Chapter - 5

DETAILS OF STRATIGRAPHIC UNITS

V. 1. INTRODUCTION:

As already discussed, the Mesozoic sequence investigated by the author ranges in age from Callovian to Post-Aptian. Considering the conventional classification it can be grouped in to three main divisions, viz., Chari, Katrol and Umia; alternatively as Jumara, Jhuran and Bhuj Formations. These rock Formations include various alternations of Shales, Limestones, Sandstones and Clay. On the whole in its lower part the rocks are found to contain marine fossil disseminations, which becomes less and less in the middle part, and completely vanishes in the uppermost portion. Trace fossils on the other hand, invariably occur throughout most of the sections - abundant at some intervals and rare or absent in others. Charred plant material and leaf impressions although distributed throughout the succession, at many locations is unidentifiable.

In order to gain a clear picture regarding the basinal developments, the present author for his studies has distinguished in all nine stratigraphic units (Members) in consideration with the different Formations. This discrimination is proposed on the basis of following objectives: Vertical and lateral extension; Thickness and geometry; Types of contacts; Grain size variation; Lithic characteristics and rock types; Sedimentary structures; and presence of trace and body fossils.

Based on the above factors, stratigraphic sections were measured at twentyeight localities. The location and other details of these sections are given in the following table-8.

Definition of each of the unit mentioned in the table is based on its field description, regional distribution including the details of its rock material, its vertical and lateral distribution. Boundaries of the units are placed at position of lithic change, distinct contacts and key bed occurrences. Care has been taken to check that all the lithological units, so recognised, generally confirm to the law of superposition and recommendations of the International Code of Stratigraphic Nomenclature (1983).

The units, designated as Members have been included under four main Formations viz., (1) Chari Formation, (2) Katrol Formation, (3) Umia Formation, and (4) Bhuj Formation; in their ascending order. Lithostratigraphic classification of the study area is given in table-9.

TABLE - 8: LOCATIONS OF MEASURED STRATIGRAPHIC SECTIONS AND IMPORTANT LOCALITIES.

LOCATION	LATITUDE	LONGITUDE	TOPOSHEET NUMBER
BALADIYA	23°05'38"	69°36'37"	41E/12
BHARAPAR	23°07'30"	69°38'00"	41E/12
BHATA TALAV	23°11'27"	69°39'15"	41E/12
BHUJ	23°14'45"	69°45'00"	41E/12
BHUJODI	23°13'37"	69°44'12"	41E/12
CHAKAR	23°05'36"	69°44'44"	41E/12
FAKIRWADI	23°11'27"	69°39'15"	41E/12
GANGESHWAR	23°12'35"	69°49'49"	41E/12
GUNAWARI NADI	23°11'00"	69°43'48"	41E/12
HAJAPAR	23°08'20"	69°46'10"	41E/16
HAMADRA TALAV	23°11'15"	69°41'16"	41E/12
JADURA MOTA	23°09'27"	69°41'16"	41E/12
JADURA NANA	23°09'33"	69°41'52"	41E/12
JAMAYWADI	23°12'39"	69°42'09"	41E/12
JAMBUDI	23°06'07"	69°44'51"	41E/12
JOGI TIMBA	23°11'30"	69°44'51"	41E/12
KERA	23°04'37"	69°35'53"	41E/12
KIRGIRIYA DUNGER	23°08'25"	69°39'49"	41E/12
KOTADA	23°06'40"	69°45'00"	41E/12
KUKAMA	23°13'50"	69°46'40"	41E/16
LER	23°11'00"	69°45'40"	41E/16
MADHAPAR	23°14'00"	69°42'30"	41E/12
TEMPLE ON MANDVI ROAD	23°11'30"	69°36'17"	41E/12
MARUTONK DUNGAR	23°10'37"	69°43'35"	41E/12
NARANPAR	23°07'00"	69°35'30"	41E/12
REHA	23°08'30"	69°44'45"	41E/12
SANATORIUM	23°09'45"	69°38'07"	41E/12
SATELLITE EARTH STATION (SES)	23°11'00"	69°38'30"	41E/12
SATPURA DUNGAR	23°11'08"	69°42'00"	41E/12
SHUTESHWAR	23°10'00"	69°46'00"	41E/16
SURALBHIT	23°15'15"	69°41'15"	41E/12
TAPKESHWARI	23°10'50"	69°40'00"	41E/12

TABLE-9: LITHOSTRATIGRAPHIC CLASSIFICATION OF THE STUDY AREA.

FORMATION	MEMBER	AGE
BHUJ FORMATION	BHARAPAR MEMBER	CRETACEOUS POST-APTIAN
UMIA FORMATION	TAPKESHWARI MEMBER	NEOCOMIAN TITHONIAN
KATROL FORMATION	JADURA MEMBER	KIMMERIDGIAN
	MARUTONK DUNGAR MEMBER	
	GUNAWARI RIVER MEMBER	
CHARI FORMATION	DHOSA OOLITE MEMBER	OXFORDIAN
	LER MEMBER	CALLOVIAN
	GANGESHWAR MEMBER	
	JAMAYWADI MEMBER	

In the paragraphs to follow, the author attempts a brief description of all such units identified by him.

V. 2. CHARI FORMATION:

Exposers of Chari Formation are found around the following localities: Gangeshwar, Jamaywadi, Ler, Bhata Talav, Temple at 9 km on Mandvi road, etc. On the basis mentioned above this Formation has been divided in to four members: viz. (1) Jamaywadi Member, (2) Gangeshwar Member, (3) Ler Member, (4) Dhosa Oolite Member. The overall thickness of the Formation is approximately 247 metres.

The base of the Chari Formation is marked by beds of its Jamaywadi Member exposed near Jamaywadi, South of Madhapar village (fig. 6), while, the top has been defined by the uppermost band of the Dhosa Oolite Member. Unconformably overlying these rocks is the Katrol Formation (Gunawari River Member). In the area studied, the rocks of the Chari Formation are exposed within the 'Amundra Ler anticline' of Biswas (1980) and form the central limb of the anticline, and include shales, sandstones and limestones.

The Chari Formation is abundant in fossils, and contains large number of invertebrates alongwith some scattered vertebrate remains. The rocks appear to have involved in a number of tectonic events as discussed earlier. Many intrusive dykes are found penetrating the sediments at various localities. The rocks, as such, have became folded, faulted, backed and at places arranged in intricate manner due to block movements (horst or graben) or step faulting.

According to Spath (1933) and Rajnath (1942), the Chari Formation covers Callovian and a part of Oxfordian age, while Pandey and Dave (1993), distinguish the sequence into two stages, Callovian and Oxfordian based on foraminiferal zonations.

V.2.1. JAMAYWADI MEMBER (JWM):

The name is derived from its type locality 'Jamaywadi' lat. 23°12', long. 69°42', South of Madhapar, where a complete exposer of the Member can be seen along a nala cutting. The Member exposes a total thickness of about 136 m, and comprises oldest rocks exposed in the area of study. In the type

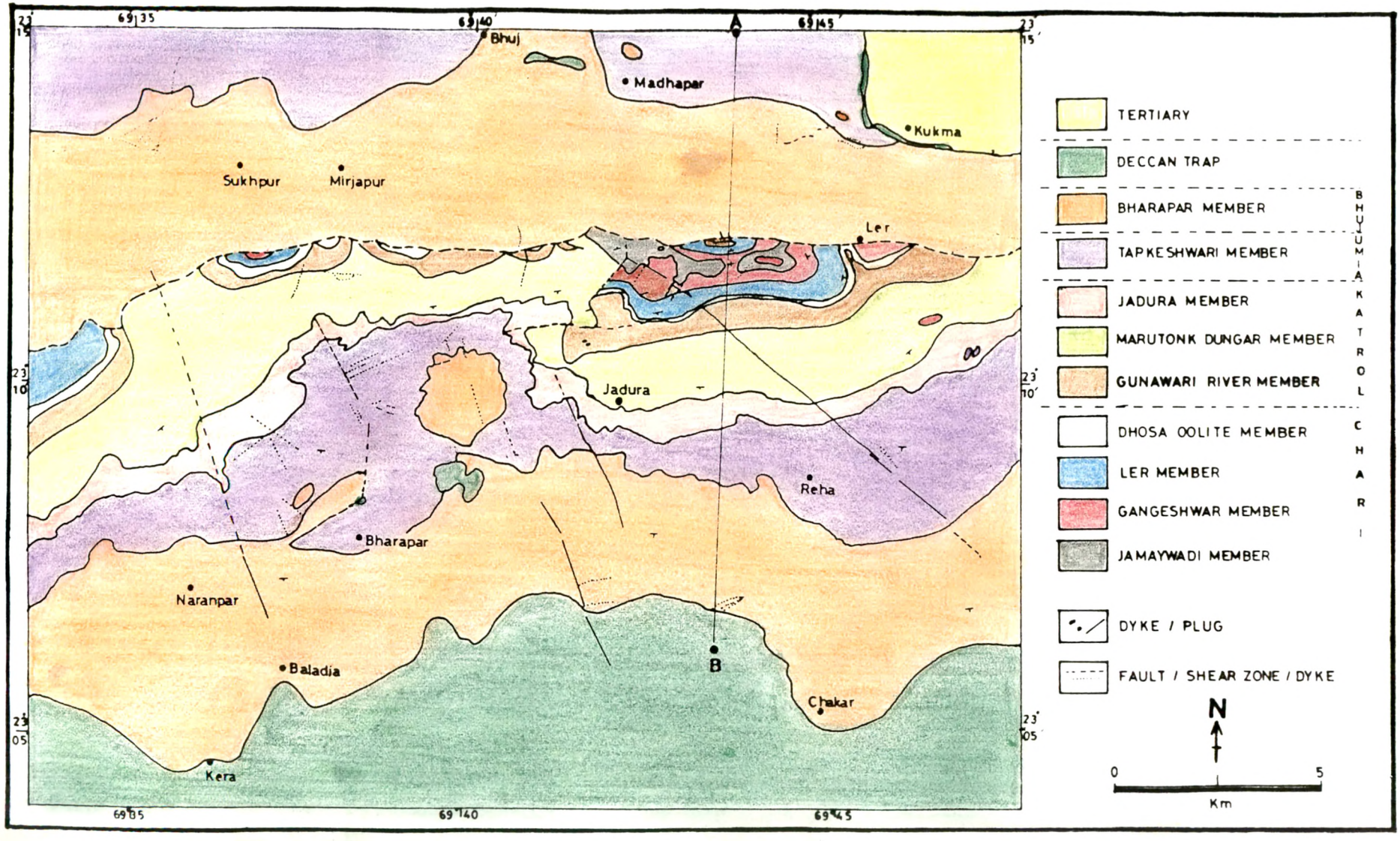

FIG. 6. GEOLOGICAL MAP OF THE STUDY AREA

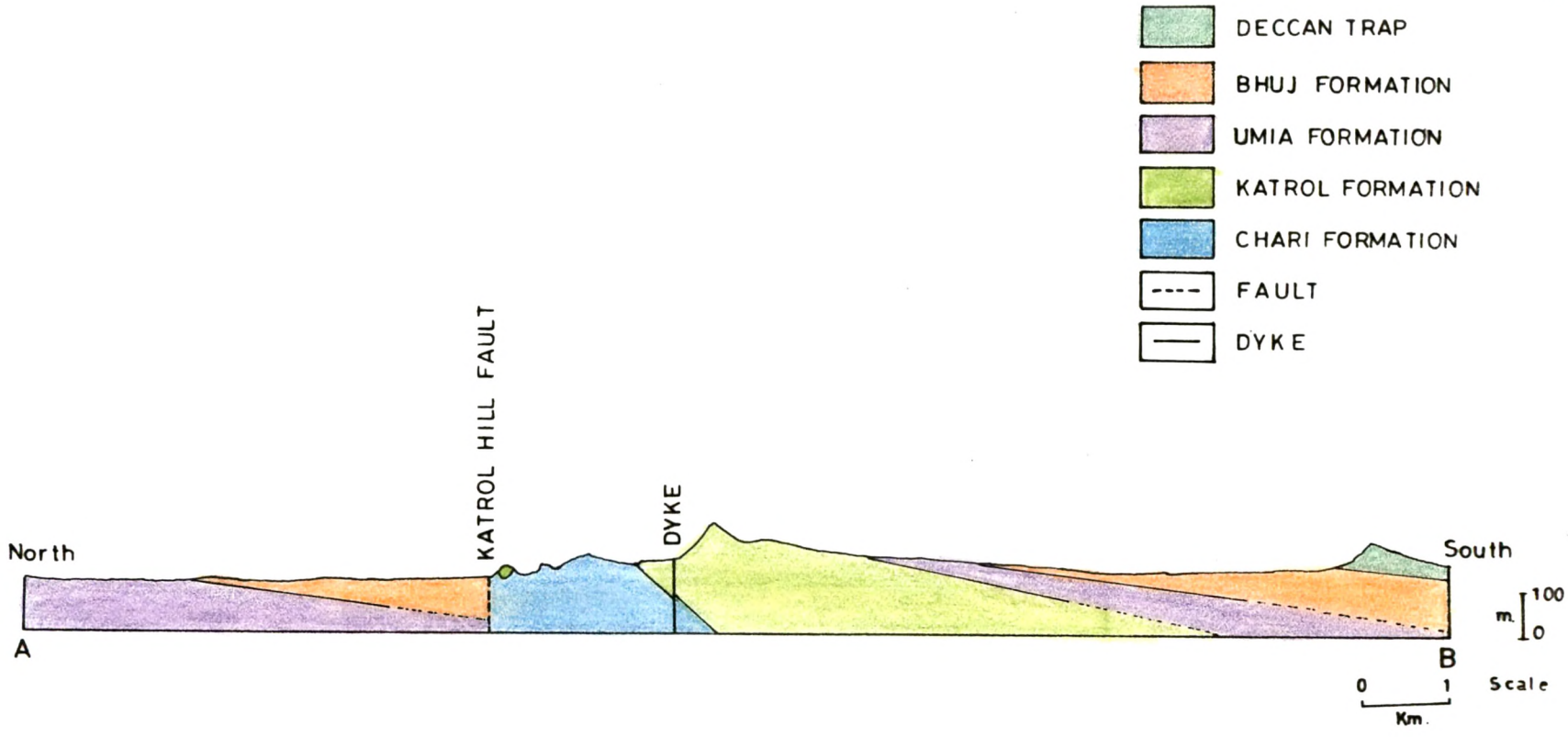

FIG. 7. GEOLOGICAL CROSS SECTION ALONG **A B** (as in fig. 6)

locality South of Jamaywadi it forms a near triangular or wedge shape inlier in between two faults (East-West trending Katrol hill fault on the North; and NW-SE trending fault filled with basic doleritic intrusion on South-West) (fig. 6). The exposer, however becomes thin towards the East where it gets concealed beneath younger rocks. The uppermost part of the JWM can be recognised throughout 'Amundra-Ler anticline' occupying kernel portions. This JWM is characterised by shale-sandstone sequence. In the field, the Member unmistakeably can be recognised on the basis of silty argillaceous sediments in its lower part with hard calcareous siltstones/fine sandstones at regularly decreasing interval, which gradually converts into thick sandstone bands and thin shale intercalations towards the top. Many of these thick sandstone bands host small channel structures filled with extrabasinal angular to subangular terrigeneous gritty quartz grains and reworked angular pebbles from the underlying beds (plate 1). Intraformational limonitic flat pebbles are present at the bottom of some of the siltstone - fine sandstone bands in the lower part. Red brown ferruginous bands and gypsum layers/lenses are common throughout the sequence. Shales are silty, micaceous with thin micritic to ferruginous silty layers. Lower sandy intercalations are micritic siltstone-sandstones. One of the most important characteristic, of some of these bands as well as thin silty partings in shales, is the presence of minute ellipsoidal white clayey pellets and irregular hard, lumpy excreta material. The upper thick bands are clayey, ferruginous, felspathic to arkosic sandstones.

Majority of the sandstone beds in the sequence of the JWM are either ripple marked or parting lineated.

Sedimentary structures are present including varieties of ripple marks (symmetrical, interference, microripples etc.), parting lineations, hummocky cross stratification etc. Slumping is observed in the lower part.

Scattered occurrences of bivalves, gasteropods, ammonoids, belemnoids are noted in the field, except, the thick fossiliferous sandstone in the upper part of the sequence, in which large number of bivalves, ammonoids, brachiopods, gasteropods, belemnoids etc., are present. Microfossils are rare and can be pinpointed in few thin sections only.Unidentifiable plant remains are present throughout the JWM.

The upper sandstone sequence shows casts of trigonia, small body fossils of turritella, echinoid

Plate - 1

Small channel / gully structure, Jamaywadi Member.
Located near Jamaywadi.

spines, etc. At the bottom of some beds moulds of turritella filled with clayey material is often observed.

A variety of trace fossils are present in the sequence to include *Thalassinoides, Gyrochorte, Rhizocorallium, Palaeophycus, Zoophycos, Chondrites, Ophiomorpha, Cylindricum, Helminthopsis*, drag and bounce marks of ammonoids, feeding crawling trails, minute tracks and trails, burrows with spines, trails with oblique movements, fish impressions etc.

The JWM shows erosional contact with overlying Gangeshwar Member (GM) depicting a minor hiatus.

Considering all the above distinguishing factors, it is now possible to recognize different lithological subunits which include:

(i) grayish to yellowish silty micaceous thick shales with thin (up to 2 cm) red-yellow ferruginous and yellowish calcareous silty layer and gypsum band or lens intercalations.

(ii) massive yellowish grayish calcareous siltstone to fine sandstone, 20 cm. to 150 cm. in thickness with scattered ammonite and tiny bivalves as well as foraminifers.

These two rock types occur in rhythmic alternate sequence in lower 120 m. section of the JWM, at regularly decreasing interval.

The next overlying sequence is:

(iii) massive to hummocky or low angle cross stratified thick, yellow, buff, gray coloured clayey, ferruginous, felspathic to arkosic sandstone band with quick intercalations (2 to 4 m.) of micaceous silty finely laminated gray shales, red, brown, ferruginous argillites, yellow calcareous silty sandstones, reddish brown ferruginous sandstones and gypsum layers,and a thin (30 to 50 cm.) hard compact fossiliferous calcareous sandstone in the upper part. The thickness of this sandstone sequence with above noted quick intercalations is about 16 m.

All these are separately described and interpreted in chapter - VI.

In the JWM, palaeowave directions varying from N60°W-S60°E to N40°E-S40°W, based on parting lineations and symmetrical to interference ripple marks are commonly noted. Cross stratification in the upper part shows SW flow direction. All these evidences support the NE to the North provenance for the extrabasinal detrital material, and accordingly the palaeoshore extension varies in N30°E-

S30°W to N50°W-S50°E direction, at the time of deposition of the JWM in this part.

Lower to Middle Callovian age is assigned to the rocks included in the JWM following Spath (1924, 1933), Pascoe (1959), Rajnath (1932, 1942), Krishnan (1968) as based on their fossil content.

The rocks of the JWM exactly underlies sandstones of the overlying Gangeshwar Member (GM) which are equivalent to China wall sandstone in Jhurio Dome and Ridge sandstone in Jhumara Dome (Pandey and Dave, 1993; Biswas, 1977) and hence, *Tewaria Kutchensis Partial Range Zone* of Callovian age can be assigned to the rocks of the JWM, following foraminiferal zonation by Pandey and Dave, 1993.

Tectonically, the rocks of JWM are found affected by folding, faulting and igneous intrusions. As mentioned earlier, the exposures in its type area are bounded by two faults. Due to the East-West trending Katrol Hill fault, the rocks towards the North came in direct contact with much younger rocks of BM - Bhuj Formation. While, in the Southwest, the rocks are seen in direct contact with rocks of Katrol Formation along a Northwest-Southeast running basic dyke developed along the fault. Over again the down throw of the fault is maximum, and as one moves towards the Southeast, displacement decreases, and later on almost ceases. The rocks are further affected by the Northeast-Southwest trending two parallel faults in the South direction, that produce step faulting and as a result shifting and repetition of beds is well observed.

The JWM have also been affected by folding and as traced in the field are found to occupy central portion to flank portion of half cut anticline/dome in between Jamaywadi and Ler. The parts of the JWM which are in direct contact with these faults show much flexures and disturbance or crumpling, as well as dragging of beds (fig. 6).

V.2.2. GANGESHWAR MEMBER (GM):

The Gangeshwar Member is best exposed in the central axial part of the'Amundra Ler anticline' particularly around Gangeshwar Mahadev Temple [lat. 23°11'35", long. 69°43'39"], South of Bhuj. Here, thickness of the Member is approximately 39.55m., but thickness of various subunits vary at different exposures. The full development of the GM is found in the type section at the base of the

hill on which Gangeshwar Mahadev Temple is situated. Good exposures can also be seen in the precipitous cliffs of an East-West trending ridge [lat. 23°11'24", long. 69°42'39"] located about one kilometer West of Jogi Timba (225), as well as in the upper quarries at the point * 259 hill towards SSE of Jamaywadi. It is also seen to constitute the basal beds of faulted domes, on Bhuj-Mundra Road near 5 km. mark in the East direction, and at 9 km. milestone near Temple on Bhuj-Mandvi Road.

The Member is mainly composed of siliciclastic sediments and can be easily demarcated in the field by the presence of various sized large scale hard rounded to subrounded boulders of sandstones particularly developed in the lowermost bed. The exposed boulders occasionally are worshiped by the local people as 'shivlinga' - representing symbol of mighty god 'shiva'. In its uppermost part, the Member is found to be characterized by cross stratified vertically and laterally graded sandstones.

These boulders, which are texturally and lithologically slightly different than the host rock, are mostly rounded, sometimes subrounded (small, 5 cm., to large more than 2 m. in diameter), have appearance as suspended at different horizons and levels in the sandstone matrix.

[Formation of the boulders (plate 2) can be attributed to any one of the following cause or combinations:

- could have produced due to early diagenesis.

- erosion of underlying sandstone in some nearby area possibly under subaerial arid conditions, later on resulting products being entrapped in this lithounit.

- these boulders might be remenants of some totally washed out sandstone bed, which during some exceptionally strong storm event rolled and entrapped in this bed.

- these objects may be the products of localised precipitation of mineral matter - mostly carbonate - in the pores of sediment about a nucleus or centre, known as 'Kugelsandstein' (Fuhrmann, 1968).

- these may be sand balls, similar in origin to armoured mud balls (Bell, 1940) and reported in various conditions, here may be beach (Kugler and Saunders, 1959).

Sandstone boulders at Gangeshwar.

- may be resulted within the depositional basin due to large scale reworking and surging under exceptionally high energy conditions].

Stratigraphically the GM is found overlying the Jamaywadi Member (JWM) and underlying the Ler Member (LM). The contact with underlying JWM is sharp erosional with development of load casts of sandstones in lower shales, which in some cases, on being inverted are worshiped by local people in faith of Ganapati or Hanumanji. The upper contact with LM is sharp nondepositional and marked by bioturbated hard ferruginous top of the uppermost cross stratified sandstone bed, and thin ferruginous crust which marks omission surface (time gap, hiatus without sedimentation). On this the lowermost strata of overlying LM lies conformably represented by cross stratified calcareous gritty sandstone. Here, the main difference between the two cross stratified sandstone strata, is the complete absence of fossils in the uppermost bed of the GM and highly fossiliferous as well as gritty nature of lowermost lithounit of the LM. The overall composition of the Member is sandy.

The Member as a whole is composed of local thin layers of gritty rock mainly on top of the different sandstone layers. Sandstone beds are uniform in grainsize except top few centimeters in vertical sections, where it depicts inverse grading in the lower beds, the upper stratas on the other hand display presence of normal graded bedding. Field observations of the sandstone beds indicate that most of these are bounded by ferruginous and siliceous cement with clay matrix. While cement in the upper cross stratified stratas appears to be calcareous. Top of all the bedding planes have developed mild to intense bioturbation at different localities. Moreover, top of lower beds are marked by the presence of ripple marks and parting lineations, with cover of thin film of argillaceous crust which is mainly reddish brown ferruginous, or in few cases dull white marly, depicting nondepositional calm time gap omission surfaces - standstill conditions. A maximum of seven beds have been recognised in the type section for the GM.

Few small *brachiopods* - mainly *rhynchonellids and terebratulids, bivalves, gasteropods* - mainly tiny *turritella*, and plant fossils are observed on top part of the lower bed.

Various types of primary sedimentary structure are present. These include ripple marks (symmetrical, interference and microripples), parting lineations, graded and inverse graded

bedding, planar and trough cross stratification, climbing ripple cross lamination, festoon bedding, herringbone structure, groove marks etc.

Symmetrical ripple marks show NW-SE palaeowave direction, which indicates NE-SW extension of the palaeoshore line. Local cross stratification in massive - horizontally stratified beds show the Southeast palaeocurrent direction. While in topmost bed, a large variety of cross stratification depicts N30°E to NE and S30°W to SW palaeocurrent directions.

Trace fossils are rare as compared to the JWM. The trace fossils present in this Member are *Skolithos, Gyrochorte, Diplocraterion*, Rivulrites etc. Mud - sand oozing structures produced by worms have been noted on top of one bed.

Middle Callovian age can be assigned to the GM following Pascoe (1959), Krishnan (1968), Rajnath (1932, 1942), etc. Furthermore, the rocks being equivalent to China wall sandstone in Jhurio dome and Ridge sandstone in Jhumara dome (Biswas, 1977) and can be placed in the lower part of *Proteonina difflugiformis Astacotus anceps - Assemblage Zone* of Upper Callovian age as per foraminiferal zonation suggested by Pandey and Dave (1993). The standard ammonites zone of Kutch, equivalent to it is *P. Athleta* zone of Upper Callovian.

Tectonically, the rocks are found affected by folding, faulting and igneous intrusions in a similar way to the JWM. But, are much less destructed due to their compactness in general. These rocks are further observed in direct contact with the rocks of the Bhuj Formation along Katrol hill fault on Bhuj Mundra and Bhuj Mandvi road and toward 1 km due East on way to Gangeshwar.

V.2.3. LER MEMBER (LM):

The name Ler Member is applied to the rocks because it is best exposed in Gunawari Nadi section due North of the dam near Ler village. Here, the cummulative thickness of the Member is 59.4 metres. Part of the LM is also exposed along the axis of the Amundra Ler anticline covering hill tops and Northernly flanking cliffs above the GM. It also occupies the Northern and the Southern limbs of the anticline exactly below Dhosa Oolite Member (DOM), covering peripheral part. The lower part of the LM is very well exposed on top of hill known as Jogi Timba, and the hill at the base of which Gangeshwar temple is situated. Around Satpura Dunger - towards the East some good sections

are exposed in low lying hill cliffs and slopes. It has been observed that LM is exposed every where in Ler Amundra anticline below the DOM. Moreover, the LM is exposed on Bhuj Mundra Road 5 km away from Bhuj near Fakirwadi, and on Mandvi Road near Temple 9 km away from Bhuj. The rocks are directly in contact with the BM, along the Eastwest running Katrol hill fault.

The Member is overlained by the DOM and inturn overlying the GM. The junction with the lower GM is nondepositional conformable, while contact with the upper DOM is unconformable. The thickness of the Member varies on different exposures.

The LM comprises shales, siltstones, sandstones and fossiliferous silty sandy bioclastic limestones alongwith inverse graded 2.5 m thick siltstone sandstone in between as an intercalated sequence, in the lower part. In the lowermost part it can be recognised on the basis of cross-stratified fossiliferous gritty sandstone as well as fossiliferous sandy limestone characterised by the presence of *Astarte* and *Trigonia*, on unfossiliferous cross stratified sandstones of the GM. An intraformational polymictic conglomerate which possibly marks a major transgressive stormy event can be seen developed over the fossiliferous beds.

At many places, the top of the LM is characterised by rhythmic sequence of thin partings of grey, yellow, red, silty shales and gypsum layers coated with ferruginous material (ferruginous layers containing gypsum as core indicates replacement of gypsum layer by iron oxides after deposition), alongwith fossiliferous mega wave rippled limestone layers and intraformational conglomerates at different intervals. This sequence terminates against red, brown, silty to conglomeratic fossiliferous horizon indicating subaerial erosional event and an unconformity.

The LM thus can be defined by sequence of thin shale siltstone sandstone limestone in the lower part with fossiliferous gritty storm lag deposits and intrabasinal polymictic conglomerate, at its base. While upper part is characterise on the basis of gypsum shale siltstone rhythmic sequence intermittently associated with or intermingled by intraformational conglomerates and fossiliferous gritty limestones.

Based on their various field characteristics the LM is divided into eight subunits from bottom to top, viz.

(1) Ferruginous bioturbated fossiliferous sandstones;

(2) Bioclastic fossiliferous at places sandy limestones (astarte beds);

(3) Intraformational polymictic conglomerate.

(4) Rhythmic or intercalated shale - siltstone - sandstone - limestone sequence.

(5) Inverse graded siltstone sandstone with *Chondrites* traces.

(6) Rhythmic or intercalated shale - siltstone - sandstone sequence.

(7) Gritty skeletal pebbly calcareous sandstone.

(8) Ripple laminated grey, yellow, purple and red gypseous shale - siltstone layers alongwith bioclastic gritty limestones and intraformational conglomerates at different intervals.

The strata of first subunit shows normal graded bedding and erosional to highly bioturbated or megarippled top surfaces. The cross stratified strata of this subunit indicates eastward palaeocurrent direction. Moreover, one mega rippled strata shows East-West surging directions, while ripple marks on gypsum layers indicate WSW direction. Furthermore, trace fossils present in this subunit are *Skolithos, Calycraterion, Diplocraterion, Gyrochorte* etc. The thickness of this subunit is about 2.5 m.

Different layers in the second subunit are full of megafossils as well as microfossils - mainly bivalves, characterise by the presence of *Astarte and Trigonia, some belemnite guards, cephalopods, brachiopods*, and *foraminifers*, as well as *bryozoans*. At places concave up and convex up *bivalve (astarte)* bioclasts form birds' eye structure.

Various types of primary sedimentary structures are observed. These include ripple marks (mega wave, symmetrical and current), graded bedding, planar and trough cross stratification, herringbone structure etc.

Characteristic feature of the third subunit is the flat intraformational pebbles of white micritic claystone, red brown ferruginous argillaceous stones, bioclasts of *bivalves, belemnite guards, foraminifers, bryozoans* and some *ammonites* embedded in a micritic skeletal cement and silty sandy matrix constitute this unit. Clasts, many a times, appear floated on the matrix or some times support each other, forming either matrix supported or clast supported intraformational polymictic conglomerate. Thickness of this lithounit varies from 20 cms. upto maximum 40 cms.

Trace fossils present in the fourth subunit are *Rhizocorallium, Planolites, Thalassinoids, Chondrites* etc. In few bands *Arenicolites* and *Skolithos* are also not uncommon. In the fourth subunit frequent gypsum layers containing ripple marks on it are noted.

The seventh subunit is also a distinct - prominant feature of the area, found few metres below Dhosa Oolite Member, separated by shales. Lithologically, it is gritty calcareous sandstone with scattered to bulk accumulation of *bivalves - trigonia, oysters -, brachiopods - rhynchonellids, terebratulids - , ammonoids,* and *belemnite guards. Guards* show preferred orientation in NE-SW direction, while skeletal bivalves show either concave up or convex up orientation in different layers. Near Gangeshwar Temple, hard ferruginous argillaceous layer sandwitched between the sandstone depicts beautiful boudinage structure due to post depositional stretching. This subunit exhibits planar and trough cross stratification which reveals Southern and Northern palaeocurrent directions. Mega wave ripples in the subunit indicate SE-NW, N60°W-S60°E, N27°W-S27°E surging directions (plate 3). Dessication cracks are often observed on the bedding surfaces while calcite veins frequently penetrate the rock transversely. Synsedimentary folding has also been observed. Trace fossils present in this lithounit are *Thalassinoides, Planolites* and some other horizontal trails.

In the last subunit, many a times gypsum found in core part of ferruginous concretions indicates replacement of gypsum by ferruginous material or development of concretions around gypsum. Throughout much of the section claret (dark red brownish) coloured ferruginous nodules concretions pebbles occur at well defined levels. Marly dirty white concretions are also common. In many horizons the concretions are secreted around an earlier generation of concretion of whitish silty marl. Unconsolidated reworked pebble layers and concretion layers at different levels is a distinct character of these shales in Ler area (type locality). According to Fursich et al. (1992) the concretions are interpreted as of early diagenetic origin during transgressive low sediment influx phases, within rhythmic transgressive-regressive cycles. It contains trace fossils like *Gyrochorte, Rhizocorallium, Chondrites* and poorly preserved feeding trails on ripple marked top. The shales repeat six times having varying thickness - mostly between 1.0 m to 3.0 m, intermittently sandwiching intrabasinal polymictic conglomerates and bioclastic/skeletal sandy limestones. On exposures on Mundra road near Fakirwadi, north of Gangeshwar, and in Gunawari nadi south of Gangeshwar, this sequence is wholly made up of gypseous silty, gray, yellow shales where intraformational conglomerates and

Mega waveripples on top of storm generated calcareous gritty fossiliferous sandstone (BS sub-facies) in Ler Member at Gangeshwar.

bioclastic limestones seemingly eroded during post Ler Member erosional event. The thickness of the subunit is approximately 12.0 to 16.0 m on these exposures.

The bioclastic limestones contain densely packed shells of whole and fragmented *bivalves, brachiopods, cephalopods, echinoids,* etc. The cementing material of these bioclastic layers is either yellow calcareous skeletal mudstone or similar kind of mixture of calcareous and ferruginous reddish brown material. Three to four such layers repeat at different levels in the lower part of the shales. Thickness of the limestones vary from 5 cm to 30 cm. At Ler two horizons of limestone found amalgamated one over the other. Mega wave ripples developed on top of one limestone band depict wave direction N37°W-S37°E It also contains reworked bioclastic conglomerate pebbles of lower horizons as well as white calcareous mudstone (marl) pebbles and ferruginous pebbles. These exhumed concretions occur concentrated at various levels, as components of thin beds of densely packed shells and shell debris as they are found in thin intraformational polymictic conglomerate layers. On the top reworked *Thalassinoides* burrows are present which are bored, and filled with white material. Some of the bioclasts are also bored. Many a times, sand grains are found concentrated in parts of the rock. In all possibilities, these bioclastic limestone deposits exhibit characteristics to be of storm originated lag deposits, which could have accumulated above the storm wave base.

The intraformational conglomerates composed of matrix supported flat pebbles of white micritic mudstones (marls) and red ferruginous silty pebbles. A large number of such pebbles are the fragmented parts of *Thalassinoides* burrows. Majority of the clasts are bored on top as well as in some cases on their bottom surfaces. The size of the clasts varies from 2 cm to 23 cm in diameter and 3 cm to 10 cm in thickness. The clasts are rounded or elongated, oblong to bifurcating in many cases. On the surface of many pebbles subaqueous cracks are present (suggesting dehydration under water at the time of diagenesis). The host sediment of these clasts is dirty white, pale yellow, reddish to brownish ferruginous to silty marls or fine sandy siltstones. Actually these bands are pebbly to cobbly siltstone or sandstone, but because of the abundance of pebbles and cobbles and their varied nature, they are designated as intraformational or intrabasinal polymictic conglomerates. At times, the matrix of these conglomerates contains scattered to no quartz grains, but it occupies large amount of silt to fine sand sized fragmented bioclastic calcite grains and mud. The cement is mainly

calcareous material alongwith ferruginous material in various proportion. Calcite and gypsum veins are found penetrating the rock at various horizons. In the upper Callovian sequence of the shales at Ler six such bands varying in thickness from 7 cm to 40 cm are recorded. They exhibit a sharp erosional base. The pebbles and cobbles consist of mudstone and are bored by *lithophagid bivalves* and encrusted by *oysters* and *serpulids* (Fursich et.al. 1991).

The concretion layers are very common within the fine grained upper Callovian sediments of Ler. Typically they consist of elongated or irregular nodules of whitish or reddish coloured silty micrite (marl) or biomicrite. The claret colour of the concretions is due to ferruginous impregnation. At several levels, the concretions exhibit a two phase origin by exhibiting a sharply defined whitish core. Neighbouring concretion layers may be as little as 10 cm apart. These are exhumed and redeposited to generate intraformational conglomerates. In case of these reworked concretions forming intrabasinal conglomerate, a 100 - 200 cm spacing is more common.

The rock contains clusters of fossils mainly *terebratulids, rhynchonellids, oysters, trigonia,* small *ammonoids, belemnoides* etc. Wood fossil is present in some of the subunits of the LM. *Foraminifers* are observed in the thin section studies.

From the varied occurrence of *ammonoids, bivalves, brachiopods,* and the position of the Member exactly below the Dhosa Oolite Member, age of the Member can be assigned as Upper Callovian following to Pascoe (1959). Furthermore, it represents Upper Callovian *Athleta* zone (Spath, 1933), and approximately corresponds the third order cycle of transgression phase of Haq, (1987, 1988).

According to Pandey and Dave (1993), the rocks of the LM belong to *Proteonina difflugiformis-Astacolus anceps Assemblage - zone* of the Upper Callovian age. And the unconformable junction between the LM and the DOM represents unconformity between Callovian and Oxfordian. The standard *ammonite* zone of Kutch equivalent is *P. athleta* zone of Upper Callovian as per these authors.

V.2.4. DHOSA OOLITE MEMBER (DOM):

The name of the Member is derived from the topmost bands of the Chari Formation popularly known

as Dhosa Oolites, which are distinct marker horizons in the Mesozoic sequence throughout the Kutch mainland. The cumulative thickness of the DOM generally tends to be around 18.0 m. At Ler the Member shows thickness of around 15.0 m.; in Satpura Dungar, it exhibits thickness of approximately 30.0 m.; and near Gangeshwar the Member depicts thickness of about 29.0 m. Furthermore, in a locality near Katrol fault on way to Tapkadevi, it exhibits a thickness of 10 m., where it is represented by oolitic sandstone. On Bhuj-Mandvi road about 9 km., it exposes a thickness of approx. 18.0 m., and on Bhuj-Mundra road at about 5 km., it shows a thickness of around 20.0 m.

The Dhosa Oolite Member exposed around the Ler village, from where it extends in the southwest direction either parallel or along the Gunawari Nadi, upto the Satpura Dungar, where it ceases along a fault; in the east direction from Ler it continues in an anticlinal form to a certain extent and then tapers along the Katrol fault; while near Gangeshwar it is exposed in an eastwest extending parabolic shape in a syncline. Furthermore, it is exposed in form of half cut anticline (dome) by the eastwest trending Katrol hill fault on way to the Tapkadevi about 5 km. away, Mundra about 5 km. away, and Mandvi about 9 km. away from Bhuj (fig. 6).

Stratigraphically, the DOM overlies the LM, and underlies the GRM of Katrol Formation, both unconformably.

The lower part of the Member is defined by the author on the basis of the red brown ferruginous silty to conglomeratic highly fossiliferous bed. It marks an erosional unconformity. The thickness of the bed varies from 10 cm., as on Mundra Road exposures, to 50 cm., as in Ler area. On exposures, towards the North of Gangeshwar, and on Bhuj-Mandvi Road, in Northern banks of a talav at about 9 km., two such beds occur with almost similar character, but the lower bed being more prominant. In area of the study, its unconformable nature with the shales of the LM and distinct angular unconformity is clear near the foundation of an in-built outlet of a pond. On Bhuj to Gangeshwar and Mundra Road, exposures of this Member almost directly overlies bioclastic limestones or gritty skeletal sandstone and 0.5 to 2 m. shale or siltstone of the LM. On Bhuj Mandvi Road, it overlies fossiliferous siltstones of the LM; while more or less complete sequence of the LM is exposed in Ler area containing rhythmic ripple laminated shales siltstones alongwith concretionary layers and intraformational conglomerates, below the unconformity. In Gunawari river section, SSE of Gangeshwar Temple, about 15 m. thick shales are exposed prior to this red ferruginous conglomeratic bed

depicting unconformity. Except Gangeshwar area, it shows apparent unconformable - disconformable relationship with the rocks of the LM. Absence of thick sequence of upper part of the LM and undulating lower surface of red ferruginous conglomeratic bed in the above mentioned exposures in the study area depict uplift and erosion prior to the sedimentation of the Dhosa Oolite Member. In Ler and Eastern part of the Gunawari Nadi a reasonably good sequence of the upper part of the LM exposed, is seen to have skipped from this erosional event. This break is considered to be a major one corresponding to the Callovian - Oxfordian unconformity as suggested by Pandey and Dave (1993).

The red ferruginous bed contains few scattered silt sized quartz grains, abundant silt to sand sized bioclastic calcite grains, disseminated limonitic or marly small pebbles and large amount of *bivalves, brachiopods, bryozoans* and *foraminifers* with ferruginised vertebrate bones and wood fossils embedded in dark ferruginous cement matrix. Here, *terebratulids, rhynchonellids* and *oysters* outright all others. This may be accumulated from the erosion of underlying rocks and preserved due to their resistant composition. Gypsum veins are commonly found penetrating the rock alongwith some calcite veins.

The above lithological unit is followed by silty shales, mainly grayish in colour. Siltstones, silty oolitic limestones, ferruginous silty bands and gypsum layers are present but mostly upto 5 cm. in thickness and at an interval of 20 cm. to 200 cm. They commonly show ripple lamination to flaser bedding, or lensoid nature. The shales contain *belemnoids, terebratulids*, few other *brachiopods*, and *bivalves*. Thickness of these shales ranges from 12.0 m to 30.0 m.

The next is rhythemic thickening upward sequence of silty sandy limestones, sandy oolitic limestones, calcareous oolitic sandstones to oolitic limestones and ferruginous oolitic skeletal limestone, 3.5 m to 9.5 m in thickness, with alternating - intervening 10.0 cm to 20.0 cm thick silty shales. These mixed siliciclastic calcareous rocks are yellowish brown to brown to olive green in colour. It shows local incipient recrystallisation. The rocks also cut by calcite veins.

In general, three prominant bands of sandy oolitic limestones are noticed - lower two brownish and upper greenish, containing larger oolites. However, on the Gangeshwar and the Bhuj Mandvi road, five such sandy oolitic limestones to oolitic limestones to oolitic sandstone beds have been observed.

In a locality near Dhrang (Habo hill section), which is not covered in the present study, fourteen such bands have been encountered reaching a cumulative thickness of more than 15 m alongwith intercalating silty shales. Generally individual bed shows thickness varying from 10 cm to 150 cm. Sandstones normally tend to be thin upto 50 cm, while oolitic limestones are thick upto 1.0 - 1.5 m. Whenever more than three prominent bands are present, the bands, except the topmost, become more silty to sandy limestones to sandstones. But whenever only three or less prominent bands are present, the silt sand proportion is much less in the constituting limestones as in Ler, Gunawari nadi and Satpura dunger and Mandvi road sections.

The oolitic limestone and calcareous sandstone incorporate *bivalves, brachiopods, ammonoids* and *belemnoids* amongst their bioclastic component. Second bed from the top is almost wholly made up of young to embrioical belemnoid remains. All the thin sections of the Dhosa Oolite invariably show presence of *foraminifers* and few also depicts presence of *ostracods.*

The topmost rock type of the Member is a thick bioclastic intraformational conglomerate and ferruginous crust at or near its top. This conglomerate layer is present everywhere, but it exceeds a thickness of 25 cm near Gangeshwar. It contains reworked rounded to elongated pebbles. Majority of these pebbles are bored and/or encrusted by *bivalves & brachiopods.* Largest measured dimension of one of these boulders is 80 cm * 60 cm * 25 cm, while dimension of the smallest pebble is 2 cm * 3 cm. Some of the boulders are part of the *Thalassinoides* burrows. This bed is highly compacted and cemented and it is difficult to take out any boulder. Some of the boulders contain ammonoid or echinoderm fossils in their core part. These boulders are mixed with fossiliferous lag deposits indicating high energy conditions. Skeletal debris are mainly of *ammonoid* and *echinoderm* origin (e.g. crinoid debris, *echinoids, holothurian wheels* etc.) but *foraminifera, brachiopods, serpulids, bivalves, echinoid spines* and *belemnites* are also common.

Reddish brown ferruginous crust has been formed on the intraformational autoclastic conglomerate. Thickness of this layer varies from exposure to exposure. It is only 2 to 4 cm at Ler and Fakirwari (Mundra road) and same is more than 30 cm near Gangeshwar. At Gangeshwar this ferruginous layer incorporates flat pebbles as well as ferruginised wood branches. Here, polygonal shrinkage cracks are also noticed, which are again filled up by the same kind of material having slightly light or dark

colour.

At Ler the Member contains a few decimeter thick oolitic calcareous band above the topmost Dhosa Oolite.

Sediment of the DOM is bioturbated. Recognisable trace fossils include *Thalassinoides* and *Planolites* on top, and *Zoophycos, Chondrites* and narrow to broad U-shape burrows filled with ferruginous material.

Fossils occur scattered throughout the DOM, except, Tapkadevi road exposures. They are also concentrated in 10 - 20 cm thick shell bed close to the top. Dominant faunal elements of the shell bed are *belemnites, terebratulids,* and *oysters*. Shells are frequently bored and encrusted, and occasionally covered with a thin ferruginous crust. The percentage of fragmented shells is high. Preservation quality varies considerably, well preserved shells and strongly corroded shells can be found side by side.

Across the outcrop belts, the top of the DOM can be recognised by features such as extensive undercuts of beds, thick ferruginous crusts, bored and encrusted pebbles and skeletal concentrations. In general, these features remain uniform for a considerable lateral distance, e.g. Bhuj-Mandvi road exposures, Fakirwadi and Ler. The top 40 - 70 cm of the Dhosa Oolite are nearly identical. Even though, their depositional condition seems to be similar, the DOM and previous LM are described and discussed separately based on the occurrence of unconformity and evidences of erosinal event and because of their lithological dissimilarities of compacted beds. Soft sediment characters are similar in both the Members but different hard and prominant beds of the LM are conglomeratic with a mixture of ferruginous and calcareous material as matrix and cement. This suggests high energy to stormy conditions with low rate of net sediment supply. In case of the DOM such beds are mainly calcareous and only ferruginous material found is in form of ooids. Further, except the topmost bed, intra or extraformational rudaceous and coarser arenaceous material is absent. This, in general, suggests low energy condition and low rate of net sedimentation. But, both of these conditions and their representative lithologies point a common fact - these are condensed horizons representing long time duration in comparision to their thicknesses.

This is the topmost Member of the Chari Formation. It exhibits on its top, a prominant disconformity and a large time lapse evident by conglomerate and mineral crust. This is not only structural but biogenic content of the DOM and immediate overlying rocks also points out same general thing (Agrawal, 1957; Fursich et al., 1992).

The rocks of the Member are involved in faulting and penetrated by intrusions which affect the rocks of the JWM, the GM and the LM. The rocks are also affected by folding movements, and thrown in form of anticlines & domes or synclines & basins. Normally they show dip of more than 30, but at places they are almost vertical.

The Member is considered to be Oxfordian in age by Spath (1933), Rajnath (1932, 1942), Pascoe (1959), Krishnan (1968) etc. based on biostratigraphic evidences. As per Fursich et al (1992), it represents the sediments of Middle Oxfordian *Plicatilis zone* (indicated by Perisphinctes orientalis), which are overlained by sediments of Lower Kimmeridgian age at Ler.

According to Pandey and Dave (1993), Oxfordian sediments of Kutch are divisible into *Epistomina majungaensis Range Zone* of Middle Oxfordian age and *Epistomina majungaensis - Lenticulina bulla Interbiohorizon (poorly fossiliferous) zone*, and Oolitic horizon of Ler and the 9 km Bhuj-Mandvi Road Temple site is stratigraphically far above the horizon of Habo.

V. 3. KATROL FORMATION:

Exposers of this Formation are found around Ler, Shuteshwar Temple, Jadura, Tapkeshwari, Fakirwadi, SES, Jamaywadi, Temple 9 km away on Mandvi road, etc. localities. The Formation involves three Members (1) Gunawari River Member, (2) Marutonk Dunger Member, (3) Jadura Member. The base of the Formation is marked by lowermost beds of Gunawari River Member, which is underlained by Dhosa Oolite Member of Chari Formation with an unconformity. The top of the sequence is represented by topmost beds of Jadura Member, overlained by Tapkeshwari Member of the Bhuj Formation. The junction between the two Formations is unconformable and at places overlapping. The rocks being mainly shales, clays and sandstones, capped by hard sandstones of Jadura Member. The overall thickness of the Katrol Formation is 350 meters. It covers major part

of the study area producing thick belts periphering older Formation, and forms outer gently Southward dipping limb portion of 'Amundra Ler anticline'. Few thin fossiliferous bands are found scattered within this Formation. It is, however, rich in trace fossil contents.

The rocks of the Formation mainly show gentle dips in the Southwardly directions. Faulting and intrusions are common features which have affected the rocks, and wherever in contact with the faults have became highly crumpled and disturbed.

A non-deposional break with abrupt change in lithology has been observed at the junction of the Gunawari River Member and the Marutonk Dunger Member. Moreover, erosional to overlapping relationship exist in between the Marutonk Dunger Member and the Jadura Member.

According to Spath (1933) and Rajnath (1942), these rocks cover Kimmeridgian and part of Tithonian ages. While as per Pandey and Dave (1993), the Formation is Kimmeridgian in age, covering two foraminiferal zones - viz. *Lenticulina Bulla partial-Range zone* and *Lenticulina Bulla - Epistomena ventricosa interbiohorizon (Barren) zone.*

V.3.1. GUNAWARI RIVER MEMBER (GRM):

GRM is the lowermost Member of the Katrol Formation. It's position can be marked everywhere in the field on the top of the DOM, which is the topmost sedimentary unit of the Chari Formation. The Gunawari River Member is found exposed South of Ler village from where it extends in the West almost parallel to the Gunawari river and ceases along an EastWest trending fault. At places, lowermost part of the Member is very well exposed in the cliffs of the river and hence the name is given to the Member. On the other side from the South of the Ler village, it extends in the NorthEast direction. It is also exposed on the top part of Satpura Dungar, where thickness is comparatively less. The Member is also seen in form of concave strips parallel to the anticlinal - domal section of the DOM cut by EastWest trending Katrol fault on way to the Tapkadevi, Mundra and Mandvi. It also appears in the form of isolated patches (-half cut dome) flanking Katrol fault on way to the Jadura. Exposures of GRM are also found half km north of Gangeshwar in form of a syncline.

Thickness of GRM is 75.0 m in its type section; while it approaches a thickness around 30 m on

Mundra road. On other exposures thickness is rather insignificant.

The Member overlies the Dhosa Oolite Member unconformably and it is overlained by Marutonk Dungar Member conformably, where contact is sharp with change in lithology.

The Member is defined on the lower part by silty shales and ferruginous partings known to stratigraphers as Katrol ammonite beds and the upper part by calcareous gritty sandstones characterise on the top by limonitic - polymictic pebbles and megaripples.

In between these two, the Member contains calcareous sandstones, yellow grey gypseous shales with thin calcareous siltstones and ferruginous partings at regular interval.

On the basis of lithological characteristics the Gunawari River Member is divided in to four subunits:
(1) Greenish gray glauconitic silty shales with ferruginous partings containing *ammonites* - Katrol *ammonite* beds.
(2) Yellowish, dirty white calcareous sandstones.
(3) Gray, yellow silty gypseous shales with thin calcareous siltstones and red brown ferruginous partings.
(4) Graded calcareous gritty sandstones with mega ripples on top.

The trace fossils present in this sequence are *Skolithos, Arenicolites, Thalassinoides, Planolites, Gyrochorte, Palaeophycus* etc.

V.3.2. MARUTONK DUNGAR MEMBER (MDM):

This represents the middle unit in Katrol Formation, and it is most uniformly developed in the field. The name of the member is given from a locality in the central part of the study area where the member is best exposed, around the Marutonk dungar. The type section of the MDM can be observed in small nala sections around Marutonk dungar, which run towards the north and meet Gunawari river. Here, rocks of the lower part of the member are very well exposed, while rocks of the upper part of the member can be studied in cliffs of east-west running ridges in the south. Good exposures of the member can also be observed on way to Mundra - in between Fakirwadi and Satellite Earth Station (SES), on way to Jadura - in a nala on which Hamadra talav is formed by building a small

masonary dam - upto the north of Jadura, and on way to Kotda Chakar - from the south of Ler upto Suteshwar Mahadev Mandir. The cumulative thickness of the member is 225.0 m. The MDM shows nondeposional contact with abrupt change in lithology to transitional contact with the underlying GRM, and erosional unconformable with overlying JM which shows overlapping relationship with the MDM.

The lower part of the Marutonk Dungar Member demarcated by lowermost shale-sandstone-ferruginous parting sequence overlying the uppermost grit/sandstone beds of GRM. In the lower part sandstone partings are more closely spaced with 5 to 15 cm thickness and same amount of intercalating shale-limonitic partings. On the Bhuj-Jadura road section the shales are carbonaceous in character. In the Ler and Bhuj-Mundra road area the argillaceous contents in the lower part is prominent with thin sandstone partitions. While middle part of the member is overall more argillaceous in entire study area with almost central sandstone beds, Which contains bivalves cephalopods alongwith leaf impressions and wood. Many a times such fossils are in form of casts. Thickness of this sandstones varies from 1 to 8 m. The upper part of the member is marked by intercalated shale sandstone siltstone sequence overlained by dark red grit, sandstone, siltstone, clay of the lowermost bed of the Jadura sandstone member above the unconformity. The upper part contains 30 to 50 cm thick sandstones at a decreasing interval of 5 to 2 m in southern exposures to the Marutonk Dungar.

In the eastern part sandstone parting are more prevalent than the western part, plus in the eastern part, erosional contact is more prevalent with the overlying JM, where gritty sandstone to clayey material, all ferruginous red to dark brown in colour, are found above unconformity. While in the western parts, particularly towards the west of Tapkadevi, directly above the erosional contact, sandstone-siltstone sequence of JM is exposed. Overall thickness of the sequence is more or less uniform, still upper beds of the sequence with sandstone partings are eroded away before deposition of the overlying JM in many areas.

The member contains few thin fossiliferous bands containing small bivalves, gasteropods, belemnoides, nautiloids, ammonoids and plant fossils, but all the sandstone-siltstone partings contain numerous trace fossils having varied genera showing diversity of life forms.

Ripple marks are present only in case of few upper sandstone bands and limonitic partings. Megaripples have been observed on top of middle thick sandstone bed. The wave direction depicted by the megaripple is N20°E-S20°W, while palaeocurrent directions evidenced by asymmetric ripple marks is N to S25°E.

The rocks of the MDM are affected by shear zones, faults, folds and dykes at different places.

V.3.3. JADURA MEMBER (JM):

The Member constitutes uppermost part of the Katrol Formation. It is most conspicuously developed in the area around Jadura nana village. Good sections can also be studied around and towards the south of Satellite Earth Station on Bhuj-Mundra road; towards the west of 6 km mark on Bhuj-Jadura road in a hill section; towards the south of Marutonk dungar; as well as around Suteshwar Mahadev Mandir on Ler-KotadaChakar road. In Tapkadevi area, beds of the JM are partly to completely concealed beneath overlapping sequence of overlying Umia Formation. The thickness of the Jadura Member is about 50.0 meters. The thickness of it could be more but complete sequence is most probably not exposed in the investigated area or is either concealed due to overlapping younger Formation.

The Member overlies the MDM unconformably with a small erosional break, to conformably. It underlies the Tapkeshwari Member of Umia Formation with an apparent angular unconformity. In the proximal part of the basin, on the Bhuj-Jadura road, and towards the north of Shuteshwar Mahadev Mandir on Ler-KotadaChakar road, the exposures of these rocks are observed above a clear minor hiatus on the MDM.

The base of the Member is defined by dark red brown ferruginous gritty, pebbly, sandstones, siltstones and clays, which at times are cross stratified. These rocks show much variation in their thickness from 1 m to more than 15 m, and completely absent on the Bhuj-Mundra road exposures.

These beds are followed by rhythmic sequence of thin sandstone, siltstone slabs with gray, yellow, at times carbonaceous shales and lenticular ferruginous bands, frequently ripple marked towards the top. In the distal parts of the basin, mainly towards the west and the southwest, these rocks are found directly overlying the shales of the MDM almost conformably, as it appears on the Bhuj-Mundra road, near Satellite Earth Station. The thickness of the sandstone increases, while thickness of the

siltstones-shales and ferruginous bands decreases and completely vanish in the upper part of the sequence.

The overlying thick sandstone beds are yellowish, pinkish to grayish in colour, hard and compact, fine to medium grained, and ferruginous, siliceous to calcareous in nature. Individual beds are normally 1 to 3 m in thickness, but less thick or more thick strata are not uncommon. In its type locality around Jadura nana village, in between these sandstones at various level, lensoid 1 to 2 m thick shale-siltstone-sandstone rhythmic sequences are developed. Thin argillaceous layers are observed on many sandstone beds depicting nondepositional periods. Mud drapes are present in some of the sandstones.

The Member is almost devoid of fossils except small *bivalves, gasteropods*, leaf impressions and tree branches. At one or two places on Mundra road exposures, the Member contains doubtful ammonoid casts. But it is full of biogenic activities in form of trace fossils. These include *Gyrochorte, Palaeophycus, Planolites, Phycodes, Ophiomorpha, Neonereites, Cochlichnus, Isopodichnus, Gyrolithes,* etc.

Planar to trough cross stratification, ripple marks, parting lineations and syndepositional to postdepositional sole marks are observed in the sequence. They show north, south to S25°E palaeocurrent direction.

The rocks of the Member are mainly affected by shear stresses, faulting and igneous intrusions. Here, in the top portion few small (upto 2 m diameter) mud and sand volcanic structures have been observed with radiating fissures, near Jadura nana, exactly below basal gritty conglomerates of Tapkeshwari Member.

The end of Katrol depositional event is followed by a break in sedimentation in the Kimmeridgian sea.

V. 4. UMIA FORMATION:

Exposers of Umia Formation are found around Bhuj, Madhapar, Bhujodi, Kukma, Hajapar, Tapkeshwari, Jadura nana, Jadura mota, Bharapar, Sanatorium, south of Shuteshwar, etc., localities. The base of the Formation is demarcated by lower gritty conglomerate distinguished by the author as lowest bed of the Tapkeshwari Member, and upper part is defined by the cross-stratified sandstone strata capped by a highly bioturbated horizon, which form the uppermost part of the Member.

The total thickness of the Umia Formation in the study area is 85 m. The Formation is exposed in form of hin belts bordering the rocks of Katrol Formation - one in the Northern part and another in the Southcentral part of the study area. The sequence is almost horizontal to subhorizontal. Physical sedimentary structures are numerously present. Minor faulting and injection of magma, is also observed in this Formation.

The entire sequence overlaps various beds of the Jadura Member (Upper Katrol Formation) and in some cases even the beds (shales) of the Marutonk Dunger Member (Middle Katrol Formation) as in Tapkadevi area. The junction between Katrol and Umia Formations is thus unconformable, in the same way, junction between Umia and overlying Bhuj Formation is nondepositional to erosional/ unconformable.

The rocks of the Formation are ferruginous/felspathic sandstones, thin shales and lensoid thin conglomerates. The fossils are rarely present. Only two or three disconnected fossiliferous bands are exposed in the study area, where fossils are highly obliterated by dissolvement of original material and filling mainly by ferruginous material (iron oxides) or silica. Thus, moulds of small bivalves are markly observed.

According to Spath (1933) and Rajnath (1942), the rocks included under the Umia Formation covers part of the Upper Tithonian and the Neocomian. While Pandey and Dave (1993) suggested *Epistomina ventricosa Range zone* of the Tithonian age for the rocks involved in the Umia Formation.

Few erosional to non-deposional breaks in the sequence have been recorded by the author.

The Umia Formation contains Tapkeshwari Member.

V.4.1. TAPKESHWARI MEMBER (TM):

Tapkeshwari Member is the only Member of Umia Formation, which is very briefly developed in the study area. The name is given from Tapkadevi locality, where (in cliffs of the hill which surrounds the temple), upper part of the Member is best exposed, and can be studied in details. Tapkadevi is famous in local people by the name of Tapkeshwari. The Member is also exposed around Meteoric

Observatory near Bhuj; in Dharawa nadi near Bhujodi; in a nala section towards the southwest of Kukma; towards the south of Jadura nana and around Jadura mota; around Bharapar Sanatorium; towards the north of Bharapar village in a nala section on Bhuj-Mundra road; and south of Shuteshwar Mahadev Mandir on Ler-Kotada-Chakar road; as well as on Bhuj-Naranpar road. The rocks of the TM are almost horizontal to subhorizontal on gently inclined beds of the JM. The entire Member from its base to top part is beautifully developed in and around sandstone quarries towards the south of Jadura nana village which is type section. Here, the basal beds are yellow to brown calcareous, ferruginous gritty conglomerates which contains fossils of *bivalves, cephalopods* etc., alongwith some small vertebrate bones and teeth. The equivalent beds are exposed in Tapkadevi area, represented by reddish to brownish black gritty to clayey bed containing moulds and casts of *ammonoids*. Thickness of the beds range from few centimeters to 50 cm. In Jadura area two such bands occur separated by half to one metre sandstone. In other localities this part of the Member is not exposed, may be concealed beneath the overlapping sequence of the Member. This in turn, followed by a ten metres of shale siltstone sandstone partings with two to three sandstone beds each one of 1 to 1.5 m thickness. The sandstones are calcareous, yellowish to grayish, apparently structureless. The shales and siltstones are grayish to yellowish in colour. In Tapkadevi area, the equivalent beds are silty shales with variety of trace fossils. While in Dharawa nadi near Bhujodi, the silty shales are crowded by *Chondrites* burrows. In other localities these beds are not found exposed.

The next sedimentary units are 10 m to 25 m thick ripple marked, red, brown, black, ferruginous sandstones interstratified with thin white, gray micaceous siltstones silty shales in a rhythmic manner. The maximum thickness of a single sandstone slab is 20 cm on the northern and eastern exposures. While thickness of these sandstones is much more upto 2 to 3 m in southern exposures. The entire sequence is rich in trace fossil contents and the most important being *Asteriacites* which occur in plenty in some of the bands. Good exposures of these beds are found in all the localities where the TM is developed and can be easily recognised on the basis of rhythmic appearance, ripple marked tops, and dark red, brown to almost black colour. In an exposure southwest of Kukma in a nala, this rhythmic sequence converts laterally into cross to massive bedded sandstones towards the south and the west within few metres' distance.

**Flame structure in Tapkeshwari Member,
Location near Bharapar sanatorium.**

The bottom and top of this sequence, near Meteoric Observatory are characterised by mega ripple marked bands, with wave length range from 0.5 to 2 m, which indicates stormy events. The ripple marks show NW-SE palaeowave direction. Below this mega wave ripples gray lensoid shales are present.

The sequence in observatory area possibly contains a minor gully structure, which is filled by oligomictic ortho- to para-conglomerate at the base with perfectly rounded pebbles. In Sanatorium area, the beds with gritty conglomerate at base are observed directly overlying sandstones of the JM. The rhythmic bands in the sequence show inverse gradation. Two to three highly ferruginised thin partings of gritty fossiliferous sandstones are present in the sequence, in which small *bivalves, gasteropods,* spines of *echinoids* and needles of sponge have been observed in form of ferruginised internal and rarely external moulds. In Sanatorium area, mud volcanic structures have been observed with radiating fissures. At places climbing ripple cross lamination to flaser bedding have been observed in this sequence. Thin ferruginous to argillaceous crust is present on almost all sandstone tops.

The next set of beds in the Member are yellow, pink, red to white, variegated massive to horizontally stratified or apparently structureless, hard to friable sandstones with uneven to ripple marked or parting lineated top surfaces and varying in thickness from 10 to 22 m on different exposures. These beds can be observed in all the localities where TM is exposed. The beds are totally devoid of body fossils but rare vertical to inclined burrows are present on the top part of lower beds, indicate the biogenic activities. In the upper part of the sequence beds are bioturbated and the trace fossils which observed in them include: *Arenicolites, Skolithos, Monocraterion, Diplocraterion, Ophiomorpha, Rosselia,* etc.

Bioturbation at many places has obliterated stratification of the beds. In the Sanatorium area, this sequence shows beautiful slumping structures, contorted beddings and flame structures. Near Observatory, the sequence also contains thin lenses of silty shales (plate 4).

The next sequence in the Member is 10 to 25 m thick, contains cross bedded yellow, red, brown, purple sandstones and gritty conglomerates. The individual cross stratified unit normally varies in

thickness from 10 cm to 50 cm. It shows varied type of cross stratification from planar to trough to climbing ripple cross stratification to flaser and hummocky cross stratification to herringbone structures. Their top parts are mostly erosional and shows deposition of next strata with reactivation surfaces but at times beautiful simple straight crested symmetrical ripples with wave length 12.0 to 15.0 cm & amplitude 5.0 cm have also been observed alongwith parting lineations depicting nondepositional surfaces. Thus, in their overall pattern of deposition, the beds show very dynamic depositional conditions with high energy environments and large amount of clastic material influx, as the thickness of the sequence depicts. In this sequence biogenic activity is very less mainly represented by few escape structures, vertical, inclined to branched burrows and horizontal tunnels. Water escape structures are common. Wherever ripple marks or parting lineations are present, such surfaces are occupied by various types of biogenic activities. Top of the sequence, which is also top of the Member, is marked by hard bioturbated sandstone, which is followed by a thick sequence of sandstones and shales of Bharapar Member of Bhuj Formation.

The junction between the Tapkeshwari Member and underlying Jadura Member is unconformable and overlapping. While the junction between TM with the overlying Bharapar Member of Bhuj Formation is apparently conformable, nondepositional to erosional with a minor hiatus.

As compared to Chari and Katrol Formation (which are involved in major folding and faulting producing a number of domes and anticlines and producing shear zones, displacements, igneous activity, etc.), the rocks of TM show least movement and involvement of any such effects in them.

V. 5. BHUJ FORMATION:

The base of the Formation is defined by lowermost beds of the Bharapar Member, which are rhythmic sequences of bioturbated dark brown to black gritty sandstones. Top of the Formation can be marked by the topmost beds of the Bharapar Member, which are felspathic friable sandstone, white in colour containing large amount of china clay.

The rocks of the Formation are exposed in form of East-West stretching outcrops in two parts - one towards the North parallel to the Katrol fault and another in the South terminating against Deccan Trap lava flows. The rocks are horizontal to subhorizontal with abundance of physical sedimentary

structures.

Mainly charred plant material, petrified stumps, rootlets and leaves are present in the sequence in form of fossils except few moulds of marine *bivalves* (mainly *Trigonia*).

The lower and upper junctions of the Formation show unconformable relationship with the underlying beds of Umia Formation, and the overlying Deccan Trap Formation.

The sequence contains bioturbated ferruginous rhythmic sandstones, amalgamated cross stratified sandstone beds with reactivation surfaces, and clay or carbonaceous shale beds containing plant fossils - mainly in its lower and middle part. These rocks are also affected by faulting as well as intrusions. The total thickness of the Bhuj Formation is approximately 310 m.

According to Rajnath (1932, 1942), this Formation is of post-Aptian of age. Pandey and Dave (1993) have suggested Neocomian-Albian age for these and proposed *Dorothia Kummi - haplophragmoides pacilis Range zone* for lowermost sediments based on microfaunal evidences provided by Bhuj Shales in the well no. Lakhpat - 1. In the area under investigation, the Aptian Ukra sediments have not been observed.

This Formation covers only one Member, viz., Bharapar Member.

V.5.1. BHARAPAR MEMBER (BM):

This is the uppermost part of the Mesozoic sedimentary sequence in the study area. It constitutes Bhuj Formation, and is the only Member of it. The total thickness of the Member is approximately 300 m. Good sections are exposed, in Tapkadevi area; towards the south of Meteoric Observatory; around Bhuj town; on way to Mundra road upto 5 km from Bhuj; towards the south of Lalan college, Bhuj; on way to Ler from Kukma in a nala section; towards the south of Madhapar in nala sections; along Ganga or Bhubhi river parallel to Hajapar - Chakar road; towards the south of Jadura in hill cliffs; from Bharapar to Kera in a nala section; from the north of Naranpar to Kera in Rudrani river section; towards the south of Reha; etc.

The name is derived from Bharapar Sanatorium area, where contact with underlying TM is clearly

exposed.

The type section for the lower part is exposed in the top part of the Tapkadevi hill. It is also found in a similar manner in the south of Meteoric observatory, towards the south of Lalan college, Bhuj, and in proper Bhuj town near GPO in a nala section. The type section for middle part of the Member is exposed in between 2 to 4 km mark on Bhuj - Mundra road as well as in Mathal nadi in between Reha and Kotada and in Rudrani nadi near Naranpar. The type section of the upper part is exposed in Bhubhi or Ganga nadi in the southeast in between Kotada and towards the south of Chakar; and in Rudrani or Nagvanti nadi towards the southwest near Kera. The sequence is exposed in different manners at different places in the study area.

The lower junction of the Member with the TM is more or less conformable with a small hiatus. The upper contact is unconformable with a sizable time interval, with overlying Deccan Trap lava flows.

The lowermost beds are amalgamated sequence of brownish black coarse gritty sandstones which are horizontally stratified to cross stratified. The sandstones are highly bioturbated, mainly contain *Skolithos, Monocraterion, Calycraterion, Diplocraterion, Arenicolites*, etc., and have completely obliterated the primary sedimentary structures. The beds can be recognised with the help of reactivation surfaces or tapering of burrows. Highly bioturbated nature of the sediments indicates long interval of time before deposition of overlying beds in each and every case.

The next set of beds in the sequence are yellow, gray, white, black or in extreme case brown, ferruginous to carbonaceous or felspathic clayey, silty to sandy shales, also moderately bioturbated when ferruginous to clayey, and when carbonaceous contains variety of plant fossils - mainly leaf impressions. These two rock types repeat number of times in the vertical sequence alongwith yellowish to dull white, cross stratified coarse to medium grained poorly bioturbated sandstones. The sequence varies from 5 m to 50 m in thickness. It also contains tidal pool and tidal gully structures symmetrical to asymmetrical straight crested to linguoid ripple marks, and petrified or ferruginised charred trunk and logs in some cases alongwith in situ root portions. Selenite variety of gypsum occurs with clays shales depicting influence of marine environments. The beds also contain silicified coral remains on exposures near Lalan college, Bhuj. The palaeocurrent directions found in this

Plate - 5

Structures produced due to differential erosion (wind action) in Bharapar Member at Tapkeshwari.

Plate - 6

Planar cross-stratification in sandstone with contortion of cross-stratification (probably effect of palaeoflood) in Bharapar Member near Chakar.

sequence are N70°W, N15°W, W, N80°W, NE-SW, NW etc. On Tapkadevi hill, the rocks also show prod marks of fish, rounded to vertical cylinder like algal structures and pointed bar (plate-5) like typical structures. (Collinson & Thompson, 1982, Pettijhon, 1975, Reineck & Singh, 1973) as is found in present day tidal flats of Soudi Arabia, may be produced due to differential erosion.

This is followed by 18.0 m to 60.0 m thick cross bedded, ferruginous, felspathic to siliceous, coarse, gritty, graded sandstone sequence. It shows large scale planar to trough cross stratification alongwith torrential beddings. On many exposures towards the south, the cross stratified strata produce herringbone structure. These beds are totally devoid of fossils except few leaf impressions, and from the exposures towards the south of Jadura nana few ferruginised moulds of bivalves - mainly *Trigonia.* Some of the cross stratified beds also consist of vertical burrows in the upper top parts. The palaeocurrent directions measured in the sequence are SW, S, W, S40°W, S30°W, S56°W, S75°W, N, N15°W, N45°E, SE, S50°W, S80°E, etc.

The next is again a silty clay - bioturbated ferruginous sandstone sequence. Thickness of these rhythmic stratas varies from 20 to 50 m. The shales/clays are mainly grayish to whitish in colour and very thin to 2 - 2.5 m thick, intercalated with hard brownish black highly bioturbated gritty to fine sandstone slabs, which frequently amalgamated with cross stratified pink, yellow, white sandstones or many a times alongwith thin shales in between.

These stratas are similar in almost all the characters to the basal sequence of the BM except decrease in thickness of sandstones and increase in or uniform in thickness of shales/clays in general. The beds show following variety of trace fossils: *Skolithos, Diplocraterion, Monocraterion, Rosselia,* etc. The palaeocurrent directions indicated by the cross stratification or highly obliterated ripple marks due to biogenic activities are S80°W, N38°E-S38°W respectively.

Overlying these beds are 40.0 m to 150.0 m thick cross stratified sandstones with very thin (2.0 to 10.0 cm) ripple marked shales and siltstones at various levels. The sandstones are 0.5 to 5.0 m thick sheet like planar cross stratified beds or lensoid trough cross stratified beds. Torrential bedding is also not uncommon alongwith graded bedding. Climbing ripple cross lamination and contortion of the cross stratification are observed (plate-6). Mud drapes are found present in sandstones and at times fine microripples also encountered, produced due to surfacial expression of small scale trough cross

beddings, only 2.0 to 5.0 cm in width of single trough. Small sandstone dykes are present in the cross stratified sandstones. Few sandstone beds are moderately bioturbated mainly contains *Ophiomorpha* burrows. Some of the uppermost sandstones are felspathic, rich in china clay contents. The rocks (sandstones) are rich in argillaceous contents - mostly wackes, and normally graded and ranges from fine sandstones to gritty conglomerates. The sandstones are ferruginous, felspathic, siliceous to calcareous in nature. The palaeocurrent directions are mainly S70°E, S40°E, S20°W, N, N85°W, NE, SE, SW, S, S60°W, S25°E, W, S30°W, N60°W, S18°W, SSW, NNW, SSE etc.

The beds of the BM are horizontal to subhorizontal. The Member is unconformably followed by Deccan Trap lava flows.

Tectonically, the rocks of the Member are least affected. Few shear zones, dykes and faults are found in these rocks. They are directly affected by E-W trending Katrol hill fault.

Occurrence of *coral* remains in the sandstone depicts development of clear oxygenated water and shallow depth with sufficient amount of food supply before influx of arenaceous sediments and covering of reef.

The large scale cross stratified sandstone units among the intertidal sandsheets suggests existence of fluviatile conditions to aeolian coastal dune conditions and it also shows fluctuating nature of coast line. Occurrence of structures showing existence of small tidal gullies and pools support development of tidal conditions.

The contortion of the sediments and frequent occurrence of sandstone dykes which are in some cases bifurcating, indicate slumping of the sediments under plastic conditions as well as episodes of tectonic activities alongwith deposition before complete hardening, compaction or diagenesis, and also suggest very fast rate of sedimentation. The dykes also show high water saturation of sediments and deposition of heavy load on it before solidification, where earthquake tremors might have induced injection of the underlying sediment in the overlying sequence.

Rootlets in the rocks support terrestrial conditions in the uppermost part of the sequence.