swings as much as NE-SW dipping due NW and abutting against the Katrol fault. Its eastern limit is marked by the above mentioned transverse fault. This underlying band shows distinct anticlinal E-W flexure, in the vicinity of the Katrol fault, ideally recorded in the ground to the west of the Bhuj-Mundra road. To the south, this sandstone band is seen overlain by a group of grey shales (gypsiferous and calcareous, rarely fossiliferous), intercalated calcareous and ferruginous siltstones and yellow limestones. These rocks are in turn overlain by Dhosa Oolite.

Further west, nearly 1 km. from Bhuj-Mundra road (2.4 km. south of Mirzapur), the Chari rocks are seen forming two almost complete domes (Fig.2). Again the

Dhosa Oolite band proves very useful in locating and demarcating the domes which show quaquaversal dips. The cores of the domes are made up of usual shales and calcareous siltstones, that underlie the Dhosa Oolite. In the central part of the north-western of the two domes a basic sill-like intrusion is recorded. A number of minor N-S faults are seen cutting the domes. To the west of these domes, a fault trending ENE-WSW with dip 70° due NNW is recorded.

Further west, again the Dhosa Oolite is seen to characteristically form a narrow elongated small dome-like structure, the length of which running parallel to the Katrol fault is about 200 metres while the width is having 50 metres. At the western extremity of this small dome a transverse fault of moderate dimension is seen affecting the strata.

Further west, a large truncated dome is exposed and noted on both sides of Bhuj-Mandvi road (Fig.2). It extends for 1.0 km. to the east of road and for 800 metres to the west of road. The southern flanks of this dome are characteristically recognised on account of the usual Dhosa Oolite band. The dips

to the south vary from 4° to 20°. The north dipping portion of the dome nearer the Katrol fault is discontinuously exposed to the east of Walakhavas tank. Near this tank, the swing in the dip direction can be easily seen in the field. The dome is bounded as usual, by the Katrol fault to the north and in the area between Dhosa Oolite and this fault, a small outcrop of overlying Katrol rocks are noted. This dome too is seen cut up by a few transverse N-S faults.

As usual, the older rocks that underlie Dhosa Oolite are seen outcropping in the core of the dome. Broadly speaking, the upper portion of the underlying rocks viz. shales are exposed in the eastern part of the area while the lower beds consisting of calcareous gritty sandstone (Member B) occupy the western part. Once again a doleritic intrusion is seen to occur in the core of the dome. This particular intrusion appears to be partly of the nature of a sill, overlying the Dhosa Oolite band.

All the above described domes which lie to the east of Bhuj-Mandvi road are comparatively of lesser

dimensions, their longer axes never exceeding 0.8 to 1.0 km.

On going further west between the villages Bharasar and Samatra, three conspicuous domes are present (Fig.2). Out of these three, the eastern one is a major dome. It is roughly elliptical in shape and elongated in E-W direction. Its longer axis extends for almost 9.5 km. Its maximum width is of about 4 km. between Katrol fault and Khandewav Chowki. The northern flank of this dome is discontinuous, having been truncated by the Katrol fault. As a result, the older Chari rocks lying below Dhosa Oolite abut directly against the Katrol fault. In the northwestern part of the dome, immediately in the vicinity of the Katrol fault, there are minor east-west trending anticlinal and synclinal flexures ideally shown by Dhosa Oolite band. The northern flanks of the Dhosa Oolite band and older rocks dip steeply to the north while in central and southern part the dips are gentle and subhorizontal. In a few sections where the northern flank is present, immediately to the south of the

Katrol fault, for a distance of 3 to 6 m. the dips are overturned and their amount varies between 65° to 85° towards south (Fig. 2).

In contrast to the steeply dipping northern flank, the southern flank of the dome has gentler dips due south. The dome, mainly in its central and southern part, is much cut up by numerous transverse faults. Effects of these faults are ideally seen in successive shifting of the Dhosa Oolite band.

In the eastern and western parts of the dome, Dhosa Oolite band swings as much as N-S and NE-SW dipping due east and northwest respectively. The dips are 10° - 20°. In the central part of this dome minor anticlinal and synclinal flexures are noted. It is in this dome that the maximum thickness (122 m.) of the Chari rocks is exposed and the complete succession as given earlier is clearly recorded. On the basis of three distinct bands which are persistent throughout this dome, the rocks of Chari series could be grouped into the three above mentioned members (Fig. 6). The central portion of this dome contains a number of basic intrusions: dykes (N-S) and plugs with occasional

sills. Similarly; in the western portion of this dome is seen intrusives and its core is practically entirely occupied by the basic rocks.

The other two small domes lie to the southwest of the above major structure (dome) and can be easily recognised 10 km. southwest of Samatra village. These comparatively smaller domes are elliptical in shape and occupy roughly an area of 8 to 10 sq.km.each. In the core of these domes, the usual underlying shales are exposed which are intruded by N-S dykes.

Katrol Series:

The formation that overlies Dhosa Oolite has been termed as 'Katrol Series' (Fig. 1). Though there is no marked unconformity between the Chari and the Katrol series, this separation has been decided upon a number of evidence. The abrupt paucity of fauna (may be because of a change in environments) in the beds that overlie the highly fossiliferous Dhosa Oolite, marks a 'paraconformity'. It is seen that the overlying bed - a sandstone or siltstone, tends to be lensoid, thus bringing shales that occur

over these sandstone in direct contact with the Dhosa Oolite. This typical discontinuous deposition signifies a minor non-sequence.

Wherever the rocks of Chari series are not exposed, the rocks of Katrol series abut directly against the Katrol fault, and many times they are overfolded and show inverted dips due south.

Characteristically enough, the Katrol series shows considerable lateral variation in its upper part. This has been very clearly recorded in the field (Fig. 6). Accordingly, the following successions for the eastern and western parts of the series, have been worked out.

LITHOLOGY		
Eastern part	Western part	
4) Brown and yellow, massive, medium grained, friable sandstones.	4) Alternating brownish yellow sandstones and pink and brown calcareous siltstones.	MEMBER D
(76 m.)	(76 m.)	

3) purple and yellow, fine grained calcareous and ferruginous sandstones and siltstones. (476 m.)	3) Grey and yellow shales with inter-stratified layers of purple, flaggy calcareous siltstones. (116 m.)	MEMBER C
2) Grey, yellow and khaki, occasionally gypsiferous shales, inter-bedded with yellow and red, nodular siltstone bands. (98 m.)	2) Grey, yellow and khaki, occasionally gypsiferous shales, inter-bedded with yellow and red, nodular siltstone bands. (107 m.)	MEMBER B
1) Alternating grey and yellow, gypsiferous shales and calcareous siltstones with micaceous, ferruginous sandstones. (430 m.)	1) Alternating grey and yellow, gypsiferous shales and calcareous siltstones with micaceous, ferruginous sandstones. (130m.)	MEMBER A

Member A : The bottommost member of the Katrol series, consisting of alternating shales of grey and yellow colour, with bands of calcareous

siltstones and sandstones (micaceous and ferruginous) is seen resting over the Dhosa Oolite. In most places this oolitic band is overlain by the shales and siltstones but in some localities, the lensoid bands of micaceous and ferruginous sandstones intervene, resting over the Dhosa Oolite. This fact is a clear indication of the existence of a paraconformity. These sandstone bands are ideally seen in the exposures on the Bhuj-Mundra road and Bhuj-Mandvi road.

Good exposures of this member are seen outcropping in a number of localities throughout the area. From east to west, these can be systematically traced and studied. In the eastern-most part (2 km.north of Tapkeshwar temple), typically grey and yellow shales form good exposures and are seen abutting against the Katrol fault. These shales contain frequent crystals of gypsum and are interstratified with thin bands of haematitic nodular siltstone and calcareous siltstone. These rocks form featureless,undulating low ground and show good sections in small stream cuttings. Here a N-S doleritic dyke cuts these rocks, and is

seen abutting against Katrol fault. Along the contact of this dyke the shales are seen to have been rendered black and indurated.

On the whole, the dips are gentle and due south never exceeding 10°. (Of course, as stated earlier, near the Katrol fault, the dips are due north and fairly high and sometimes even inverted.) Distinct E-W anticlinal and synclinal flexures in the Katrol rocks immediately in the vicinity of Katrol fault (Fig. 2) are a common feature. These folds are obviously a product of the drag effect of the fault.

On going west, the succession of shales and calcareous siltstone continues, forming undulating grounds. Wherever the ferruginous siltstones have been exposed on the surface, they weather very characteristically into small reddish brown, angular chips which lie scattered all over the surface of shales. In this part, a few metres east of Bhuj-Mundra road a thin bed of red, yellow, variegated, ferruginous siltstone is seen separating the shales from the Dhosa Oolite. This siltstone bed appears to be

a locally developed lens, as when traced further west it disappears. To the west of the Bhuj-Mundra road the Dhosa Oolite band is again seen overlain directly by the usual shale-siltstone unit. These shales, (east of the road) about 800 metres south of Katrol fault are seen intruded by a NNW-SSE doleritic dyke which extends for few metres to the south.

Along Bhuj-Mandvi road, Dhosa Oolite band is overlain by a locally developed greenish, medium grained ferruginous sandstone. This is lensoid, in nature and disappears after a short distance on both sides. A few metres east of the road the overlying shale-siltstone unit of this member is seen cut by a NW-SE doleritic dyke.

This member comprising mainly shales and siltstone is not so characteristically developed in the western part of the area, and is seen at a few places only.

Member B: Member A is succeeded by grey, yellow, gypsiferous shales interstratified with about a metre thick, brown, purple, hard, calcareous siltstones.

This shale-siltstone sequence, on erosion, forms a characteristic uneven topography and constitutes a diagnostic feature.

On going from east to west, right upto the western limits of the area, these shales and siltstones are encountered almost continuously. Good exposures are seen in the nala-cuttings and road sections. Near Godpur village and further 1 km. west of the same village, two major N-S doleritic dykes are seen cutting this member. These are seen extended in the north and abut against the Katrol fault. In the extreme western part of the area these rocks are intruded by a major NS to NNE-SSW dyke. This dyke and a few sill-like masses together cover a major part of the area.

Practically all over, the dips remain low and due south. Whenever this member is exposed in the vicinity of Katrol fault, the rocks dip due north showing somewhat higher (35^{o}) dips. Occasionally the unit shows gentle E-W flexures, somewhat away from the Katrol fault, and one good example can be seen in the west of Sanitorium and to the southwest of

of Shedata. These flexures die out in the north and the east, while to the south and the west are bounded by an E-W and N-S faults respectively. The former fault is recorded in the nala 400 metres west of Bharapur, to the north of which shales and siltstones of this member are exposed. While the latter is ideally exposed at 8 mile 4 furlong milestone, where along with it a dyke has arisen.

Sections noted all throughout the area reveal that the layers of these gypsiferous shales and calcareous siltstones are of unequal thickness varying between 100 cm. to 30 cm. Not only this variation in the thickness is seen in vertical sense, but individual layers also increase and decrease in thickness when traced laterally. The stratification is such that practically most of the layers are discontinuous and lens shaped and tend to pinch out when traced over a distance.

The uppermost layer of this member is a thin calcareous siltstone, which forms typically discontinuous hard crust over the shaly surface. This is a very conspicuous feature of the Member B

and is very useful in separating this group from the overlying rocks. This marker band shows marked lithological variation from east to west. In the eastern part it is more sandy, less calcareous and somewhat ferruginous, while towards west it tends to become more and more calcareous. In the area lying to the east of the Bhuj-Mundra road this calcareous siltstone capping (described above) is seen lying over a thin (about a metre or so in thickness) band of compact gritty calcareous sandstone. This band has a very restricted occurrence and is confined to the area mainly to the east of Bhuj-Mundra road. It extends for about a kilometre when traced eastward of the road and then gradually disappears. To the west of this road this band can not be traced. Obviously it pinches out on both sides, suggesting a lensoid shape. A similar band of gritty, ferruginous and calcareous sandstone is again noted in the extreme west of the area and its exposures are seen at 1.5 km. northeast of village Sarli and 2 km. southwest of Pragsar. Here also it is thin and lensoid and is characteristically absent from the intervening ground.

Member C: The next overlying member C comprises the rock types which show a lateral variation in lithology from east to west. In the east this member is seen to be dominantly sandy and silty, while to the west it is more shaly. Outcrops of this member in the eastern part of the area are mostly silty sandstones - yellow, purple, brick-red, and pink in colour. Generally compact and massive, at some places they tend to be micaceous and laminated. Intercalations of thin layers of white silty shales are quite numerous. It is observed that in this part the upper layers of this unit are somewhat more ferruginous and slightly calcareous. Good exposures of this succession, are seen near the Tapkeshwar temple, which extend as far as Bhuj-Mundra road. This purple sandstone is a typical one and is utilized as marker in separating underlying and overlying members. To the west of the Bhuj-Mundra road, these rocks form poor exposures for about 0.6 km. and after that they disappear. In the ground between Bhuj-Mundra road and Bhuj-Mandvi road this member does not outcrop, perhaps being eroded away.

Further west of the Bhuj-Mandvi road, member B is seen overlain by shales. A careful mapping has revealed that it is the same member as the one seen in the east, but has gradually become shaly westward. These western outcrops, extending from Bhuj-Mandvi road right upto the western limit of the area, are of the nature of silty shales - grey and yellow in colour, with carbonaceous impressions and streaks. These shales are seen interbedded with variegated calcareous siltstones. The top layer of this member(C)is a red to yellow, hematitic siltstone, which weathers in a characteristic manner, giving rise to small polygonal chips strewn over the rolling mounds of the shales.

On the whole, the dips of the rocks are as usual low (5^{o} - 10^{o}) and due south. But in the outcrops immediately to the east of Bhuj-Mandvi road, a local change in the direction and amount of the dips of these beds is noted. This, infact, is the continuation of flexures recorded in the east in the rocks of member B.

Member D: The next younger member (D) is a group of brown and yellow sandstones. In the east, practically the entire succession consists of these sandstones, while on being traced to the west, these sandstones are seen alternating with pink and brown calcareous siltstones.

In the eastern part of the area, good exposures are seen in the vicinity of Sanitorium, from where they extend eastward across the Bhuj-Mundra road. At several places the siltstones of member C are seen distinctly overlain by a massive (exceeding 35 m. in thickness), yellow, friable sandstone. While the main bedding is not distinct, this sandstone amply shows large-scale cross-bedded structure. The uppermost layers of this sandstone are of brickred colour and rather ferruginous. The dips are very low, the strata being almost subhorizontal or dipping with, 2° to 5° due south. At few places, mostly to the east of Bhuj-Mundra road, these sandstones are cut across by transverse faults (NNW-SSE, N-S and NE-SW). These eastern outcrops are terminated

southward by a strike fault (Bharapur-Godpur fault) (Fig.2). On account of this faulting, this member is seen coming directly in contact with rocks of Bhuj series, the Umias having been eliminated.

To the west this member is exposed again along Bhuj-Mandvi road. In the intervening ground, these rocks do not occur, perhaps having been eroded away.

Along the Bhuj-Mandvi road, these rocks are seen to have been thrown into a number of gentle flexures; on account of the folding, its exposures are noted more than once on proceeding southwards. Broadly, the exposures mark two bands separated by older rocks occupying the core of the anticlinal flexure. The northern outcrop on being traced westward is seen abutting against the Katrol fault (2.0 km. SE of Mankuwa). Along the synclinal axis south of this northern exposure a strike fault (WNW-ESE) is recorded. The southern band extends beyond the limits of the area westward, but to the east is cut by the above mentioned transverse fault (page 64). In the extreme west, however, the

succession is complete and these rocks are seen underlying the Umia series.

Cross-bedded structures are less frequent in the western part as compared to the eastern and are restricted to a few exposures north of Godpur.

On the whole, it is evident in the field that the members of the Katrol series are better differentiated in the eastern part as compared to the west.

Umia Series:

The rocks of Umia series, the next younger formation of the area, are mostly variegated siltstones, pseudo-oolitic, gritty sandstones, brown sandstones and silty carbonaceous shales. There is a considerable interbanding of these various lithological types and the entire formation, about 82 metres thick, consists of layers of siltstones, sandstones and shales. No succession can be decided upon in this series, and thus it has been studied and described as a whole. (As will be seen in subsequent chapters, the rocks of

Umia series, are of transitional type indicative of the change of environment - from marine to non-marine.)

The exposures of the rocks of this series are rather discontinuous, having been affected by the major E-W (Bharasar-Godpur) fault. Lithologically, the exposures of Umia rocks to the south of Katrol fault, are in a broad way identical to those north of Katrol fault. The siltstones are of many shades of red and brown colour. The sandstones are either gritty, pseudo-oolitic and rather ferruginous, being yellow and brown in colour, or they are cream coloured, massive and friable. The shales are of grey colour, generally silty but with some carbonaceous streaks and poorly developed plant impressions.

Exposures of these series are seen in two places and always to the south of Katrol rocks. In the eastern part of the area, a few outcrops are seen along the nala cuttings e.g. north of Narayanpur. In these outcrops Umia sandstones and siltstones are clearly seen overlying the shales

and calcareous siltstones of Katrols and dip very gently (3^{o} - 6^{o}) due south. Again to the west of Bhuj-Mandvi road, this series outcrops rather continuously for more than 100 metres. In the stream cuttings near the village Godpur, excellent section of the entire series is preserved, which furnishes a complete record of the rocks of the series. West of Godpur village the rocks of this series are seen intruded by the same doleritic dykes seen in the north and recorded in the Katrol series. Identical sections are again recorded in the extreme west at the places 1.2 km. northwest and 0.8 km. north of Sarli. The rocks of Umia series show well marked bedding and lamination. Structures like cross-bedding are scarce and only poorly developed at a few places in sandstones.

Bhuj Series:

These Cretaceous rocks, overlie the Umia series rather conformably, and form good outcrops in the areas to the south of Jurassic exposures. Occurring almost continuously from east to west, the Bhuj series forms a band about

2 to 3 kms. wide. Sections and surface exposures of sandstones of this formation are recorded at a number of places - viz. east and southeast of Bharapur, around Baladia, Kera, Daisara - villages. Along Bhuj-Mandvi road, 1.6 km. south of Daisara village, a clean section of this formation is recorded. On going further west from Daisara village right upto the western limits of the area this formation is exposed continuously.

The rock-types are sandstones - massive and friable, ferruginous and sometimes silty, quite identical to those occuring north of Katrol fault. The succession of the various lithological unit is also the same.

Just like the rocks of this series to the north of Katrol fault, here also, a slight variation in the lithology from east to west - the sandstones tending to become increasingly more ferruginous, is again recorded. Similarly, their origin due to a sort of cyclic deposition under a continental environment is also abundantly clear. Bedding and lamination are quite well developed,

and a number of sandstone sections show very good cross-bedding. The dips are very gentle, almost sub-horizontal and flexures are absent, though slight variations in dips from place to place are noted. A number of transverse faults are seen cutting these rocks throughout the area. One and half km. northeast of Bharapur, a prominant plug like mass mostly of basalt intrudes these rocks. West of Bhuj-Mandvi road doleritic dykes described earlier are seen continued through these rocks also.

Deccan Trap:

To the south, the sandstones of Bhuj series are covered by the basalts of the Deccan Trap, and mark the limit of the area investigated.

Supra Trappean Beds:

At a number of places, small scattered patches (never exceeding a few metres in thickness, and 1000 sq.metres in extent) of greenish, medium grained, calcareous sandstones are recorded. These sandy patches are seen resting over the rocks of Katrol, Umia and Bhuj series. Good examples are seen near Shedata, Narayanpur, Meghpur. These appear

to have deposited sporadically in small depressions, and are essentially fresh-water deposits. The most characteristic feature of these sandstones is their fossil wood content. Some of these patches contain tiny pebbles of trap-material and it is obvious that these were formed during post Deccan Trap period.

Sub-Recent Deposits:

In a few localities (viz. one km. southsouthwest of Sukhpur - both east and west of Mandvi road, south of Bharasar), Sub-Recent deposits occupy small areas of 1500 sq.metres each. These deposits include dirty brown, compact and laminated sandy limestones and show a characteristic cross-bedding and are generally 20 m. thick. These are found to be fossiliferous (Miliolids) and oolitic. Generally these rocks occupy the foothills of the slopes (Fig.1).

Section B

Sedimentary Structures

According to Krumbein and Sloss (1963 p.124) "Sedimentary structures include the larger features of a sediment, which are better seen in outcrop

than in hand specimens. These structures depend on relations between sedimentary aggregates than on the grain to grain relations that control texture."

"Like texture and composition structure is an inherent property of rock and a guide to its origin. Whereas texture deals with the grain to grain relations in a rock, structure has to do with discontinuities and major inhomogeneties. Structure is concerned with the organization of the deposit - the way in which it is put together" - (Pettijohn and Potter, 1964; p.2).

The sedimentary structures have been classified in many ways. The recent classifications by Krumbein and Sloss (1963) and Pettijohn and Potter (1964), are the most comprehensive and widely accepted.

Krumbein and Sloss (1963, p.24) have classified the sedimentary structures into (1) Syngenetic and (2) Epigenetic. Syngenetic structures are those formed contemporaneous with the sediment. They include beddings, ripple marks, organic features, and others. Epigenetic structures are formed after deposition.

Certain concretions, compaction features and large-scale features such as folds and faults belong in this catagory.

Bedding is the most characteristic structure of all the sedimentary rocks, and the basic entity is a single bed which has been defined as "that thickness of sediment which was deposited under essentially constant physical conditions"(Otto, 1938).

Pettijohn and Potter (1964, p.4-9) have suggested an ideal classification of various sedimentary structures based on the external and internal characters of beds, and the same is summarised below.

I. Classification on the basis of external form of beds:

Class A: 1) Beds equal or subequal in thickness.
2) Beds laterally uniform in thickness.
3) Beds continuous.

Class B: 1) Beds unequal in thickness.
2) Beds laterally uniform in thickness.
3) Beds continuous.

Class C: 1) Beds unequal in thickness.

2) Beds laterally variable in thickness.

3) Beds continuous.

Class D: 1) Beds unequal in thickness.

2) Beds laterally variable in thickness.

3) Beds discontinuous.

II. Classification on the basis of internal organization and structure:

Class A: Massive.

Class B: Laminated.-

(i) Horizontal laminations.

(ii) Cross-laminations (simple and multiple).

Class C: Graded.

Class D: Imbricated (gravels) and other oriented internal fabrics.

Class E: Growth structures (such as exhibited by stromatelitic limestones, some reef-rock travertine, etc.).

III. Classification on the basis of markings and irregularities on the bedding planes.

Class A: On the base of bed.-

(i) Load structures (load casts).

(ii) Current structures(scour marks and tool marks).

(iii) Organic markings (trail and burrow casts, "fucoids").

Class B: Within the bed (parting lineation).

Class C: On top of bed.-

(i) Ripple marks.

(ii) Erosional marks (rill marks, current crescents).

(iii) Pits and small impressions (bubble and rain prints, etc.).

(iv) Mud cracks, mud crack casts, ice-crystal casts, salt crystal casts, etc.

(v) Organic markings (tracks, trails, footprints,etc.).

IV. Classification on the basis of the pene-contemporaneous deformation of beds.

Class A: Founder and load structures (load casts, ball-and-pillow structures,etc.).

Class B: Convolute bedding.

Class C: Slump structures (fold, faults, breccias).

Class D: Injection structures (sandstone dikes, sill, etc.).

Class E: Organic structures (barrows, "Churned" beds, etc.).

In the following lines, the author has briefly touched upon the characteristics of the beds as recognised in the different formations of the area; and classified them as per the scheme given above.

It is seen that the sedimentary structures of Chari are similar to those of Katrol series, while those of Umia and Bhuj series are identical. Hence, for the purpose of description, Charis have been included with Katrols, while Umia and Bhuj series have been grouped together.

Sedimentary Structures in Chari and Katrol Series:

So far as the external forms of the beds are concerned, those of Chari and Katrol series are

A

B

PLATE II (A & B) Interstratification in Katrol Series.

somewhat identical. Interstratification of shales, sandstones and siltstones is a very common feature and the individual beds of sandstones occurring in thick shales, vary in thickness from 5 to 50 cm. Occasionally the variation in the thickness of beds is as much as 50 to 100 cm.(Plate II). Not only the beds vary in thickness vertically, but laterally too, they are of variable thickness. On the whole, individual beds can not be traced continuously for long distances and tend to pinch out. All these characters place these rocks in to the Class D of external forms of bedding.

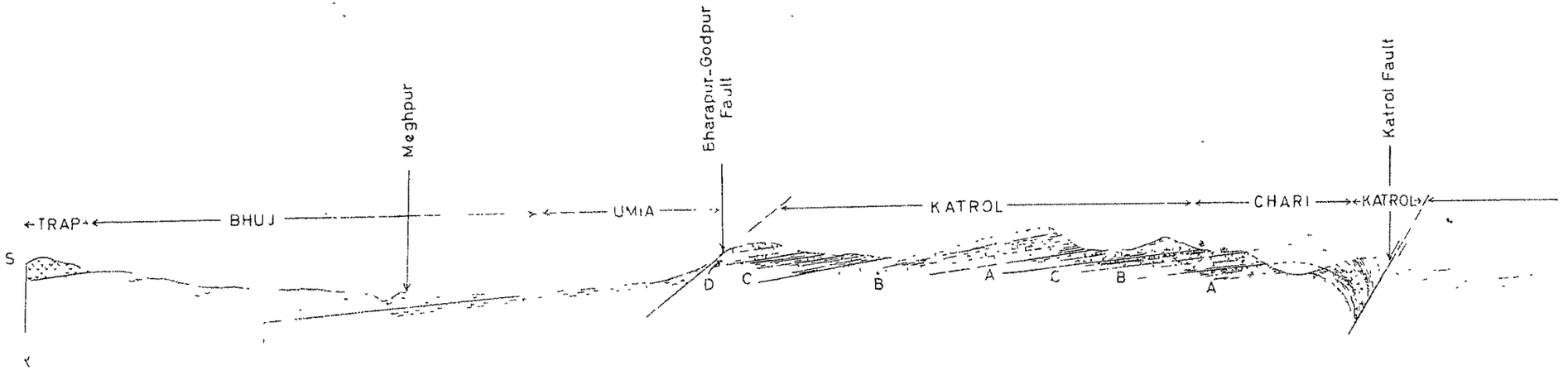
On the basis of the internal structures of the beds of Chari and Katrol series these could be placed in Class B of Pettijohn and Potter. The siltstones and shales are highly laminated, the laminae marked by the alternation of silt and clay particles. Sometimes the lamination is due to thin layers of calcareous material. The sandstone layers often show cross-laminations. On the whole cross-bedding is more common in Katrols as compared to the Charis. Both small as well as large scale cross bedding is recorded,

A

B

PLATE III (A & B) Type of cross-bedding in Katrol Series.

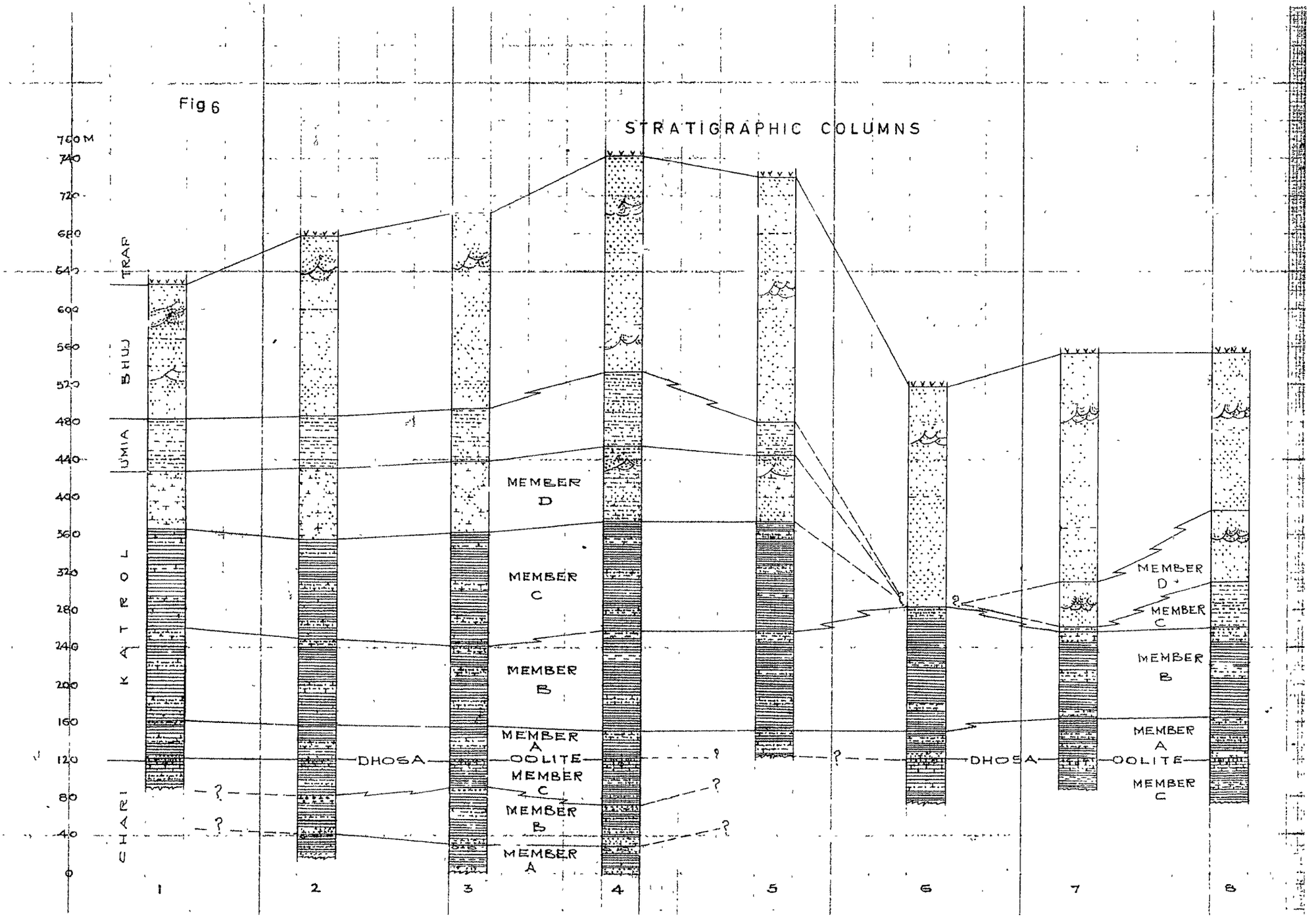
Fig 5



DIAGRAMATIC SECTION ALONG X-Y

SCALE
0 1
1 Km

Fig 6


STRATIGRAPHIC COLUMNS
760 M
740
720
680
640
600
560
520
480
440
400
360
320
280
240
200
160
120
80
40
0
TRAP
BHUJ
UMIA
KATROL
CHARI
MEMBER D
MEMBER C
MEMBER B
MEMBER A
DHOSA
OOLITE
MEMBER C
MEMBER B
MEMBER A
MEMBER D
MEMBER C
MEMBER B
MEMBER A
DHOSA
OOLITE
MEMBER C
1
2
3
4
5
6
7
8

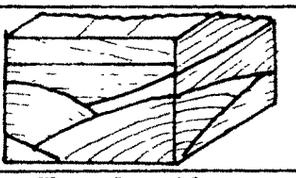
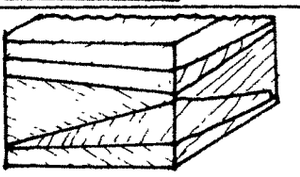
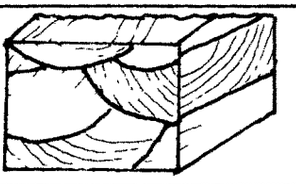
Type	Character of LWR Boundary Surf.	Cross strata shape	Appearance
Simple	Non-erosional	Lenticular or wedge	
Planar	Planar surface of erosion	Wedge or Tabular	
Trough	Curved surface of erosion	Lenticular	

fig: 7a. Three major types of cross-stratification (after Mckee & Weir, 1953)

Series	Simple (Non erosional)		Planar (Planar surface of erosion)	
	Lenticular	Wedge	Wedge	Tabular
Bhuj	Most Common	Occasional.	–	Occasional.
Umia	Sporadical.	–	Occasional.	common
Katrol	sporadical.	–	Common	Common
Chari	Common	–	–	–

fig: 7b. Type of cross-bedding in the study area.

and in many cases the entire bed is involved such that forsets extend from the bottom to the top of the bed (Plate III).

Mackee and Weir (1953) have given an ideal tabular classification of the different types of cross-bedding (Fig. 7A). The nature of the cross-bedding in Chari and Katrol rocks have been accordingly classified and shown in Fig. 7B.

In a general way, markings and irregularities on the bedding plane, are not so prominantly seen. Only in a few localities, ripple marks are seen in the sandstones of Katrol series. No other features have been recorded. Similarly structures indicative of penecontemporaneous deformation of beds, are restricted to a few localities, and are seen both in Chari and Katrol rocks. The most common are ball and pillow structures, slump structures.

Sedimentary Structures in Umia and Bhuj Series:

The beds of Umia Series, mostly consisting of sandstones, siltstones and some shales, differ considerably from those of the underlying formations

in their external form. Unlike the Chari and Katrols and the Umia series consists of beds of unequal vertical thickness, but laterally, the individual beds maintain more or less same thickness and tend to continue for considerable distances (Class B of external forms). The sandstone beds of Bhuj series also show unequal thickness and continuous lateral extension without any variation in the thickness laterally.

Cross-bedding is not so prominent in these sandstones and siltstones of Umia Series, and this structure is recorded at a few localities only. On the whole, the beds of the Umia Series are rather massive-devoid of any internal structures. But on the other hand, sandstones of Bhuj series show cross-bedding on a much larger scale. The nature of the cross-bedding in Umia and Bhuj rocks have been shown in Fig. 7B. Both massive as well as cross-laminated beds are present in this series and both these types are recognised practically all over the exposures (Class A and B of Internal forms)(Plate IV).

A

B

PLATE IV (A & B) Type of cross-bedding in Bhuj Series.

No surface markings like ripple marks, mud cracks,etc. are present in these rocks, but at some localities the beds of sandstones and siltstones (both in Umia and Bhuj series) show convolute bedding - a penecontemporaneous deformation structure of Class B.

The author has found this classification and description of sedimentary structure very useful. It is needless to emphasize that the various external and internal forms of bedding, are important structural features which go a long way in revealing the depositional sequence of different beds in an area.