5.1 INTRODUCTION

The structure of sedimentary rocks are those features that are studied best in the outcrops. These are formed from materials of varied composition and are products of physical, chemical and biological processes. Certain processes are common in present day environments, but combination of processes, often with particular directional properties, are diagnostic of specific environments. The study of sedimentary structures are helpful to understand the sedimentary environment or facies in which the rocks were deposited.

Sedimentary structures are divided into primary and secondary classes. Primary structures are those generated in a sediment during or shortly after deposition, which result mainly from physical processes. The secondary
Sedimentary structures are those which formed sometimes after sedimentation. They result from essentially chemical processes.

The classification of sedimentary structures present in the study area are as follows:

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5.2 PRIMARY SEDIMENTARY STRUCTURE

INORGANIC

5.2.1 BEDDING

The universal primary structure of sedimentary rock is their bedding or stratification. Bedding or stratification expressed by rock units of general tabular or lenticular form that have some lithologic or structural unity (Pettijohn, 1984). Most sedimentary rocks are arranged in layers or strata. According to Payne (1942) a
stratum is an individual layer of 1 cm. thickness or greater and is separated from strata above and below by a discrete change in lithology or a physical break. A lamina is similar to stratum but is less than 1 cm in thickness. A bed is a rock unit composed of several strata or laminae.

Individual bed is observed to be deposited under essentially constant physical chemical and biological conditions by uniform processes or sequence of processes. Bed contacts represent changes in conditions to non-deposition or erosion. The greater part of calcium carbonate in the limestones, results from the activities of organisms which precipitate it as part of their metabolic processes.

Village Sirsa and Jhenjhit of Lithofacies-A and village Boria of Lithofacies-C show small exposure of well laminated structure in limestone and calcareous shales respectively. The beds are horizontal or with 1-2° dip towards north east. In Nandini Mines of Lithofacies-B small patches of well laminated limestones are observed (Plate 22 B). Other than the field area
bedding and cross beddings are shown in Kalipur sandstone and shale at Kumhari, Khapri, Rawan and Siltara (Wadhwa, 1976).

5.2.2 DESICCATION CRACKS/SHRINKAGE CRACKS

Desiccation and compaction of water filled calcareous or argillaceous muds produce a system of shrinkage cracks, which in their typical development, form a network and divide the surface into irregular polygonal shapes. If these fissures remain open while the surface is being buried and persist after sediment has hardened to rock, they constitute a characteristic indicator of the top surface.

If the plates of mud-cracked layer are subjected to fragmentation followed by some erosion and transportation before burial, they will be rounded to some extent. If deposited with variable orientation they constitute one type of intraformational conglomerate or breccia. This structure is not characteristic of top or bottom of beds.

In Lithofacies A and C small exposures of limestone at village Jhenjhiria & Boria show characteristic
desiccation cracks and intraformatinal conglomerate respectively (Plate: 22 A). Desiccation cracks and mud pebbles are formed in the upper tidal and supratidal zones (Flugel, 1982).

ORGANIC SEDIMENTARY STRUCTURE

5.2.3. STROMATOLITES:

Stromatolites are organosedimentary structures produced by the carbonate precipitating and sediment binding activities of blue/green algae.

The Raipur limestones show an abundant growth of stromatolites. The term was coined by Kalkowski (1908) referring to laminated structures of problematic origin. They occur in rocks from Precambrian to Recent, but predominant in rocks older than Ordovician and most predominant in Upper Precambrian.

The potential usefulness of algal stromatolites as indicator of environment is apparent and many palaeogeographical and palaeo-ecological reconstructions have been made based upon algal stromatolite assemblages. On the other hand many workers, specially from the USSR,
claim that the various forms reflect time controlled evolutionary phenomenon and have attempted regional biostratigraphic correlations based upon stromatolitic assemblages. The present study attempts to make some specific contribution towards their usefulness as stratigraphic markers and as environmental indicators. The associated sedimentary structures have also been useful in deducing the palaeoenvironmental condition during sedimentation of Raipur limestone of Raipur Group.

In the present area of study, they were earlier reported as concretions by King (1885), Sen (1966), briefly described their morphology. Vishwanathaiya & Shastri (1973) have reported the presence of algal stromatolites at Nandini (M.P.), whilst studying the occurrence of phosphorites. Chandra & Bhattacharya (1973) studied the stromatolites from Raipur limestone at Mandir Hasaud. Ghosh & Shah (1965), Schnitzer (1971), Wadhwa (1976), Jairaman & Banerjee (1984), N (Jha) Chatterjee et al (1990), Moitra A.K. (1986), Murti (1978) described their occurrence in the Raipur Group. Kreuzer et al (1977) carried out the geochronological studies of Chandarpur Sandstone.
CLASSIFICATION & DESCRIPTION OF STROMATOLITES

The stromatolites are here divided into different groups on the basis of their morphological features like shape and ornamentation of the columns, types of branching etc. as suggested by Raaben (1969) & Cloud & Semikhatov (1969). The columnar stromatolites of Raipur limestones identified belong to Colonnella and Baicalia groups. The domal non-branching stromatolites are identified as Nucleela Komar (1966). The various forms identified are described below along with field sketches and photographs.

Group - Colonnella Komar 1966
Form - Colonnella columnaris
(Plate 19A Fig.17A to E)

SHAPE AND MODE OF OCCURRENCE

Columnar form, columns being 4 to 8 cms. long and 2 to 4 cms. wide, developing perpendicular to the bedding planes. The laminae shows different degree of convexities. The columns are arranged close to each other (1 to 2 cms. apart). The gap is filled with carbonate mud and void filling calcite (fenestral). The spacing between columns is almost equal. The density of the colony varies from 40 to 60 percent.
MICROLAMINATIONS

Laminae exhibit banded microstructure of alternate dark and light coloured ones 600 µm to 2000 µm thick. The darker laminae are relatively thin and composed of micrite and microdolosparite grains, while the light coloured ones are made of micrite and microsparite grains. Microlaminae are smooth and continuous resulting into banded microstructure (Plate 21 B).

COMPARISON

The form compares well with the non-branching group Colonnella Komar (1966) and form Masloviella columnaris Korolzuk (1960). Such forms are known from Burzyan Series (Lower Riphean) and Avzyan Series (Middle Riphean) of Southern Urals (Keller et al, 1960; Krylov, 1960). In the Raipur limestone these are associated with Baicalia baicalica which is very significant. Similar associations has been reported from Jammu Limestone (Raha, 1984) and from Gangolihat Dolomites (Pant, 1985).
LOCALITY

Village Jhenjhiri (Lithofacies A) and Nandini Mines (Lithofacies B)

Group - Nucleella Komar, 1966
Form - Nucleella Fm. Komar, 1966

(Plate 19 B)(Fig.17F)

SHAPE AND MODE OF OCCURRENCE

Leaf like solitary hemispheroidal forms. The hemispheroids are 5-7 cms. in diameter, margins being smooth. The growth laminae show higher convexities at the base and becoming almost flat at the top. The density is 40% to 60%.

MICROLAMINATIONS

The laminae are composed of alternate thin dark grey micrite and microdolosparite (1500 μm) and relatively thick (1500 to 2000 μm) light coloured microsparite grains. The nature of contact between these layers is sharp (Plate 21 A).
COMPARISON

These depressed forms were reported earlier as Collenia symmetrica Fenton & Fenton (1937). Such forms have very little stratigraphic significance. However, they are known to develop in quiet subtidal conditions. Krylov & Semikhatov (1976) noted that such forms have long range extending from Aphebian to Riphean.

LOCALITY

Nandini mines of (Lithofacies B), associated with Colonnella columnaris

Group - Baicalia Krylov 1963

Form - Baicalia baicalica Maslov

(Plate 20 A,B) (Fig. 17 G,H,I)

SHAPE AND MODE OF OCCURRENCE

Colonies are slightly oblique to bedding with characteristic dichotomous branching. The branches/club shaped, constricted at base and widening upward. Branching is seen at angle of 20-30°. The density of colonial growth is 50-70%. The transverse section are more or less oval
shaped. The marginal areas are highly irregular and at places bumps are also seen. Unlike Tungussids there are no horizontal tuberous branching in these forms.

**MICROLAMINATIONS**

The thickness of dark and light laminae is 200\(\mu\)m to 600\(\mu\)m, which is very much less, as compared to other forms of Raipur stromatolites. The dark lamina is made up of micrite, while light coloured is of microsparite. The contact between the two laminae is gradational.

**COMPARISON**

These forms show similarities with Tungussids broadly but the columns are sparsely widening and horizontal tuberous branching is absent. The other distinction demonstrated by the present forms is that these are wall-less while Tungussids are walled forms, and form tube like structure. In USSR *Baicalia baicalica* is characteristic of Middle Riphean sometimes extending up to Upper Riphean. These forms are very much similar to the *Baicalia baicalica* (Valdiya, 1969; Pant, 1985) recorded from Gangolihat Dolomites. Valdiya (1989) compares these forms
FIG. 17. COLUMNAR STROMATOLITES FROM RAIPUR LIMESTONES (AROUND NANDINI, DURG, M.P.)
with Tungussida of Bhandar and as such Raipur limestone can be assigned an Upper Middle Riphean to Upper Riphean age. However, the peculiar association of Baicalia baicalica with Colonnella columnaris being significant and suggests a Middle Riphean age.

**LOCALITY**

Nandini mines (Lithofacies B) and near village Chikhli (Lithofacies A) 20 Km SW of Nandini.

**PALAEOENVIRONMENT**

Considerable doubt still persists as to whether variations in morphology of different stromatolites are controlled biologically or are a function of physical environment. In Russian literature the concept of biotic control of the morphological feature of Precambrian stromatolites is predominant, and the influence of ecological factors on gross shape of Riphean stromatolites is under estimated (Serebryakov & Semikhatov 1974) and sometimes practically denied (Raaben 1969).
However, any conclusion concerning either physical environment can only be broad and tentative till the specific effects of these factors on the stromatolite morphology are more properly understood. The environmental aspects of stromatolite study have been developed largely through analogy of ancient stromatolitic forms with recent stromatolites.

The different type of algal stromatolites identified in the present study indicate marine intertidal flat environment. The main part of the tidal environment consists of the intertidal zone which passes seawards to subtidal zone and shoreward to supratidal zone. The shallow water intertidal environment is also supported by the occurrence of ripple marks, current bedding and other shallow water structures in the Raipur Sandstones, associated with the Raipur Limestones in the Raipur area (Wadhwa, 1976) and mud cracks, intraformational flat pebble conglomerate in Raipur limestone (near Boria village) (Lithofacies C). Separately, it has been shown that the depositional site of these limestones trends NE-SW.

The stromatolites of Raipur Limestones are predominantly composed of columnar type. These structures are suggestive of a local exposed intertidal environment to
-ed
protect/intertidal mud flat environment. This view can be
supported by the presence of mudcracks and intraformational
flat pebble conglomerate such as seen near Boria, north east
of Nandini.

Additional detailed studies may enable a further
sub-divisions into sub-environments and also lead to the
delineation of the strand line.

AGE

Several workers had attempted stratigraphic
classification of Precambrian formations on the basis of
stromatolite assemblages. Notable is the sub-division of
Riphean (Late Proterozoic) of USSR into three sub-divisions—
Lower (1650-1350 m.y.); Middle (1350-950 m.y.) and Upper
(950-650 m.y.) by Raaben (1969). It is remarkable that this
zonation is in good agreement with palaeontological evidence
being supported by absolute age data.

The stromatolite assemblage of Raipur Limestones
thus comprises predominantly of *Colonnella columnaris*,
*Nucleella, Haicalia baicalica* etc. (suggestive of Middle
Riphean 1350-950 m.y.). This age is further confirmed by the absence of Group Kussiella and Jurusanica which if present would have indicated Lower Riphean (1650-1350 m.y.). Therefore, all these forms can tentatively be assigned to Middle Riphean.

5.3 SECONDARY SEDIMENTARY STRUCTURES
5.3.1 KARSTIFICATION

Karst is the province in Yugoslavia, where cavernous limestones were first identified and studied for the first time for its unique morphology and, thus, the term Karstification has become classic and universal application for cavernous limestones of all shades, composition and of stratigraphical horizons and has become the subject by itself. Karst can be viewed as an open system composed of two clearly integrated hydrological and geochemical subsystems operating upon the karstic rocks. Karst landforms are the product of the interplay of processes in these linked subsystems.

The karstic system can be grouped into two zones erosional and depositional, according to its origin. In the
erosional zone, there is net removal of the Karstic rock, by
dissolution, same redeposition of eroded rocks occurs in the
zone mostly in the form of precipitates. Erosional karstic
features are common than depositional features.

Erosional Karstic features are developed in the
Raipur limestones at various localities in the present area
of study. Some of them are Durg-Dhamdha road at Pitora,
Deorjhal, Nandini-Kundini etc (Plate 25, 26). The type of
karsts found here can be classified as sub-soil Karst
(covered by sub-soil); and bare karst (exposed on the
surface). Both the karstic feature are characteristic of
limestone terrain.

The solution cavities running along horizontal
planes may be regular (clints) or may have irregular form
(bleby cavities). Vertical solution openings are termed as
grikes (Plates 25 B).

5.3.2'b) STYLOLITES

Stylolites are thin zones of discontinuity within
rocks. They generally consist of conical to columnar
projections with intervening depression. These structures
vary in size from microscopic 'sutured contact (microstylolites) up to stylolites' several meters in length.

They are generally regarded as the result of pressure-solution. This involves solution around points of contact between mineral grains in response to pressure (weight of overburden). Since certain minerals are more susceptible to pressure solution than others, various burial depths are necessary in order to produce a strong stylolitisation. Pressure-solution is an important process for supplying carbonate for the formation of carbonate cements.

Stylolites are very common in Raipur limestones of study area. They are generally parallel to bedding planes and cut perpendicular to stromatolitic limestones. Small exposures at Jhenjhi (Lithofacies A) and Biroda (Lithofacies B) show this structure very clearly (Plates 24B).

5.3.3. **CALCITE VEINS**

Many limestone display various systems of calcite filled veins and veinlets. Experimentally deformed
carbonate rocks indicate that the mechanical behaviour and the origin of fracture is controlled by the amount of sparite, micrite and dolomite. Limestone with more than 50% micrite are relatively strong as compared to sparry limestones. In pure dolomites or dolomitic limestones strength and ductility depend on the texture. In the study area micrite limestones show very few calcite filled veins. But these are very common in dolomitic limestones of Nandini mines which are more brittle and fractured (Plate 23B). The width of veins range from a fraction of 2 to 30 cm and are filled with rhombohedral and scalenohedral calcite crystals (Plate 27A).
A: Colonnella columnaris Komar, showing vertical stalked hemispheroids perpendicular to bedding planes. Intercolumnar area is filled with carbonate mud. Locality: Nandini Mines (Lithofacies-B).

B: Nucleella Fm. Komar showing solitary hemispheroids. Locality: Nandini Mines (Lithofacies-B).
A & B: Baicalia baicalica showing conspicuous branching the columns being constrained near the branching.
Locality: Black stone quarry (Nandini Mines) (Lithofacies-B).
A: Photomicrograph showing microlaminations of Nucleella Fm Komar.

Bar scale: 200 μm

B: Photomicrograph showing microlamination of Colonnella columnaris.
A: Desiccation Cracks in shaly limestone
   Locality: Boria N.E. of Nandini (Lithofacies-C)

B: Bedded micrite showing alternate dark and light coloured bends.
   Locality: Nandini Mines (Lithofacies-B).
A: Stromatolite bearing limestone (Lithofacies-A) showing polygonal mud-cracks on the outcrop. Locality: Village Jhenjhri.

B: Stylolite traversing parallel to bedding plane. Locality: Village Jhenjhri (Lithofacies-A).
A: Karstification on Raipur limestone. Stylolites are clearly observed. 
Locality: Deorjhal (Lithofacies-B).

B: Karstic rock showing grikes (Horizontal) and clints (vertical openings). 
Locality: Deorjhal (Lithofacies-B)
A: Karstification produced by solution action on Raipur limestone.
Locality: Deorjhal (Lithofacies-B)

B: Karst topography.
Locality: Pitora (Lithofacies-B)
A: Calcite vein traversing Parallel to joints. 
   Locality: Dhamdha bridge (Lithofacies-A).

B: Thickness of soil cover Raipur limestone. 
   Locality: Dhamdha Bridge (Lithofacies-A)