



FACIES AND ENVIRONMENT OF DEPOSITION OF THE TRIASSIC SUCCESSION OF THE MALLA JOHAR AREA, KUMAON TETHYS HIMALAYA

ASHOK K. SRIVASTAVA* and S. KUMAR**

*DEPARTMENT OF GEOLOGY, AMRAVATI UNIVERSITY, AMRAVATI - 444602, INDIA
e-mail: ashokamt2000@hotmail.com

**DEPARTMENT OF GEOLOGY, LUCKNOW UNIVERSITY, LUCKNOW - 226007, INDIA
e-mail: surendra100@hotmail.com

ABSTRACT

The Triassic succession of the Malla Johar area is about 800m thick dominantly represented by calcareous and argillaceous rocks with subordinate sandstone and siltstone. It represents all the stages of Triassic from Scythian to Rhaetic. Lithostratigraphically, it is represented by the Kalapani Limestone, the Kuti Shale, the Passage Formation and the Kioto Limestone Formation.

The succession has been studied for detailed petrography, lithofacies and microfacies analysis. A total of eleven lithofacies have been identified, i. e. shaly limestone lithofacies, nodular limestone lithofacies and limestone-shale lithofacies (the Kalapani Limestone); calcareous shale lithofacies, argillaceous-calcareous shale lithofacies and silty shale lithofacies (the Kuti Shale); calcareous lithofacies and arenaceous lithofacies (the Passage Formation) and oolitic limestone lithofacies, nodular limestone lithofacies and well bedded oolitic-bioclastic lithofacies (the Kioto Limestone). Similarly, on the basis of the thin section study, eight microfacies are recognised viz., skeletal wackestone microfacies with three sub-microfacies, i.e., bivalve-gastropod-echinoid-algal wackestone sub-microfacies, echinoid-brachiopodal wackestone sub-microfacies and foraminifer-bivalve-echinoid wackestone sub-microfacies (the Kalapani Limestone); quartz-arenite microfacies, calcareous siltstone microfacies, brachiopod-bryozoan wackestone microfacies, skeletal-peloidal grainstone microfacies (the Passage Formation); oolitic grainstone microfacies, peloidal grainstone microfacies and skeletal-peloidal grainstone microfacies (the Kioto Limestone.)

On the basis of detailed field observations, petrographic study, lithofacies and microfacies analysis, an attempt has been made to establish the depositional environments. The Triassic succession is a shallowing-upward sequence ranging from the deeper parts of the shelf to a carbonate coastal complex. Emphasis has also been given on the condensed nature of Upper Scythian to Lower Carnian carbonates of the Kalapani Limestone, and broad nature and pattern of sedimentation and overall basin configuration during the Triassic period.

Key words : Triassic, Tethys Himalaya, Microfacies, Lithofacies, Sedimentation, Condensed succession.

INTRODUCTION

In India, the marine Triassic succession is developed only in the Tethys Himalayan zone, particularly in Kashmir, Himachal and Kumaon-Garhwal regions. In the Malla Johar area of Kumaon-Garhwal, all stages of Triassic are well recognised and constitute a part of the Malla Johar Supergroup (fig.1). The Malla Johar Supergroup shows a more or less complete succession ranging in age from Precambrian to Cretaceous (Kumar, Singh and Singh, 1977). The Triassic succession is represented in stratigraphic order by the Kalapani Limestone, the Kuti Shale, the Passage Formation and the Kioto Limestone (Griesbach, 1893; Heim and Gansser, 1939, Srivastava and Kumar, 1990). The succession records continuous sedimentation and attains a thickness of ca. 800m. The Lower to Middle Triassic (Scythian to Carnian) is represented by only a ca. 30m thick condensed sequence whereas the Upper Triassic (Norian and Rhaetic) is ca. 770m thick

(Heim and Gansser, 1939; Kumar *et al.*, 1977). The limestone, dolostone and shale constitute the dominant lithology with subordinate sandstone and siltstone. The succession shows gradational contacts with the underlying Kuling Shale (Permian) and overlying Laptal Formation (Lower Jurassic) (Heim and Gansser, 1939; Kumar *et al.*, 1977).

Since the last century, the Triassic succession has been studied for its fauna (Strachey, 1851; Salter and Blandford, 1865; Griesbach, 1891, 1893). Diener (1912) proposed a detailed bio-stratigraphy on the basis of ammonoids. Shah and Sinha (1974) presented biostratigraphic subdivisions of the entire supergroup on the basis of macrofossils. In recent years, much emphasis has been given to micropalaeontological studies i.e. conodonts (Chhabra *et al.*, 1973; Chhabra and Sahni, 1981; Chhabra and Kumar, 1984, 1992; Agarwal and Kumar, 1984; Chhabra, 1988), ostracods and foraminifers (Agarwal and Kumar, 1980, 1981; Agarwal and Mandwal, 1994) and palynology (Tiwari,

Tripathi, Kumar, Singh and Singh, 1980; Tiwari, Singh, Kumar and Singh, 1984). A good account of the palynoflora of the Kalapani Limestone with a comparison to Australia has been given by Vijaya, Kumar, Singh and Tiwari (1988). Biozonation on the basis of conodonts by Chhabra and Kumar (1992) also supports the age assignment given on the basis of the ammonoids. Sinha (1989) and Thakur (1993) compiled data on various aspects of the geology of the Higher Himalaya including work on the Triassic succession of Malla Johar area. However, there is no published work on the petrography, lithofacies and microfacies of these rocks.

The present paper deals with the study of lithofacies and microfacies, depositional environment, nature and pattern of sedimentation during the Triassic period. The lithofacies have been established on the basis of observable field criteria while the microfacies analysis is based on the detailed thin-section study.

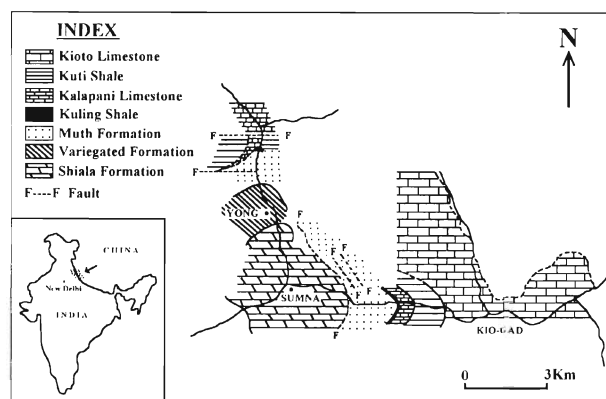


Fig. 1. Geological map of the area, modified by Srivastava and Kumar (1990) after Kumar *et al.*, (1977). Samples were collected in the Yong Valley north of Sumna and in the Kio-Gad (Kio Valley) east of Sumna.

The work is based on samples and data collected during two expeditions in the years 1986 and 1988. The samples are collected along the Yong and Kio Valleys located at about 2 km north and 3 km east of

Table 1 – Lithostratigraphic subdivisions of the Rawalibagar Group in Malla Johar area, Kumaon Himalaya (after Kumar *et al.*, 1977; Srivastava and Kumar, 1990).

Group	Formation	Member	Lithology	Environment of deposition	Age
	LAPTAL FORMATION (70 m)		Shell limestone, limestone, oolitic limestone, marl and shale	High energy shoals and channels	Liassic
R A W A L I B A G A R	KIOTO LIMESTONE (140 m)	Kioto D (30m) Kioto C (30m) Kioto B (30m) Kioto A (50m)	Oolitic limestone and shell limestone Limestone, shell limestone and shale Nodular limestone Oolitic limestone, limestone and shale	Oolitic sand bar Coastal carbonate complex Coastal carbonate Carbonate shoal-sandbar	Rhaetic
	PASSAGE FORMATION (100m)		Shell limestone, limestone, silty shale and orthoquartzite	Tidal flat complex	Noric
G R O U P	KUTI SHALE (510m)	Kuti C (100m) Kuti B(280m) Kuti A (130m)	Silty shale and sandy limestone Greyish black, friable shale with hard calcareous shale Black friable shale and shaly limestone	Transition zone - subtidal zone Transition zone Upper part of shelf mud region	Noric
	KALAPANI LIMESTONE (30m)		Nodular limestone, shell limestone and shale with abundant megafossils	Deeper part of the shelf	Late Scythic to Carnic
	KULING SHALE (20m)	Kuling B (20m)	Black shale and siltstone with calcareous nodules	Shallow shelf mud region	Permian to Early Scythic

Sumna respectively (fig. 1).

GEOLOGICAL SETTING

The Malla Johar area lies in the Tethys Zone of Himalaya, which forms the most spectacular mountain terrain with peaks attaining heights of more than 8000m and valleys forming deep gorges with glaciers occupying large areas in the higher reaches. In general, the area is inhospitable and hazardous and this restricts the field work to only a few tracks.

The structure and stratigraphy of the area was given as early as 1891 by Griesbach. Diener (1912) provided the ammonoid biostratigraphy of the Triassic succession. In 1939, Heim and Gansser gave a much needed detailed account of the lithostratigraphy, palaeontology, structure, tectonics and sedimentology. Gansser (1964) summarised the available data of the Tethys Himalaya. Kumar *et al.*, (1972) provided a generalised stratigraphy and structure on the basis of the work done in Niti and Darma valleys. Banerjee (1974) has discussed the stratigraphy and depositional characteristics of the Tethyan sediments exposed in the eastern part of the Malla Johar area.

Kumar *et al.*, (1977) ranked the entire succession ranging in age from Precambrian to Cretaceous as the Malla Johar Supergroup and provided information on lithostratigraphy, palaeocurrent analysis, trace fossils and depositional history. They subdivided the Supergroup into four groups namely, the Malari Group, the Sumna Group, the Rawalibagar Group and the Sancha Malla Group. The Rawalibagar Group constitutes a major part of the Triassic succession and has been subdivided into six formations, viz., the Kuling Shale, the Chocolate Formation, the Kalapani Limestone, the Passage Formation and the Kioto Limestone by Heim and Gansser (1939). However, the Chocolate Formation (Scythian) is not identified in the study area (Srivastava and Kumar, 1990), and the Scythian is represented by the lower most part of the Kalapani Limestone (Table 1, fig. 2). It is also supported by the presence of conodonts viz., *Neogondolella jubata* and *Neospathodus homeri* (Chhabra, 1988). The Kalapani Limestone shows a conformable contact with the underlying Kuling Shale (Upper Permian) and the Kioto Limestone also grades

to the overlying Laptal Formation (Lower Jurassic) (Heim and Gansser, 1939; Kumar *et al.* 1977).

FIELD DATA, PETROGRAPHY, LITHO-FACIES AND MICROFACIES

The carbonate rocks of the Kalapani Limestone have been collected at very close intervals of 0.5 - 1 metres because of the condensed nature of the succession. The Kuti Shale could be sampled only at 5 - 15 metre intervals due to the inhospitable terrain and monotonous argillaceous nature of the succession while the Passage Formation and Kioto Limestone were sampled at 2-3 metres interval depending upon the variation in the lithology. Carbonate thin sections

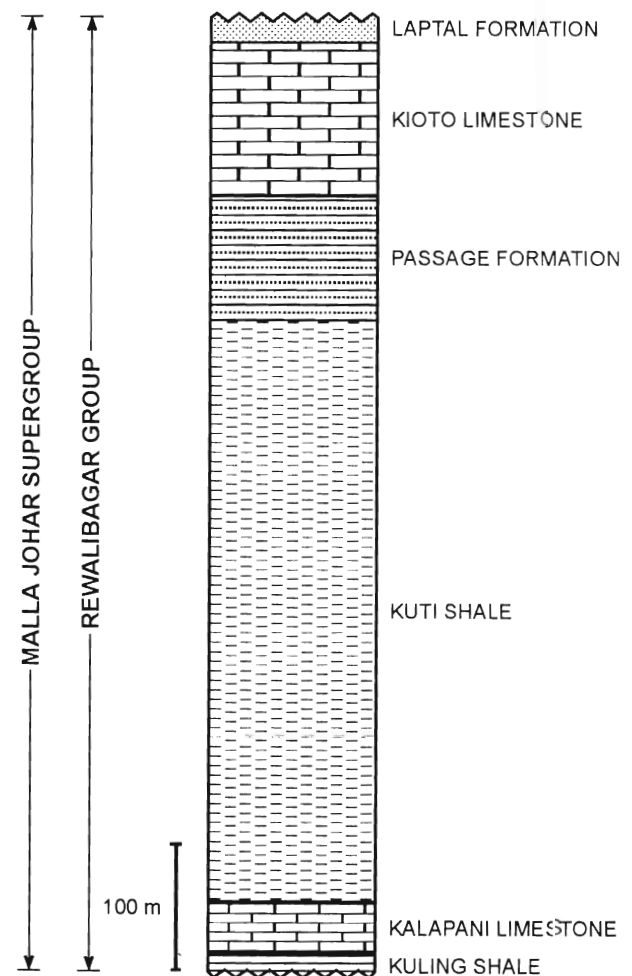


Fig. 2. Litholog of the Triassic succession exposed in the Malla Johar area showing different formations of the Rawalibagar Group (simplified after Kumar *et al.*, 1977).

were stained by the Alizarin Red S and potassium ferricyanide in order to differentiate the calcite, ferroan calcite, dolomite and ferroan dolomite.

THE KALAPANI LIMESTONE

Field observations and lithofacies

The Kalapani Limestone (Scythian to Lower Carnian) is exposed in the Kio (44m) and Yong (30m) valleys lying conformably over the argillaceous Kuling Shale (Upper Permian) which is about 27 m thick, dominated by argillaceous contents with a few horizons of siltstone/fine sandstone and shell limestone.

The succession is an alternations of 10-40cm thick black, fossiliferous, nodular limestone and equally thick grey, ash grey and black shale (Heim and Gansser, 1939; Kumar *et al.*, 1977; Srivastava and Kumar, 1990) (Pl., I, figs. 1, 2, 3). The carbonate and shale beds are equally fossiliferous with cephalopods, echinoderms, gastropods, bivalves, brachiopods, corals and bryozoans. However, ammonoids are quite conspicuous with pronounced size variations and do not show any orientation with respect to the bedding.

Three trace fossil horizons are recorded in the Yong Valley section (Srivastava and Kumar, 1992). The lower is about 5cm thick, carbonate horizon showing poor but dense preservation of cylindrical to subcylindrical trails, which do not show any pattern. The middle horizon is 9-10 cm thick, made up of fine grained, black, fossiliferous limestone and shows the development of long, horizontal to inclined, cylindrical burrows with superimposition of *Chondrites* represented by dark coloured, minute, rounded structures which are locally elongate. The upper horizon is 10-11 cm thick, black shaly limestone showing the development of *Chondrites* burrows similar to those of middle horizon.

On the basis of bedding geometry and lithology, the following three lithofacies have been identified (fig. 3);

i) *Shaly limestone lithofacies*: It represents the lower 7m (Yong Valley) - 10m (Kio Valley) thick succession represented by greyish black, shaly, compact fossiliferous limestone. Shale beds are absent. Megafossils are rare.

ii) *Nodular limestone lithofacies*: Overlying the compact limestone lithofacies, it forms 18m (Yong Valley) - 25m (Kio Valley) thick unit, dominantly nodular in nature, interbedded with shale beds. The thickness of the shale beds decreases upward in the succession. Some beds entirely made up of nodules are also encountered. It is highly fossiliferous and the major fauna is ammonoids though brachiopods, gastropods, bivalves, echinoderms and corals are also present. Trace fossil horizons are recorded showing trails, feeding burrows of polychaetes and feeding-dwelling burrows. It grades into the limestone-shale lithofacies.

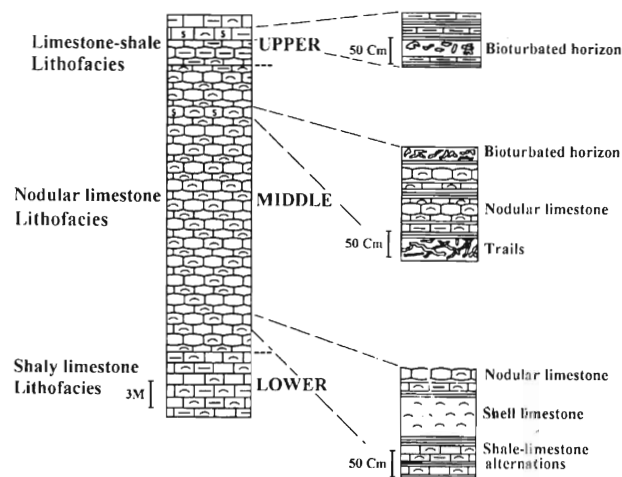


Fig. 3. Lithological succession of the Kalapani Limestone (Yong Valley section) showing the stratigraphic position of the various lithofacies in vertical column.

EXPLANATION OF PLATE I

1. Middle part of the Kalapani Limestone showing the nodular limestone succession (Yong Valley section). 2 - Alternations of the fossiliferous limestone and shale (Yong Valley section). 3 - Photograph showing the bed (bottom) made up entirely of the nodules alternating with the shale (Yong Valley section).



iii) Limestone-shale lithofacies : It is 5m (Yong Valley) - 8m (Kio Valley) thick, fossiliferous, black shaly limestone, interbedded with thin shales. The limestone is 5-15cm thick interbedded with equally thick or more shale beds. The shale beds dominate over the limestone and subsequently grade into the Kuti Shale. Bioturbated horizons are present showing feeding burrows of polychaetes.

Petrology and microfacies

The carbonate rocks of the Kalapani Limestone are dominantly skeletal wackestone (Dunham, 1962) or biomicrite (Folk, 1962). The grains are represented by bivalves, gastropods, echinoderms, algae, brachiopods, bryozoans, foraminifers and conodonts. However, bivalve and echinoderm fragments are common throughout the formation. The grains constitute about 15-45 percent of the total rock. In general, the fragments are broken and angular. The bivalve fragments are thin shelled, thick shelled, disarticulated and rarely articulated. The thick shells are generally recrystallised. Microbial (algal) borings have also been noticed (Pl. V, fig. 6). The gastropod shells are calcic and recrystallised (Pl. VI, fig. 7). Geopetal structures have also been recorded. The echinoderm fragments are variable in size and shape. They are generally yellowish to dirty yellowish in colour and often surrounded by syntaxial growth in optical continuity of the fragment (Pl. VI, fig. 5). Rarely, the fragments are corroded by dark coloured microbial crusts (Pl. VI, fig. 6). The brachiopods are fibrous to lamellar and are dominantly represented by punctate type (Plate, VI, fig. 4). The foraminifers are elliptical to rounded, chambered structures. The arrangement of chambers are uniserial in elliptical form and planispiral in rounded form. The chambers are filled with ferroan calcite cement (Pl. V, fig. 5

and Pl. VI, fig. 8). The bryozoans are generally fenestral type with zooecia filled with ferroan calcite (Pl. V, fig. 1, 2 and Pl. VI, fig. 3). The calcareous algae show much variation in shape, size and microstructure. They are represented by filamentous, circular, elliptical, boring, branching and encrusting types. The conodonts are blade shaped elongated structures (Pl. VI, fig. 2). Rarely, microcephalopods are also recorded (Pl. VI, fig. 1).

The matrix is dominantly represented by microcrystalline calcite and is locally dolomitized. Presence of siderite crystals (Pl. V, fig. 8) and rhombs of dolomite (Pl. V, fig. 7) are recorded in a few horizons. The diagenetic changes are well represented by fibrous growth of calcite on bivalve fragments (Pl. V, fig. 3) and development of ferroan calcite as cavity filling in voids of gastropods, bivalves (Pl. V, fig. 4), brachiopods, foraminifers and bryozoan. The syntaxial growth on echinoderm fragments is also recorded.

On the basis of thin section study, the entire succession can be grouped as skeletal wackestone microfacies. However, some distinctions have been noticed regarding the distribution of the skeletal fragments in the lithocolumn. On the basis of predominance of the skeletal fragments, following three sub-microfacies have been established (Fig. 4. Pl. VII).

i) Bivalve-gastropod-echinoid-algal wackestone sub-microfacies : It constitutes a major part of the succession and is repeated three times in the lithocolumn (fig. 4). Broken angular fragments of bivalves and echinoids dominantly represent it. A few horizons of this sub-microfacies shows preservation of complete gastropod shells filled with micrite. The matrix is micritic (Pl. VII, fig. 1).

EXPLANATION OF PLATE II



1. Field photograph of the Passage Formation showing very high dip. The light coloured part represents quartz arenite. 2 - Field photograph of Kuti Shale in Kio Valley near Rawalibagar showing intense folding. The dark and light coloured bands are because of differential weathering of calcareous shale and argillaceous shale/siltstone.



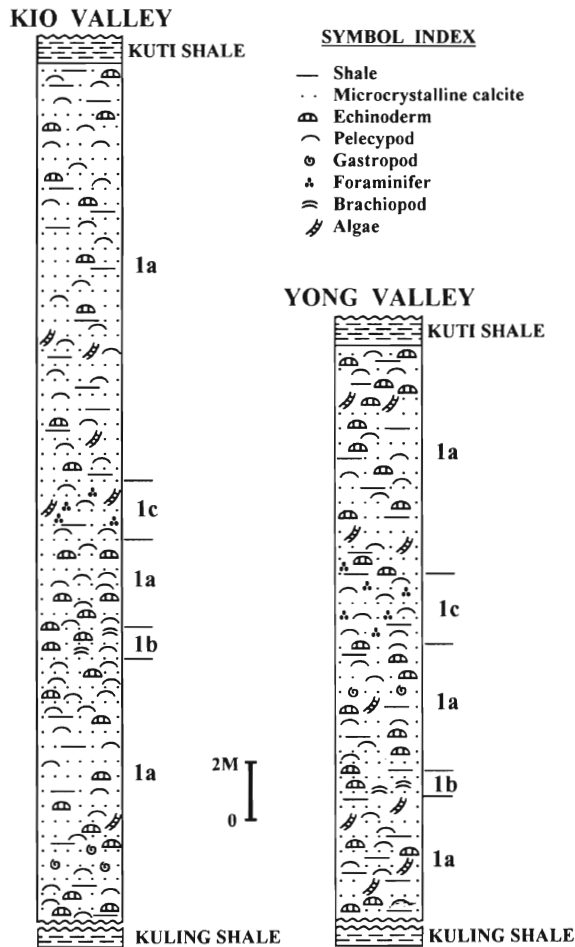


Fig. 4. Lithologs showing distribution of various sub-microfacies of the Kalapani Limestone in vertical succession exposed in the Kio and Yong Valleys. 1a- Bivalve-gastropod-echinoid-algal wackestone, 1b- Echinoid-brachiopod wackestone and 1c- Foraminifer - bivalve-echinoid wackestone.

ii) *Echinoid-brachiopodal wackestone sub-microfacies* : This constitutes a unit about 4 metres thick overlain and underlain by the previously described sub-microfacies. It is represented by dark yellow to brown coloured, sub-angular to angular echinoid fragments and brachiopods having a fibrous

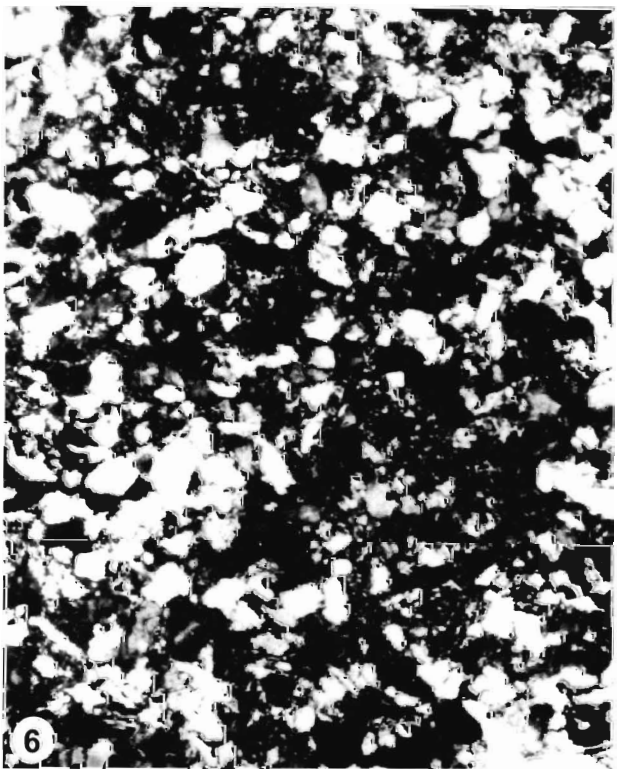
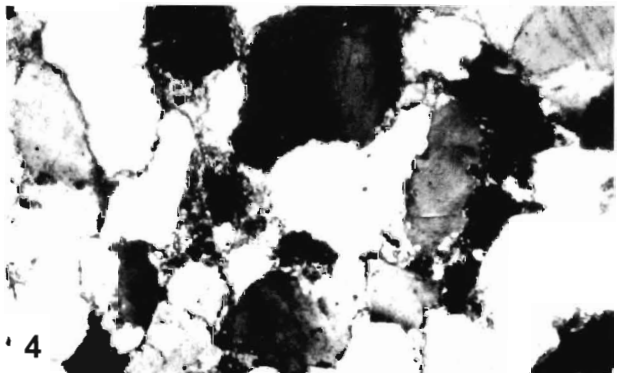
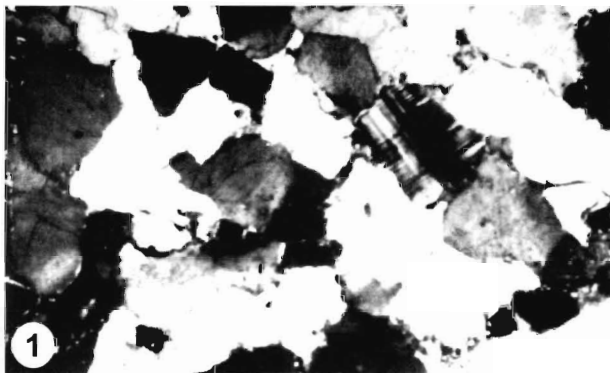
microstructure with micritic matrix (Pl. VII, fig. 2).

iii) *Foraminifer-bivalve-echinoid wackestone sub-microfacies* : The sub-microfacies constitutes about 2 metre thick unit. It is represented by spirally coiled, multichambered, locally dolomitized foraminifers; thin shelled, rarely recrystallised, angular fragments of bivalves and irregular, small fragments of echinoids. Micritic groundmass rarely shows recrystallisation (Pl. VII, fig. 3).

Depositional environment - The field data and lithofacies analysis reveals that the succession has been laid down in calm and quiet water conditions. There is complete absence of any current or wave-generated structures. The compact limestone lithofacies forming the lower part of the Kalapani Limestone is massive in nature with abundant argillaceous content. It is underlain by the Kuling Shale of Permian age which is marked by the emergence of a transgressive phase (Shah and Sinha, 1974; Kumar *et al.*, 1977). The overlying nodular limestone facies of the Kalapani Limestone may be considered as the continuation of the calm and quiet water conditions which started during the Upper Permian. The environment of deposition for the nodular lithofacies and carbonate-shale lithofacies was more or less the same with improved oxygenation and nutrient-rich condition as it is represented by rich faunal remains. However, the supply of argillaceous material was more during the deposition of the carbonate-shale lithofacies. In addition, the presence of numerous ammonoides in almost all the horizons with a lack of any orientation also indicates the general absence of any current or wave activity. The diversity of the rich fauna and presence of echinoderms, brachiopods and cephalopods give strong support for an open shelf region below storm wave base and can be placed in the facies belt 2 of Wilson (1975). Heim and Gansser (1939) have given

EXPLANATION OF PLATE III

- 1- Photomicrograph of quartz arenite showing microcline with cross-lamellar twinning (Crossed Nicols x 60).
- 2 - Lath shape mica fragment with one set of cleavage (Crossed Nicols x 60).
- 3 - Photomicrograph showing sutured contacts and interfingering of the quartz grains (Crossed Nicols x 60).
- 4 - Photomicrograph showing angular to subangular quartz grains, sutured contacts and fine grained feldspathic matrix (Crossed Nicols x 60).
- 5- Photomicrograph of Quartz arenite microfacies showing well to moderately sorted, subangular to subrounded quartz grains. Magnification x45.
- 6 - Photomicrograph of Calcareous siltstone microfacies showing monocrystalline, fine to medium quartz grains. Magnification x35.



an indication of bathyal environment of deposition on the basis of ammonoids.

The trace fossil horizons are significant because of the condensed nature of the succession. The middle horizon is especially significant as it shows extensive burrows of *Chondrites*, superimposed over long feeding-dwelling burrows (Srivastava and Kumar, 1992). It is interpreted that very calm and quiet water conditions are required for such activity and its preservation. Initially, the long burrows of feeding-dwelling habitat were formed, probably because of the activity of crustacean or similar animals. The *Chondrites* was later formed when the previous activity ceased and hard-ground was formed for feeding activity of the polychaetes, preserved as endichnial burrows. Bromley and Ekdale (1984) reported the superimposition of the *Chondrites* on the *Thalassinoides* from the Cretaceous Chalk of Texas and suggested that *Chondrites* can tolerate lower level of oxygen than any other organism. The lower and middle horizons show the development of dense trails and *Chondrites*. The presence of these trace fossil horizons indicates changes in palaeoecological conditions.

Petrological and microfacies analyses also indicate very low energy conditions of deposition. Only skeletal wackestone microfacies have been established with three distinctive subdivisions i.e., bivalve-gastropod-echinoid-algal wackestone sub-microfacies, echinoid-brachiopodal wackestone sub-microfacies and foraminifer-bivalve-echinoidal wackestone sub-microfacies. All the sub-microfacies show the presence of angular to sub-angular bioclasts which are mud supported. The bioclasts constitute about 15 - 45% of the rock while the matrix is micritic which constitutes almost rest of the rock except for the minor content of cement. The fragments, in general, do not show any evidence of transportation. Sorting is poor and fragments seem to float in the matrix. Some of the intact walled bivalves and complete gastropods show geopetal structure suggesting quite water conditions. This suggests that the energy was not enough to move the fine particles of mud. Therefore, the probable site of the deposition may be considered as deeper parts of the shelf below the storm wave base. Similar skeletal wackestone

microfacies are reported from Mishrif Formation of Middle East (Flügel, 1982) which have been interpreted as deposits of shallow water, in low energy shelf area. Thus, the Kalapani Limestone can be placed in drowned platform (Read, 1985) where rate of relative sea level rise exceeded vertical accumulation rate. Kumar *et al.*, (1977) considered the Kalapani Limestone as a deposit of high-energy shoal and sand bar in which a part of the succession has been laid down in transition zone to shelf mud below the wave base which is based on the record of ooids in the field. So far, in the present study, no ooids could be recorded, thus, the high-energy carbonate shoal sand bar environment of deposition as proposed by Kumar *et al.*, (1977) is ruled out. However, the interpretation of Chhabra and Kumar (1992) for the succession as offshore carbonates of a relatively deep water environment on the basis of pelegic nature of conodonts, is close to our interpretation

THE KUTI SHALE

Field observations and lithofacies : The Kuti Shale is a ca. 510m thick, fine grained, clastic succession well exposed at Rawalibagar in the Kio Valley (Plate II, fig. 2). It has been assigned Norian age by Heim and Gansser (1939). Its lower and upper boundaries are gradational with the underlying Kalapani Limestone and the overlying Passage Formation. The lower 410m thick succession is represented by alternations of black friable shale and hard calcareous shale or siltstone. The upper 100m is represented by the alternations of black silty to sandy shale, siltstone and calcareous shale. The sandy shale grades to siltstone with increasing amount of quartz. The compact siltstone horizons show a positive relief in the outcrop due to differential weathering. The succession is fossiliferous, but because of the friable nature of the rocks, the recovery of the fossils is poor.

Lithostratigraphically, Kumar *et al.*, (1977) have divided the Kuti Shale into three informal members viz., Kuti A, Kuti B and Kuti C which more or less represent three lithofacies, i.e. calcareous shale lithofacies, argillaceous-calcareous shale lithofacies and silty shale lithofacies respectively (fig. 5).

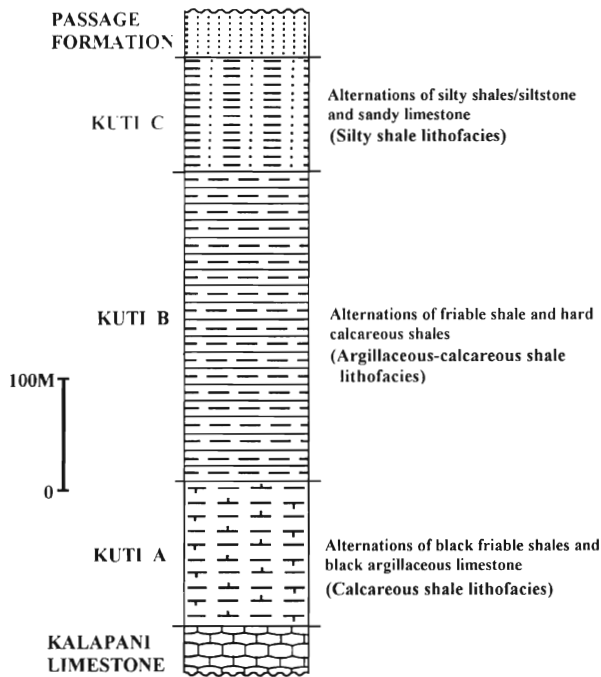


Fig. 5. Lithological succession of the Kuti Shale (Rawalibagar section) showing the stratigraphic position of the various lithofacies in the vertical column.

Calcareous shale lithofacies : This lithounit is about 130m thick black, friable calc-argillaceous succession characterised by the alternations of black friable shale and black argillaceous limestone. The black shale dominates over the shaly limestone. The fossils are represented by badly preserved small ammonoids and lamellibranchs. It has a gradational boundary with the underlying Kalapani Limestone. The upper boundary grades into argillaceous-calcareous shale lithofacies.

Argillaceous-calcareous shale lithofacies : This is represented by rhythmic interlayering of 50 cm - 1 m thick friable shale and decimetre thick hard

calcareous shale. The interlayering is very prominent due to differential weathering. It covers ca. 280 m thick succession and grades into silty shale lithofacies.

Silty shale lithofacies : The lithofacies covers uppermost 100m thick succession and is represented by alternations of 20 - 30 cm bands of silty shale/siltstone with equally thick bands of sandy limestone with calcareous nodules. Arenaceous content gradually increases in the upper part of the facies. It shows well developed small ripple bedding, parallel bedding, lenticular and flaser bedding. Bioturbated horizons are also recorded. With the increase of calcareous content and compactness in the upper part, the lithofacies grades to the overlying Passage Formation.

Petrography

The shale is friable, black coloured made up of unidentifiable admixture of clay. The other minerals present are quartz, calcite, hematite and magnetite. Quartz grains are subrounded to subangular. Locally, flakes of mica are encountered. The calcareous shale is brown to black with homogeneous distribution of carbonate contents of microcrystalline nature. Bioclasts are locally present. The siltstone is grey to dark grey with abundant quartz grains of subangular to subrounded nature. The flakes of muscovite and albite, orthoclase, hematite, magnetite are the other constituents. Calcite is predominantly present in the matrix.

Depositional environment

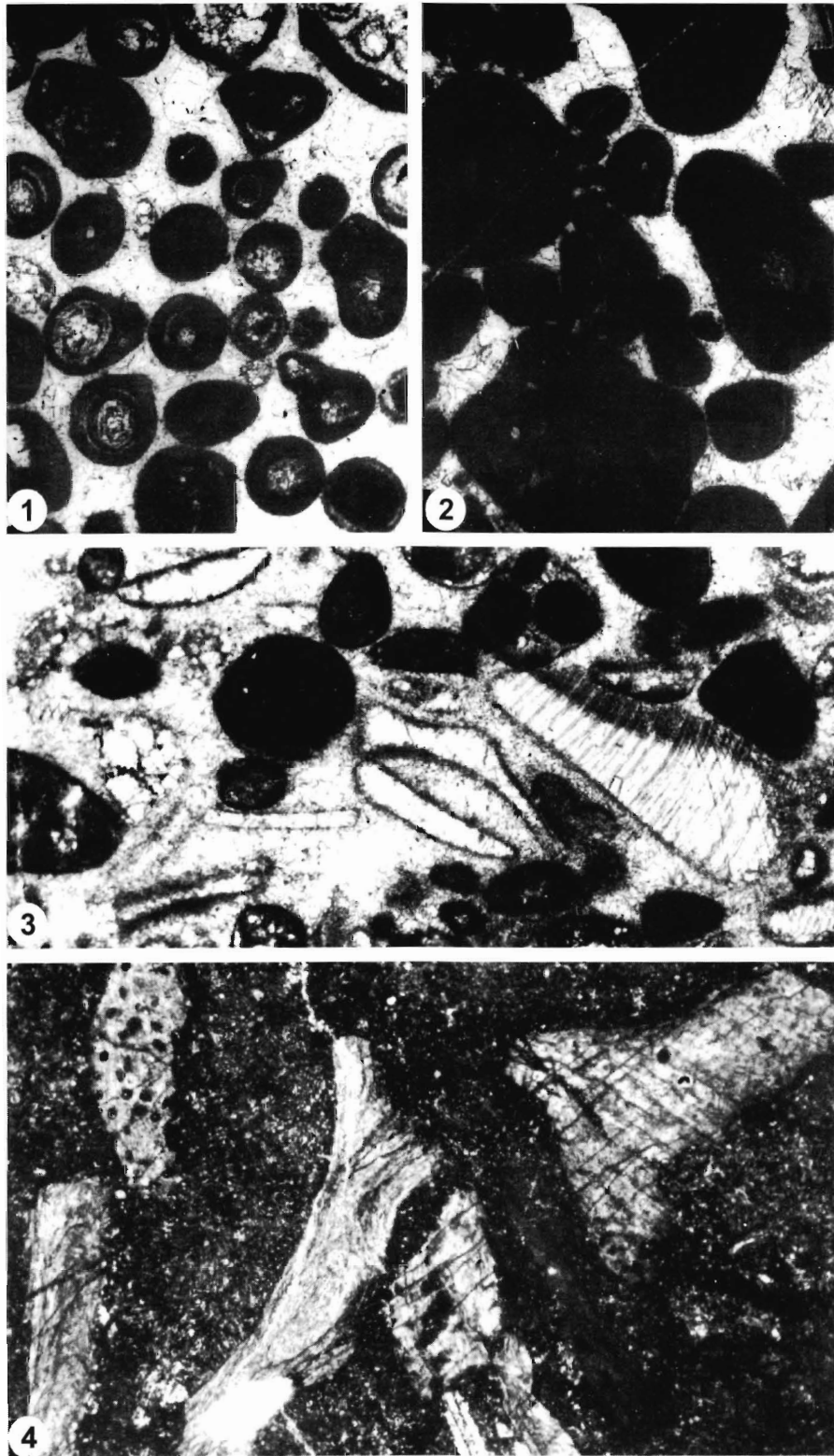
The environment of deposition of three lithofacies established in the Kuti Shale are the same as suggested by Kumar *et al.*, (1977) for the three informal members, i.e. Kuti A, Kuti B and Kuti C.

EXPLANATION OF PLATE IV



1. Photomicrograph of Oolitic grainstone microfacies showing rounded to elliptical concentric ooids with nucleus of quartz. Magnification x37.
2. Photomicrograph of Peloidal grainstone microfacies showing rounded to subrounded peloids with growth of tooth spar cement on outer surface. Cement is sparite. Magnification x37.
3. Photomicrograph of Skeletal - peloidal grainstone

4. Photomicrograph of Brachiopod-bryozoan wackestone microfacies showing brachiopod fragments with fibrous microstructure and bryozoan with zoecia filled with drusy cement of ferroan calcite. Magnification x 40.



The details are as follows;

1. The deposition of the calcareous shale lithofacies has taken place in the deeper part of the shelf environment. A gradual shifting of the site of deposition towards the shallower part of the basin was taking place because of the continuous high input of the argillaceous material. The energy of the depositing medium was low, input rate of argillaceous material was high.
2. The argillaceous-calcareous shale lithofacies may be considered as a deposit of transition zone of deeper part of the shelf to the lower limit of tidal complex. The argillaceous input was as high as during the deposition of the calcareous shale lithofacies. One probable source of detrital content may be considered as due to the gradual sliding of the material from the raised portion of the basin existing at the shallower part.
3. The silty shale lithofacies shows the deposition of sub-tidal to infra-tidal zone of coastal complex. The detrital input is represented by clay and fine-grained sand. Besides this clastic input, the carbonate precipitation as micrite was taking place resulting in the deposition of calcareous shale. The cross bedding can be taken as representing medium energy conditions.

Heim and Gansser (1939) and Kumar, *et al.*, (1972) proposed a deep sea environment of deposition for the Kuti Shale. Bhattacharya (1981) studied the Kuti Shale of an adjacent area, i.e., in Milam-Topidunga section and subdivided the 500 m thick succession into Kuti A (lower 300m) and Kuti B (upper 200m). He interpreted shelf mud region in which the lower part, i.e. Kuti A represents comparatively deeper environment of deposition from Kuti B. Banerjee (1974) studied the Kuti Shale of eastern part of the Malla Johar area but could not suggest the depth range. However, he has inferred slow rate of subsidence in shallow water conditions.

THE PASSAGE FORMATION

Field observations and lithofacies

The Passage Formation is about 100m thick dominantly arenaceous succession exposed on the escarpment overlooking the Rawalibagar in Kio-Valley (Pl. II, fig. 1). Heim and Gansser (1939) used the term Passage Zone for the sandy horizon acting as a transition zone between the Kuti Shale and the Kioto Limestone. Kumar *et al.*, (1977) ranked it as a formation and published a detailed sedimentary log. The succession is dominated by arenaceous rock, however, a few horizons of shelly limestone and fossiliferous micritic limestone are present in the lower part. The arenaceous unit dominated over the calcareous unit and shows the development of parallel bedding and cross bedding.

On the basis of above observations, two lithofacies have been identified which are as follows (fig. 6);

i) Arenaceous lithofacies : It is a dominant unit and constitutes about 70-75m succession. It shows alternations of the sandstone and siltstone beds. The sandy beds are grey to dirty white in colour, 50cm - 2m thick, medium-grained rock with siliceous cement. The silty horizons are also equally thick, with high amount of calcareous content. Both the lithounits show good development of parallel lamination, cross bedding, parallel bedding with low angle discordances. Bioturbated horizons marked by long feeding burrows, *Thalassinoides*, *Palaeophycus* and *Planolites* have been recorded (Srivastava, 1991).

ii) Calcareous lithofacies : This constitutes a unit about 10-15m thick and forms the lower part of the succession. The rock is black to grey in colour, fossiliferous, micritic to sparitic in nature. This unit also shows preservation of parallel bedding.

Petrology and microfacies analysis

On the basis of thin section study, quartz arenite, calcareous siltstone, skeletal wackestone and grainstone have been identified. The quartz arenite is white, grey to greyish brown rock with more than 95% quartz grains. The quartz grains are angular to subangular, 0.5-1.0mm in diameter, often show quartz overgrowth. It is mineralogically mature and well to

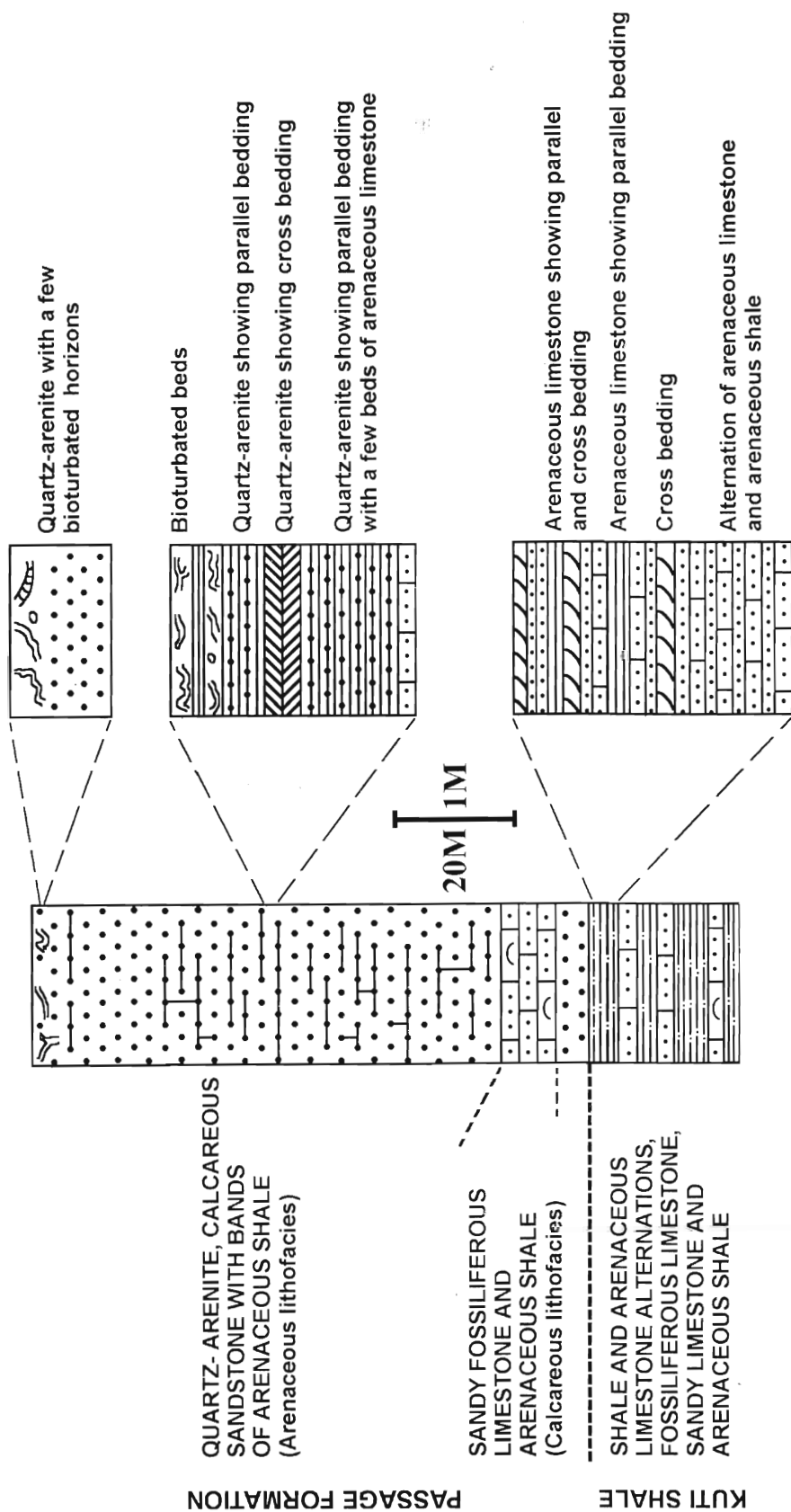


Fig. 6 - Lithological succession of the Passage Formation (Rawalibagar section) showing the stratigraphic position of the various lithofacies in vertical column

moderately sorted. Microcline (Pl. III, fig. 1), orthoclase and mica flakes (Pl. III, fig. 2) are occasionally recorded. The matrix is poorly developed. Cementing material is silica or iron oxide. At places clay lining is noticed in between the quartz grain and syntaxial siliceous cement. Interfingering structures, sutured and corroded margin of quartz grains can be easily noticed (Pl. III, fig. 3, 4).

The siltstone is dominantly made up of angular to subangular quartz grains, feldspar, clay minerals and carbonate. The carbonate content is comparatively higher. The quartz grains are loosely packed and seem to float in the matrix. Sorting is good to moderate. Matrix is dominantly microcrystalline calcite, which constitutes 15-30 % of the rock. Authigenic growth of silica on quartz and sutured margin of the quartz grains are visible at a few places.

The carbonate rocks are represented by skeletal wackestone to skeletal-peloidal grainstone. The wackestone shows the presence of brachiopods and bryozoans with minor occurrence of molluscs and echinoderms. The brachiopod fragments are angular to subangular, dominantly fibrous which locally show regularly arranged circular to elliptical structures filled with spar of the ferroan-calcite. The bryozoans are calcitic with lamellar microstructure having zooecia. The grains constitute about 20 - 25 % of the rock. The matrix is micritic, locally recrystallised with scattered dolomite rhombs. Cement is mostly ferroan-calcite, drusy type occurring in the intraspaces of the skeletal fragments. The grainstone is dominated by skeletal fragments and peloids. The peloids are 0.25-0.5mm in diameter, dark brown coloured, elliptical to rounded structures showing lack of any internal structure. The bioclasts are subangular to subrounded in shape mostly represented by dirty white to dirty yellow echinoid fragments, recrystallised molluscan fragments, algal clots and foraminifers. Some of the bioclasts show dark coloured coating on the outer surface. The grains constitute about 60-65% of the total rock. The cement is mostly sparry calcite. Fibrous growth on the peloids, syntaxial growth on the echinoid fragments, veins of calcite and ferroan-calcite can be noticed.

On the basis of the detailed petrography four microfacies are established in the Passage Formation

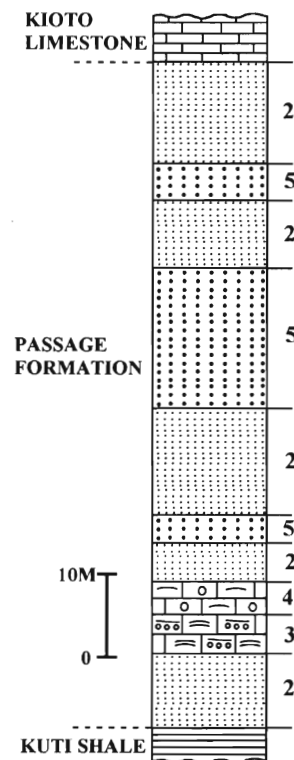


Fig.7. Litholog showing distribution of various microfacies of the Passage Formation in vertical column. 2 - Calcareous siltstone, 3 - Brachiopod- bryozoan wackestone, 4- Skeletal-peloidal grainstone, 5 - Quartz arenite.

which are given as below (fig. 7):

i) *Quartz arenite microfacies* : The microfacies is characterised by the dominance of monocrystalline, subrounded to subangular quartz grains, which constitute more than 95 percent of the total rock having good to moderate sorting. It is represented at three places in the lithocolumn, alternating with the calcareous siltstone microfacies (Pl. III, fig. 5).

ii) *Calcareous siltstone microfacies* : It is also characterised by the dominance of monocrystalline, fine to medium grained quartz with angular to subangular margins. The matrix is made up of fine-grained clay, silica and considerable amount of calcite. The calcite constitutes 10 to 30 percent of the total rock. Sorting is moderate. This microfacies is alternating with the quartz arenite microfacies and also represents the lower most part of the succession which is gradational with the upper part of the Kuti Shale. The argillaceous content in the lower part is slightly more (Pl. III, fig. 6).

iii) *Brachiopod-bryozoan wackestone microfacies* : The microfacies shows the dominance of brachiopod and bryozoan fragments constituting 70-75%. It is about 5 metre thick unit overlying the lowermost horizon of the calcareous siltstone microfacies (Pl. IV, fig. 4).

iv) *Skeletal-peloidal grainstone microfacies* : The microfacies is characterised by the dominance of peloids and skeletal fragments. The matrix is dominantly sparitic. It covers only 5m column in the lower part, overlying the brachiopod-bryozoan wackestone microfacies (Pl. IV, fig. 3).

Depositional environment

The field observations, lithofacies and microfacies show that the Passage Formation is made up of calcareous lithofacies in lower part and the arenaceous lithofacies in the upper part. The calcareous lithofacies constitutes only lower 8 - 10 metre succession which is interpreted as representing low to moderate energy environment as the microfacies ranges from mud-supported to grain-supported carbonates, i.e., brachiopod-bryozoan wackestone microfacies and skeletal - peloidal grainstone microfacies. The supply of terrigenous material as sand was very low during the deposition of this unit. The microfacies may be placed into standard facies belt 4 of Wilson (1975). This standard facies includes the foreshore and characterised by limesilt and bioclastic wackestone to packstone.

The upper arenaceous lithofacies is represented by the quartz arenite microfacies and calcareous siltstone microfacies. It is dominated by the abundant quantity of quartz grains showing little transportation, as can be interpreted from sub-angular margins. The

rate of sand supply shows two different energy conditions as represented by the alternations of quartz arenite and calcareous siltstone microfacies. Carbonate sedimentation took place only when the quartz input was low. The environment of deposition for the arenaceous part may be considered as moderate to high energy condition. The rhythmicity of quartz abundance can be easily noticed in the vertical sequence.

The deposition of the Passage Formation appears to be fluctuating between a moderate to high energy shallow marine environment, possibly a mixed flat where deposition of carbonate and sand both were taking place. Heim and Gansser (1939) and Kumar *et al.*, (1972) presumed that the shallowing of the basin started at the time of deposition of this lithounit. Banerjee (1974) suggested marine realm with deeper depth conditions. Kumar *et al.*, (1977) interpreted it as a tidal flat complex which supports the present interpretation.

THE KIOTO LIMESTONE

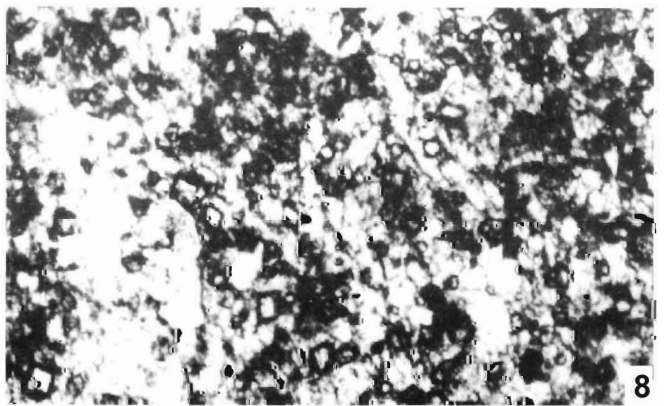
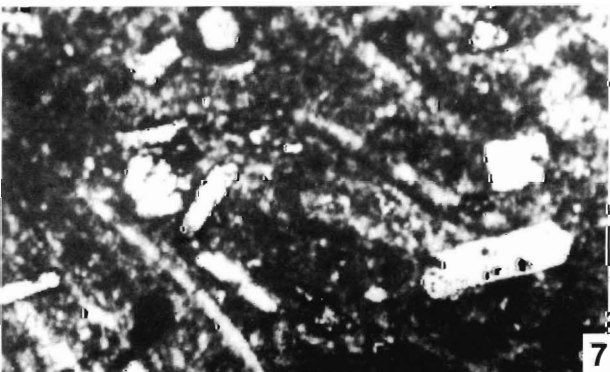
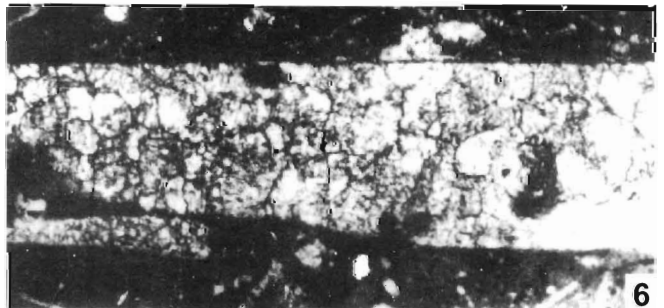
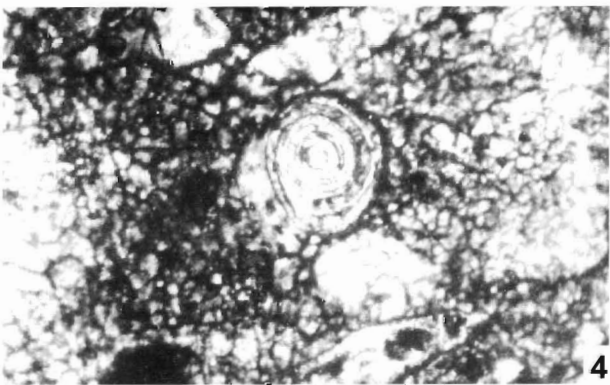
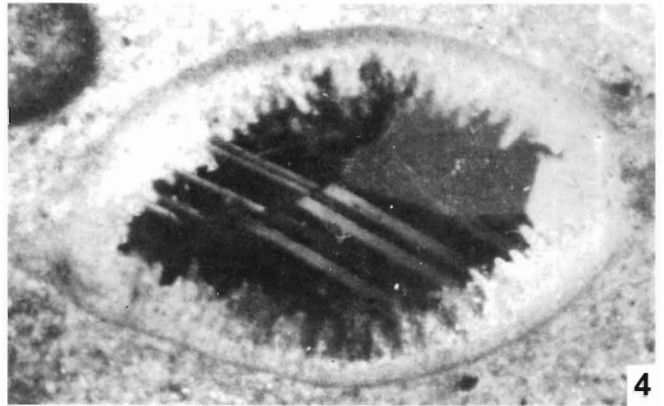
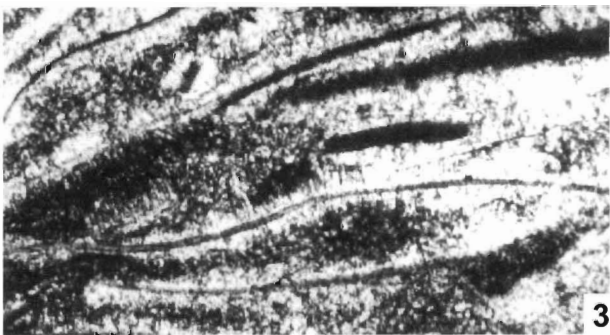
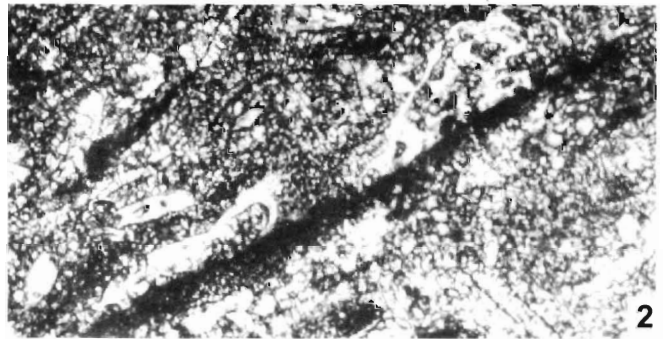
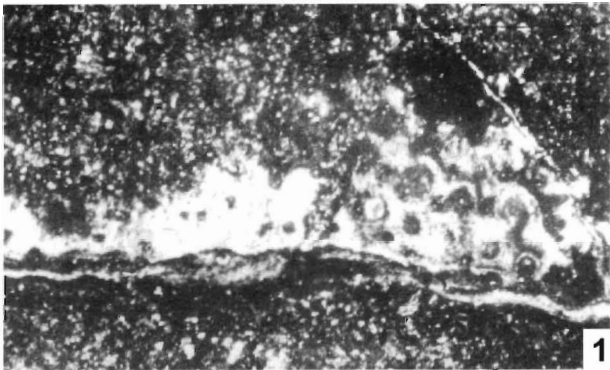
Field observations and lithofacies

The Kioto Limestone is a ca. 140m thick calcareous succession exposed on the escarpment of Rawalibagar in the Kio Valley. It shows gradational contacts with underlying Passage Formation and overlying Laptal Formation (Heim and Gansser, 1939; Kumar *et al.*, 1977). The Laptal Formation is a 60-80m thick succession represented by shelly limestone associated with well-bedded black to grey limestone, oolitic limestone, marl and shell layers. Large scale cross bedding is a common feature. Kumar *et al.*, (1977) interpreted it as a deposit of high energy shoal, channels and associated tidal flats.

EXPLANATION OF PLATE V

The photomicrograph of the Kalapani Limestone

1. A bryozoa showing rounded zooecia filled with ferroan calcite (Pol. Light x 60).
2. Encrustation of bryozoan on a biofragment (Pol. Light x 60).
3. Development of fibrous cement growth on the bivalve fragment (Pol. Light x 60).
4. A bivalve showing two generations of cement growth i.e., fibrous cement followed by the drusy cement (Pol. Light x 60).
5. Cross section of a multichambered foraminifer showing circular test (Pol. Light x 60).
6. Microbial boring represented by irregular distribution of mud fillings in a recrystallised biofragment (Pol. Light x 60).
7. Development of dolomite crystals in the micritic matrix (Pol. Light x 60).
8. Development of siderite crystals bounded by dark coloured rim (Pol. Light x 60).



The Kioto Limestone is assigned Rhaetic age by Heim and Gansser (1939). Kumar *et al.*, (1977) have divided it into four lithostratigraphic units and provided detailed sedimentological log. The Kioto Limestone is dominantly made up of carbonate rocks with minor shales. The ooids, peloids and bioclasts are common. The sedimentary structures are well developed and are marked by parallel bedding, cross bedding, herringbone structures and ripple mark. The shale beds are common in lower and upper part and show lenticular bedding. The fossils are represented by the bivalves and belemnites. Trace fossils are recorded representing long feeding burrows. On the basis of lithological criteria and bedding structures, the following three lithofacies are identified (fig. 8);

i) *Oolitic limestone lithofacies* : This forms the lower 50m succession, dominantly oolitic limestone having a few intercalations of minor shale and thinly laminated sand horizons. Some bands of shelly limestone are also recorded. The limestone horizons show parallel bedding, herringbone cross bedding and penecontemporaneous intraclastic conglomerates. Shaly horizons show lenticular and flaser bedding.

ii) *Nodular limestone lithofacies* : The overlying 30 m thick unit is represented by compact, black to grey fossiliferous, nodular limestone. Sandy or shaly horizons are present but are comparatively less. Shell fragments, ooids, peloids are present but rare. Macrofossil remains of bivalves and belemnites are common. The unit is devoid of wave or current generated structures.

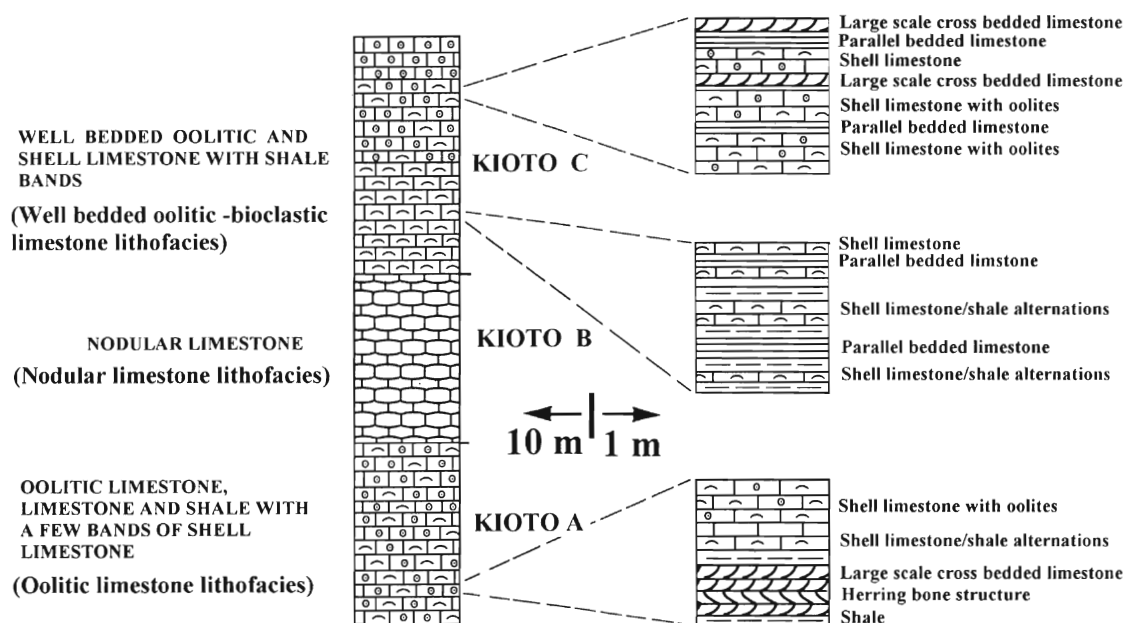
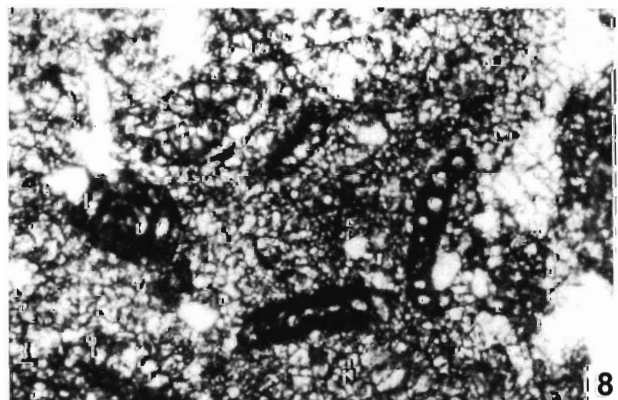
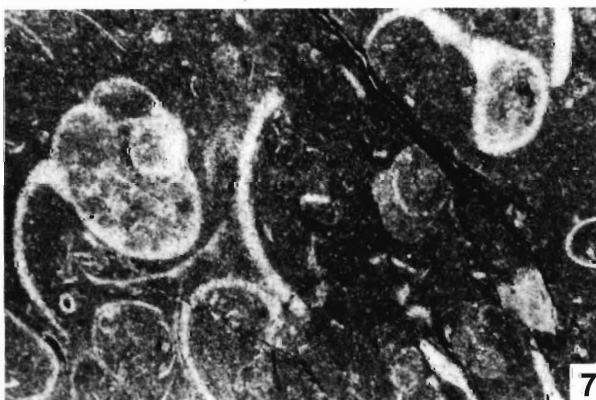
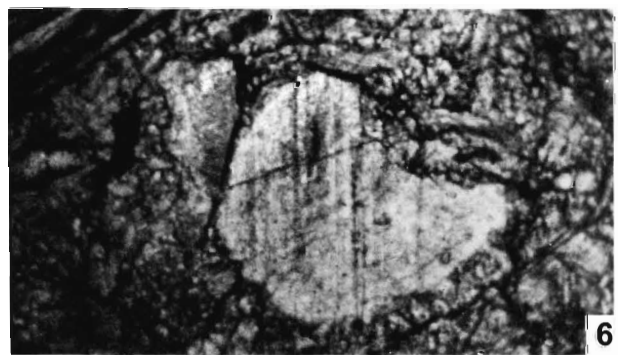
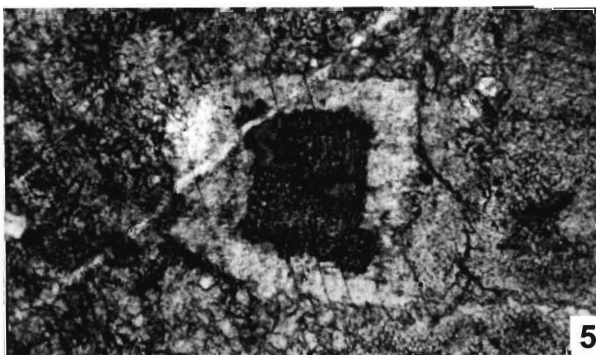
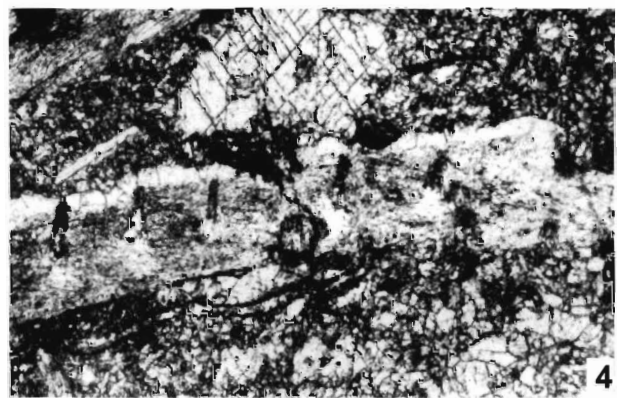
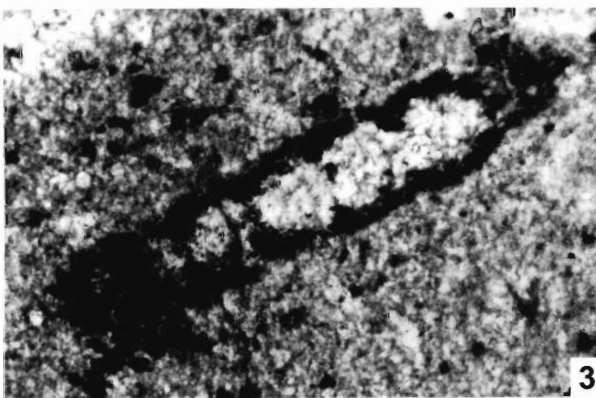
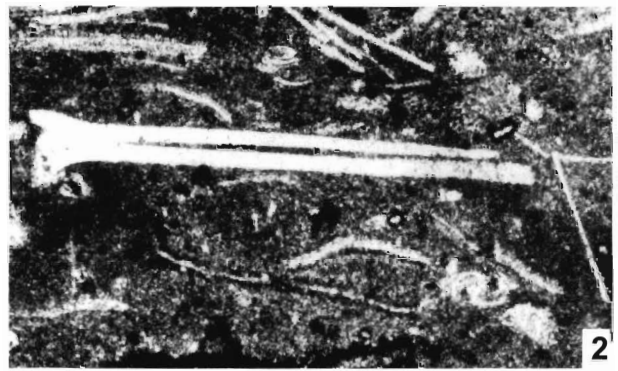
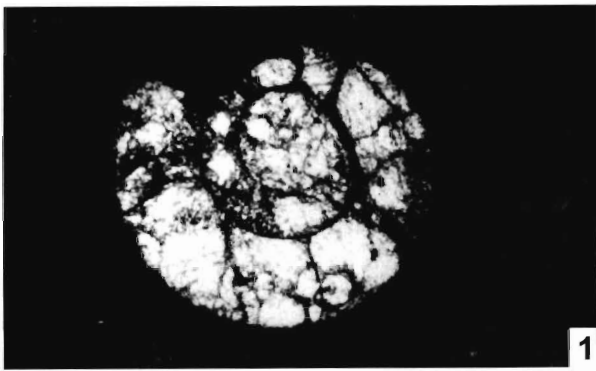


Fig. 8. Lithological succession of the Kioto Limestone (Kio Valley section) showing the stratigraphic position of the various lithofacies in vertical column.

EXPLANATION OF PLATE VI

The photomicrograph of the Kalapani Limestone

1. Cross section of a cephalopod (Pol. Light x 60).
2. Section through a long, elongated conodont (Pol. Light x 60).
3. A bryozoa showing linear pattern of zooecia filled with ferroan calcite (Pol. Light x 60).
4. Photomicrograph showing a brachiopod fragment (punctuate) showing outer prismatic and inner fibrous layer (Pol. Light x 60).
5. Syntaxial cement growth on the echinoid fragment (Crossed Nicols x 75).
6. Microbial encrustation on the echinoid fragment (Pol. Light x 60).
7. Cross section of a gastropod (Pol. Light x 60).
8. Cross section of foraminifers cut in various planes (Pol. Light x 60).



iii) Well-bedded oolitic-bioclastic limestone lithofacies : This represents a 60m thick unit of well bedded grey to black, shelly limestone, oolitic limestone and thin shale layers in lower 30 metres. In the upper part, sandy or shaly horizons are rare. The sedimentary structures are represented by parallel bedding and small ripple bedding. Bioturbated horizons are recorded. Stylolites are common in lower part.

Petrology and microfacies

The carbonate rocks of the Kioto Limestone are dominantly grainstone with variable amount of the different grains. The grains are dominantly ooids, peloids and rounded to subrounded skeletal fragments. The ooids are circular to elliptical, concentric type having 3-4 rings (Pl. VIII, fig. 1). The nuclei are microcrystalline calcite, subangular to subrounded quartz grains or rarely skeletal fragments of echinoderms or molluscs (Pl. VIII, fig. 2). Locally 2-3 ooids are bound together by a common envelope (Pl. VIII, fig. 3). A few ooids show recrystallisation (Pl. VIII, fig. 2). The peloids are similar to those of the Passage Formation, i. e. rounded to elliptical, lacking in any internal structure (Pl. VIII, fig. 4). Rarely, the peloids show the effect of compaction (Pl. VIII, fig. 5, 6). The skeletal fragments are represented by the bivalves, echinoderms, foraminifers, brachiopods, gastropods and algal clots. A considerable portion of the biofragments is rounded to subrounded and is coated with dark coloured micrite. Ferroan-calcite spar constitutes most of the cement. Occasionally, the ooids and peloids show isopachous rims of calcite as a first generation cement (Pl. VIII, fig. 7, 8). Drusy ferroan-calcite cement occurs in the intraspaces of the skeletal fragments

and is mostly of the second order. Sometimes zoning in the calcite is noticed. Quartz grains of subrounded to subangular shape are present in varying amount.

On the basis of predominance of the grains, three microfacies have been established (fig. 9), which are as follows;

i) Oolitic grainstone microfacies: The microfacies is characterised by the dominance of ooids. The other grains present are peloids, skeletal fragments of echinoderms, bivalves, gastropods and foraminifers. The cement is represented by sparry calcite. Rounded to subrounded detrital quartz makes 5 to 25% of the rock. The quartz percentage shows variation in the vertical profile (Pl. IV, fig. 1).

ii) Peloidal grainstone microfacies : It shows the dominance of peloids. Locally, the peloids show recrystallisation. The other grains recorded are ooids and bioclasts of echinoids, bivalves and foraminifers. Rarely monocrystalline, rounded to subrounded quartz has also been noticed (Pl. V, fig. 2).

iii) Skeletal-peloidal grainstone microfacies: Dominance of peloids and skeletal fragments is the characteristic feature of this microfacies. Peloids are similar to those of the peloidal grainstone microfacies i.e., rounded to subrounded in shape. The skeletal fragments are mostly represented by echinoids, molluscs and brachiopods with rounded to subrounded margins. Elongated, calcareous foraminifers are locally present. Algal clots and bryozoans are recorded. A micritic coating is sometimes visible on the skeletal fragments. Ooids with 2 - 3 concentric rings have been recorded. The cement is a clear calcite spar (Pl. IV, fig. 3).

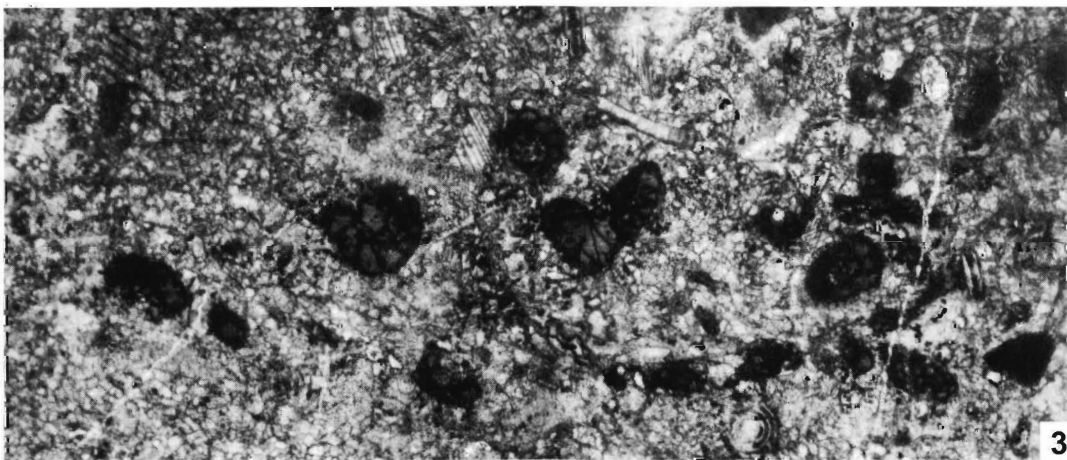
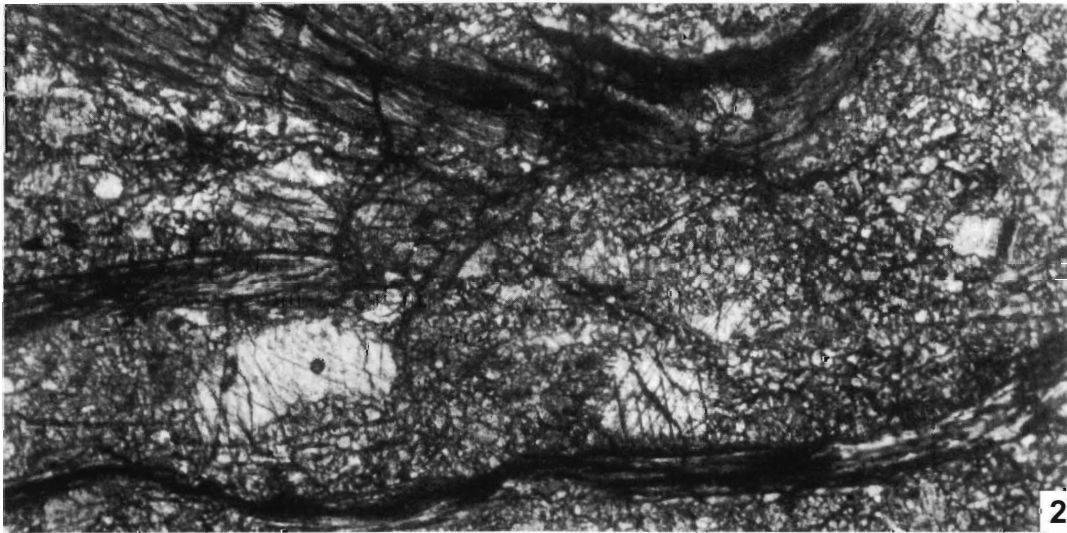
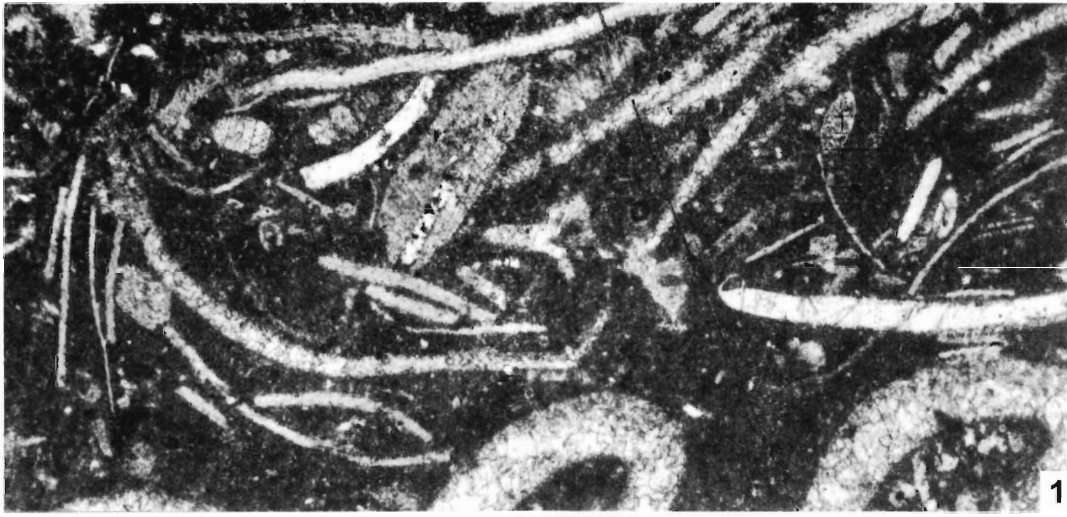
EXPLANATION OF PLATE VII

The photomicrograph of the Kalapani Limestone

1. Photomicrograph of Bivalve-gastropod-echinoid-algal wackestone sub-microfacies showing recrystallised bivalve fragments and small fragments of variable shape. Part of a large recrystallised fragment of bivalve is seen in lower side of the photomicrograph. Magnification 40X.
2. Photomicrograph of Echinoid- brachiopod wackestone sub-

microfacies showing rounded to subrounded echinoid fragments and brachiopod with fibrous microstructure. Micrite shows recrystallisation. Magnification 40X.

3. Photomicrograph of Foraminifer-bivalve-echinoid wackestone sub-microfacies showing planispirally coiled foraminifers and irregular fragments of echinoids. The micrite shows recrystallisation. Magnification 40X.



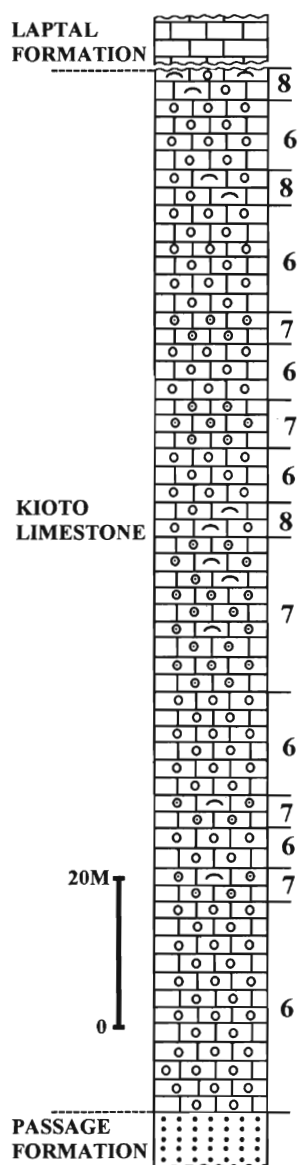


Fig. 9. Litholog showing distribution of various microfacies of the Kioto Limestone in vertical sequence. 6- Oolitic grainstone, 7 - Peloidal grainstone and 8- Skeletal - peloidal grainstone.

Depositional environment

The field observations and lithofacies analysis suggest that the Kioto Limestone was the product of a high-energy environment. The oolitic carbonate lithofacies is definitely a product of the tidal flat complex as represented by the herringbone cross-bedding and parallel bedding. The compact nodular limestone is a grainstone. It is massive looking and is full of ooids, peloids and subrounded skeletal

fragments. This lithofacies indicates slight change in the environment but broadly falls into the carbonate coastal complex. The overlying well-bedded oolitic-bioclastic limestone is a high-energy deposit as reflected in the high percentage of ooids, peloids and skeletal fragments apart from good development of cross-bedding, parallel bedding and ripple marks.

The microfacies of the Kioto Limestone are grain-supported with ooids, peloids and skeletal fragments consisting about 50-80% of the rock. The bioclasts are represented by two groups of biota. One group is represented by bivalves, gastropods, brachiopods and echinoids which are rounded to subrounded in shape and suggested transportation. Occasionally, they show coating of dark coloured micritic rim on the surface. While the other group represented by foraminifers, bryozoans and algal clots does not show any coatings and may be considered as in situ, which does not show any transportation. The cement is a sparry calcite. In the lower 30-40 m, oolitic grainstone microfacies, the quartz grains of rounded to subrounded shapes have been noticed which shows the rhythmicity in stratigraphic column i. e., an increasing or decreasing trend of quartz content ranging from 5-25 percent.

On the basis of the microfacies analysis, the Kioto Limestone may be considered as a product of moderate to high energy environment. Following Wilson (1975), the microfacies belonging to the Kioto Limestone can be placed into the standard facies belt, 6 i.e., winnowed platform edge sand (fig. 10). This facies belt includes dominantly the high energy environments like shoals, beaches, offshore and tidal bars. Similar microfacies have been widely reported from the Triassic marine carbonates of Asian and European continents (Wilson, 1975, Flügel, 1982). Braun and Friedman (1978) described oosparite from the Tribe Hill Formation (Lower Ordovician) of Mohak Valley, New York and interpreted sub-tidal environment. Carrozi (1989) proposed a few models for the carbonate deposition based on the microfacies analysis, of which, the microfacies of the Kioto Limestone can be placed into type 3 and 4 of simple ramp, which is characterised by the site of deposition in high energy environment, above the normal wave base. Heim and Gansser (1939) proposed a shallow

water environment of deposition for the Kioto Limestone. Kumar *et al.*, (1972) considered it a deposit of shallow agitated water condition on the basis of presence of ooids. Banerjee (1974) has suggested shallow to deeper depth zones. A shallow-water marine environment is interpreted by Kumar *et al.*, (1977) which is mainly based on the field observations.

DISCUSSION AND CONCLUSIONS

1. The facies analysis of the Triassic succession (Late Scythic to Rhaetic) of the Malla Johar area, Tethys Himalaya is done which is represented by the Kalapani Limestone, the Kuti Shale, the Passage Formation and the Kioto Limestone formations.
2. The Kalapani Limestone shows three lithofacies viz., i) Shaly limestone lithofacies, ii) Nodular limestone lithofacies, iii) Limestone-shale lithofacies. Only one skeletal wackstone microfacies has been identified which has been subdivided into three sub-microfacies. It has been assigned environment of deposition in deeper part of the shelf below the storm base.
3. Three lithofacies have been recognised in the

Kuti Shale. These are calcareous shale lithofacies, argillaceous- calcareous shale lithofacies and silty shale lithofacies. The Kuti Shale has been assigned environment of deposition between the deeper part of the shelf region and tidal flat.

4. The Passage Formation is made up of arenaceous lithofacies and calcareous lithofacies. Four microfacies viz., quartz arenite microfacies, calcareous siltstone microfacies, brachiopod-bryozoan wackstone microfacies and skeletal peloidal grainstone microfacies. The environment of deposition fluctuated between moderate to high energy environment of a mixed flat.
5. The Kioto Limestone shows three lithofacies and three microfacies. These are oolitic limestone lithofacies, nodular limestone lithofacies and well bedded bioclastic limestone lithofacies and the microfacies are oolitic grainstone microfacies, peloidal grainstone microfacies and skeletal peloidal grainstone microfacies respectively. It has been assigned moderate to high energy carbonate coastal

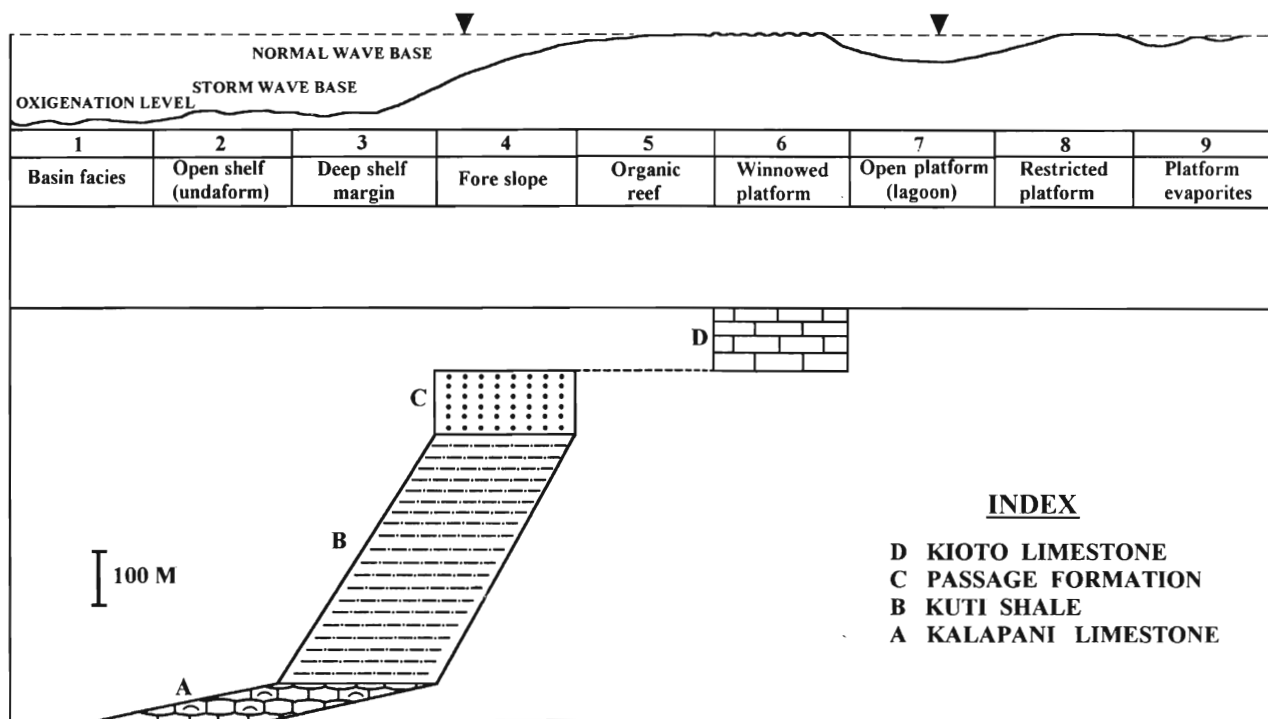


Fig.10. Model for the depositional environment of the Triassic succession of the Malla Johar area (based on Wilson, 1975).

complex as the environment of deposition.

6. The lithofacies and microfacies analysis of various lithounits viz., the Kalapani Limestone, the Kuti Shale, the Passage Formation and the Kioto Limestone shows an upward-shallowing succession. During the deposition of the Kalapani Limestone, it appears that the sea level was at high stand. The site of deposition was away from the effective zone of waves and tides because the lithofacies and microfacies are indicative of very low energy conditions. The calc-marly, nodular succession is dominantly represented by the skeletal wackestone similar to the deep shelf and ramp facies of Read (1985) which may show storm-generated structures, but in the present case, the probable

site of deposition may be more deeper, exceeding storm wave base. The overlying Kuti Shale that has a gradational contact with the Kalapani Limestone shows a gradual shallowing of the basin from the deeper part of the shelf to the tidal-flat complex. The argillaceous input was very high with high rate of sedimentation. The fine-grained arenaceous content was also rhythmically supplied to the basin from nearby areas. However, the carbonate precipitation was also taking place during the deposition of the middle and upper parts of the succession. The overlying Passage Formation is dominantly arenaceous and represents a mixed flat transition zone and tidal complex. The same continued up to the deposition of the lower part (lower 50m) of the Kioto Limestone with

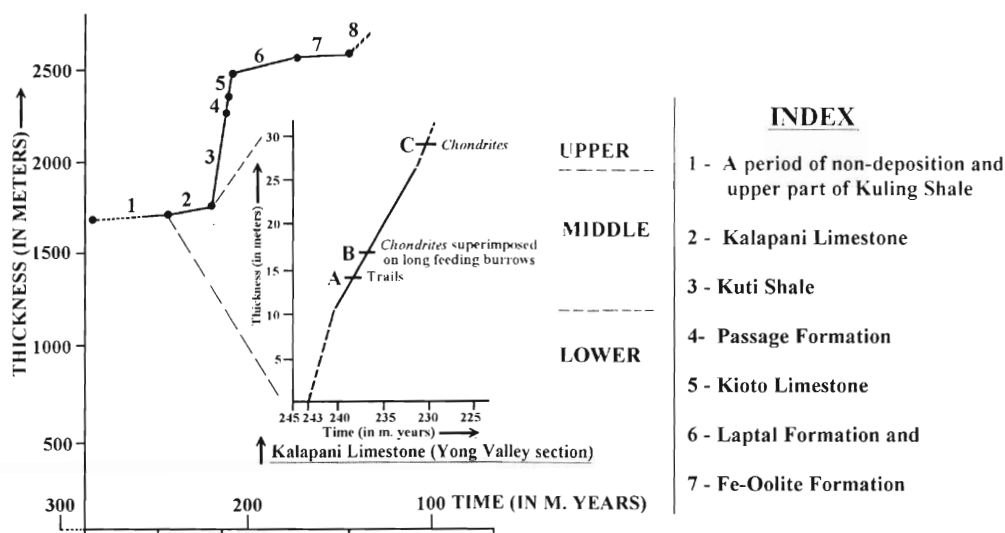


Fig. 11. Plot of thickness vs. time for the Triassic succession of the Malla Johar area showing very slow rate of sedimentation during the Kalapani Limestone followed by rapid sedimentation during the Kuti Shale, the Passage Formation and the Kioto Limestone. The plot inside is of the Kalapani Limestone of Yong Valley section showing the variations in the rate of sedimentation during the deposition of various lithofacies and also the stratigraphic position of the trace fossil horizons as A, B and C.

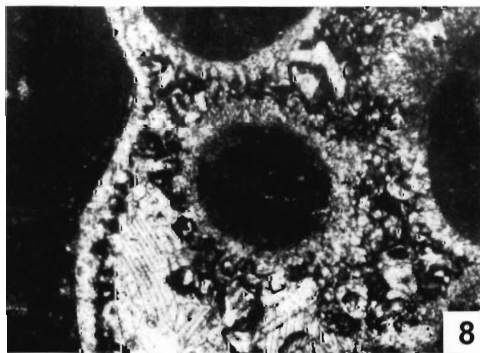
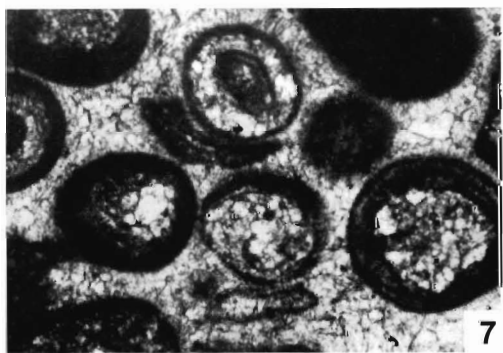
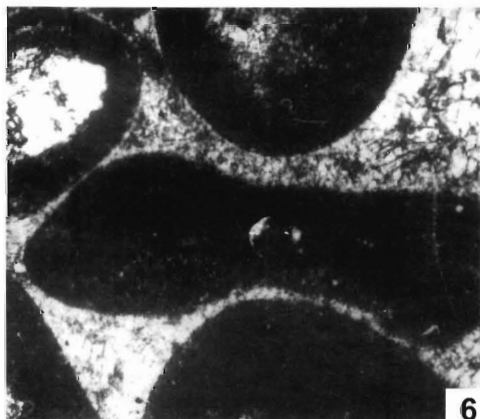
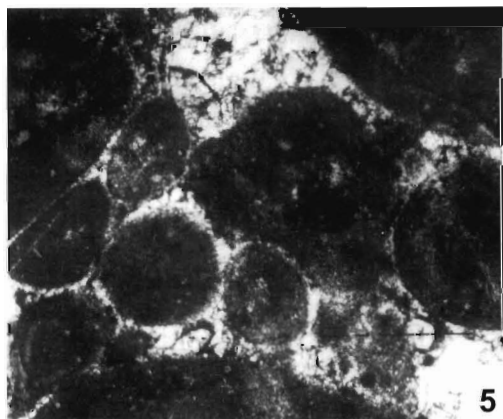
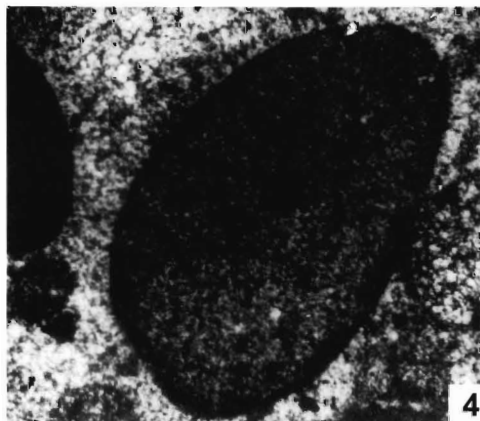
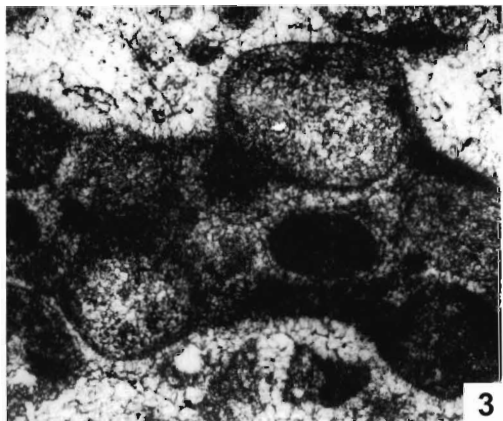
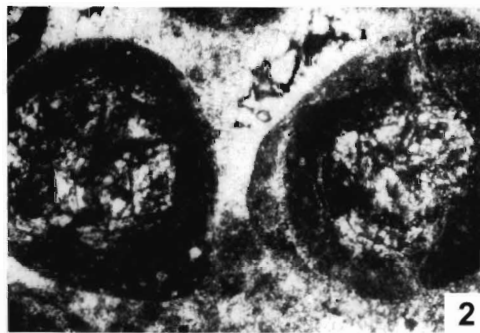
EXPLANATION OF PLATE VIII

The photomicrograph of the Kioto Limestone

1. Photomicrograph of a concentric oolite (Pol. Light x 60).
2. Recrystallised ooids – the concentric rings are present only on the outer surface, recrystallised part is partially dolomitised (Pol. Light x 60).
3. Composite oolite in which a few ooids are bounded by a

common sheath (Pol. Light x 60).

4. A pellet with homogeneous microtexture (Pol. Light x 60).
- 5 & 6. Distortion of the peloids due to compaction (Pol. Light x 60).
- 7 & 8. Development of the dog tooth spar cement on ooids and peloids respectively.



increased carbonate precipitation. The rest of the succession, i.e., middle and upper parts of the Kioto Limestone is characterised by a medium to high-energy carbonate coastal complex. Therefore, a shallowing-upward succession is interpreted for the Triassic succession. It is comparable with the depositional model proposed by Wilson (1975) for different part of an ideal basin. In this model, the Triassic succession can be placed from the open shelf (facies 2) to winnowed platform (facies 6) (fig. 10).

The shallowing-upward succession or stacking of the shallowing-upward successions in vertical column during the Triassic is well witnessed in different parts of the globe, e.g., Middle Triassic Latemar Carbonate, northern Italy (Goldhammer *et al.*, 1987, 1990; Hinnov and Goldhammer, 1991), Middle Triassic carbonate of south-east Iberian ranges, eastern Spain (López-Gómez *et al.*, 1993, Gómez and Fernandez-López), the Triassic and associated rocks of Nakhlak and Aghdarband in central and north eastern Iran (Alavi *et al.*, 1997), the Croci d'Acerno sequence, Salerno province, southern Italy (De Castro, 1990), Shubalik Formation, Arctic Alaska, U.S.A. (Parrish *et al.*, 2001) etc. The reasons for the shallowing upward nature of these sequences are widely explained as due to the fluctuations of the sea level either coupled with submergence or emergence of the site of deposition. In the present case of the shallowing upward nature of the succession may be due to two factors i.e., i) global sea level fluctuation during the Triassic and ii) impact of rate of sedimentation in a localised area of the basin. The Triassic is reported to be a phase of global sea level rise with minor fluctuations (Vail *et al.*, 1977; Haq *et al.*, 1987) in which an ideal transgressive sequence should have been developed, instead, a regressive shallowing-upward sequence is present with almost all the facies from open shelf to winnowed platform as proposed by Wilson (1975). Secondly, the rate of sedimentation i.e., plot of thickness vs. time shows very drastic changes during different stages of the Triassic period (fig. 11). The data used for the age assignment of the Kalapani Limestone are based on the conodont biozonation (Chhabra and Kumar, 1992) whereas, the ammonoid

biostratigraphy and lithological variations serve the basis for the rest of the succession (Diener, 1912; Heim and Gansser, 1939; Kumar *et al.*, 1977). The rate of sedimentation graph (Fig. 11) clearly indicates that the Kuti Shale and Passage Formations show very high rate of sedimentation as compared to the Kalapani Limestone. The supply of the argillaceous material was high at the time of deposition of the Kuti Shale while the supply of arenaceous sediments from the near by area was high during the Passage Formation. It may be pointed out that Upper Scythian to Lower Carnian is represented by only ca. 30m thick, dominantly carbonate rocks of the Kalapani Limestone while the Norian is represented by ca. 600m thick argillaceous Kuti Shale and arenaceous Passage Formation. About 150m thick Kioto Limestone was deposited in Rhaetian. It suggests that in the beginning, the rate of sedimentation was very slow but subsequently there was a considerable increase that caused the development of the regressive shallowing-upward succession. Probably, the rate of subsidence was low and the site of deposition continued to approach towards shore line due to very high rate of sedimentation, particularly in Norian and Rhaetian times which caused the gradual uplifting of the site of deposition. The rate of the gradual upliftment of the site was more than the rise of the eustatic sea level, i.e., the sediments with continuous high supply accumulated with higher rate than the increase in sea level. This resulted a condition most similar to the regressive phase i.e., formation of shallowing-upward sequence. Thus, it can be interpreted that a regressive sequence is formed in a period of transgression due to continuous high supply of argillaceous and arenaceous materials.

The structural and palaeogeographic settings during the Late Permian to Late Triassic show the grouping of the Arabia, Antarctica, India, Australia and Tibet in the south-east hemisphere. These continents (except Tibet) formed the southern and south western margins of the Tethys Ocean. All these continents show differential movement during Triassic but roughly towards north, which was responsible for the changing palaeogeographic configuration (Condie, 1988; Condie and Sloan, 1998). The palaeogeographic reconstruction as proposed by Zeigler *et al.*, (1983) mark the position of India during the Triassic as

between 40° - 60° lat. south and 30° -38° long. which in Early Jurassic occupied the position roughly 30° - 50° lat. south and 24° -32° long. due to ENE movement of the Indian plate. The vast Tethys Ocean was restricted by the respective borders of above-mentioned continents in the south. However, the respective margins of these continents were passive in nature favouring the deposition of platform carbonate at various sites e.g., platform carbonate of Transdanubian Range, Hungary (Balog *et al.*, 1977), southern Alps, Italy (Mutti and Wessert, 1995), Sumeini Group, Arabian carbonate platform (Watt, 1987), etc. The India, as a part of the same palaeogeographic set-up also shows a good development of the Triassic platform carbonate which are presently exposed along northern boundary at Malla Johar (Kumaon), Spiti (Himachal Pradesh), Kashmir and Salt Range (Pakistan). These exposures show good development of carbonate succession of variable nature and thickness but with good preservations of time marker ammonoids and conodonts (Diener, 1912; Pascoe, 1959; Krishnan, 1969; Chhabra and Sahni, 1981; Chhabra and Kumar, 1992). The variability of nature and thickness of the Triassic deposits in the Salt Range, Kashmir, Kumaon and Himachal Pradesh may indicate a local variation in basinal set-up, in spite of being a part of the vast Tethys ocean. This basinal set-up for the Triassic succession can be placed in passive continental margin setting of the ideal basin in context of the plate tectonics as proposed by Reading (1986). The conclusion is based on the thick deposit of shallow-marine carbonates. The basin continued to have relatively more or less shallow marine nature up to the Lower Jurassic and evidences of deepening of the basin appeared only in the later phases of the Jurassic (Heim and Gansser, 1939; Kumar *et al.*, 1977). It acquired subduction-related settings in Late Jurassic – Early Cretaceous period (Molnar and Taponier, 1977).

ACKNOWLEDGEMENTS

The authors are grateful to Prof. S. K. Singh, and Prof. I.B. Singh for help and encouragement. We are thankful to Dr. Purnima Srivastava for the help during the course of investigation. One of us (AKS) is thankful to Dr. Uma Kant Shukla for the

help during fieldwork. The financial assistance was provided by C.S.I.R., New Delhi in the form of a project (No. 24/159/85 EMR. II). Thanks are extended to the government officials and local people for their help and cooperation during the expeditions.

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Manuscript Accepted June 2004