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FORAMINIFERAL BIOSTRATIGRAPHY AND PALAEOENVIRONMENT OF THE LAKADONG LIMESTONE OF THE MAWSYNRAM AREA, SOUTH SHILLONG PLATEAU, MEGHALAYA

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ABSTRACT

Biostratigraphy of the Lakadong Limestone, Mawsynram area in the present work is based on species association of foraminifera. The FAD and LAD of larger benthic foraminifera used for biozoation are *Miscellanea juliettae* (Leppig, 1988), *Miscellanea yvettae* (Leppig, 1988), *Miscellanea miscella* (d' Archiac and & Haime, 1853). On this basis two Taxon Range Zones viz. *Miscellanea juliettae* Taxon Range Zone and *Miscellanea miscella* Taxon Range Zone and one Concurrent Range Zone (*Miscellanea juliettae - Miscellanea miscella* Concurrent Range Zone) have been identified.

Data base used for palaeoenvironment interpretation of the Lakadong Limestone is species association of foraminifera of families Pellatispiridae, Nummulitidae, Lepidorbitoididae, Alveolinidae and Discocyclinidae. This suggests a reef complex environment for these limestones where both the back–reef and fore–reef environments were prevalent.

Keywords: Biostratigraphy, Palaeoenvironment, Lakadong Limestone, Mawsynram, South Shillong Plateau, Meghalaya

INTRODUCTION

Larger benthic foraminiferal record is important to provide a high resolution biostratigraphy for shallow marine carbonate sequences. Their diversity, evolutionary rate and abundance make them more useful for deciphering age and palaeoenvironment of such rock strata. A thick early Palaeogene carbonate succession alternating with sandstones, known as the Sylhet Limestone Formation, is well exposed on the southern fringes of the South shillong plateau in the Cherrapunjee and Mawsynram areas of the Khasi hills, Meghalaya, northeastern India (Oldham, 1859; Medlicott, 1969; Evans, 1932; Wison and Metre, 1953). The succession is rich in larger benthic foraminifera which have been investigated in detail especially in the Cherrapunjee and adjoining areas to provide the early Stratigraphic framework. In the Mawsynram area, only the lower part of the Sylhet Limestone Formation (Lakadong Limestone and Lakadong Sandstone) is better exposed. However, these coeval successions despite their rich fossiliferous nature have not yet been studied in detail. In the present study, larger foraminiferal assemblages from the Lakadong Limestone exposed in the Mawsynram area have been studied in detail and used for biostratigraphic and palaeoenvironmental interpretations.

MATERIAL AND METHODS

The observation is based on the study of foraminifera in thin sections. The thin sections are prepared following normal procedure of thin section preparation. From each sample four orintations to five thin sections are prepared in different of the sample.

PREVIOUS WORK

Oldham (1859) mentioned the presence of the Eocene beds with Nummulitic fossils from Khasi Hills and suspected the occurrence of Upper Cretaceous rocks in the Cherrapunji plateau. Evans (1932) reported the occurrence of "Sylhet limestone stage" from Garo Hills, near Therria Ghat and Cherrapunji area of Khasi Hills. However, he did not mention the occurrence of the limestone in Mawsynram area. Nagappa (1956, 1959) made foraminiferal biostratigraphical study for Cretaceous-Eocene succession of Meghalaya and confirmed the occurrence of Danian foraminiferal assemblage in the Langpar Formation. Pandey (1981) and Jauhri (1988) studied foraminiferal fauna of the Lakadong Limestone from Therria Ghat section of south Shillong plateau. Jauhri (1996) reported *Ranikothalia nuttali* (Davies) as a distinctive early Ilerdian marker in a study from Therria area near Cherrapunji and in 1998 reported *Miscellanea* Pfender, 1935. Previous records show that most of the works are confined to Cherrapunji plateau of south Shillong region. The only literature available on foraminifera from Lakadong Limestone of Mawsynram area (fig. 1), is found in a preliminary report made by Kalita and Gogoi (2003), and Matsumaru and Jauhri (2003) where they reported a new Orbitoidal foraminiferal genus *Lakadongia*.

Pal and Dutta (1979) made a study on fossil algae from Sylhet Limestone Formation of Meghalaya and Mikir Hills, Assam. In Meghalaya they had reported fossil algae from Lumshnong area of Janintia Hills and Mawmluh Hills, near Cherrapunji. Misra *et al.* (2002) made another report of Calcareous algae from the Lakadong Formation of Therria area near Cherrapunji. Kalita and Gogoi (2002) first reported the occurrence of fossil calcareous algae such as *Distichoplax biserialis, D. raoi, Dissocladella lakadongensis* etc. from Lakadong Limestone of Mawsynram area. Gogoi *et al.* (2003) had made another report of fossil calcareous algae from the area. Kalita and Gogoi (2006) have also reported nine species belonging to eight genera of coralline red algae from the Lakadong Limestone deposits of Mawsynram area. Garg and Khowaja-Ateequzzaman (2000) considered Lakadong

Table 1: Stratigraphic succession in Mawsynram area.

Formation	Member	Lithology	Age
Sylhet Limestone	Lakadong Sandstone	Fine to medium grained coal bearing sandstone	Thanetian (Late Palaeocene)
	Lakadong Limestone	Dark grey to gray coloured hard and compact algal and foram rich limestone	Thanetian (Late Palaeocene)
Therria	------	Hard, compact, coarse to medium grained sandstone	Selandian (Early Palaeocene)
Langpar	------	Calcareous, fine shales with occasional carbonaceous bands with foraminifera	Late Maastrichtian to Danian (Early Palaeocene)
Mahadek	-----	Medium to very coarse grained massive sandstone	Late Campanian to Late Maestrichtian (Late Cretaceous)

Limestone and Lakadong Sandstone as Pateral facies equivalents in the Khasi Hills developed during sea level highstand. They suggested close correspondance of dinoflagellate cyst Apectodinium acme with Ranikothalia nuttalti-Miseellania miscella Assemblage (SBZ5-SBZ6). Prasad *et al.* (2006) studied *Apectodinium* acme and palynofacies characteristics of Palaeocene Eocene Thermal Maxima of Mawsynram area.

STRATIGRAPHY

The stratigraphic succession observed in Mawsynram area is given in Table 1. The oldest lithotype in the area is represented by Mahadek Formation. The rocks are reddish brown to light green coloured medium to very coarse grained massive sandstone and occasionally gritty in nature. Along Mawsynram-Syntein village footpath in the basal part of the formation the sandstone is characterised by presence of hard nodules of pyrite and thin small patches of coal. Moreover, impression of tree trunks and several conglomeratic layers in the lower part of the formation have also been observed at places.

The Mahadek Formation is succeeded by calcareous shales and sandy shales of Langpar Formation.

Light coloured hard compact and medium to fine grained sandstone sandstones of Therria Formation overlies the Langpar Formation in the area.

In Mawsynram, among the members of Sylhet Limestone Formation, only Lakadong Limestone Member and Lakadong Sandstone Member have been observed. The Lakadong Limestone Member constitutes the basal most unit of Sylhet Limestone Formation. It occurs sporadically and normally occupies the top of the hillocks in Mawsynram area. It is light grey to dark grey coloured hard and compact limestone with rich assemblages of foraminifera and calcareous algae. The Lakadong Sandstone Member overlies the Lakadong Limestone Member and constitutes the upper most lithounit of whole the succession in the area. It is coal bearing fine to medium grained light grey to buff coloured sandstone.

Geological map of the area with schematic cross sections along NNE-SSW and NWW-SEE direction is given in Figs. 2, 3 and 4 respectively.

BIOSTRATIGRAPHICAL ZONATION

Distribution frequencies of different species of foraminifera in the present studied limestone are shown in Figs. 5 and 6. They comprise both short and long ranging species. Species association of foraminiferas of the families Valvulininae, Textulariidae, Hauerinidae, Fabulariidae, Alveolinidae, Eponididae, Lepidorbitoididae, Pellatispiridae, Nummulitidae, Discocyclinidae is taken in to consideration for biostratigraphy in the present work. The FAD and LAD of larger benthic foraminifera species *Miscellanea juliettae* (Leppig, 1988), *Miscellanea yvettae* (Leppig, 1988) and *Miscellanea miscella* (d' Archiac and & Haime, 1853) are used for biozonation. Based on these data *Miscellanea juliettae* Taxon Range Zone, *Miscellanea miscella* Taxon Range Zone and *Miscellanea juliettae* - *Miscellanea miscella* Concurrent Range Zone have been identified (figs. 7 and 8).

Miscellanea juliettae Taxon Range Zone

Definition: The total stratigraphic range of *Miscellanea*

EXPLANATION OF PLATE I

1-4. ***Miscellanea juliettae*** (Leppig, 1988)
1. megalospheric equatorial section, Slide No. MPT/BG/LTL 22.A
2. megalospheric axial section, Slide No. MPT/BG/LTL 20.E
3. microspheric equatorial section, Slide No. MPT/BG/LTL 5.C
4. megalospheric axial section, Slide No. MPT/BG/LTL 3.A

5,6. ***Miscellanea yvettae*** (Leppig, 1988)
5. megalospheric axial section, Slide No. MPT/BG/LTL 17.D
6. microspheric axial section, Slide No. MPT/BG/LTL 3.C

7,8. ***Miscellanea miscella*** (d' Archiac & Haime, 1853)
7. megalospheric equatorial section, Slide No. MPT/BG/KPL 44.A
8. slightly slating megalospheric axial section, Slide No. MPT/BG/KPL 41.E

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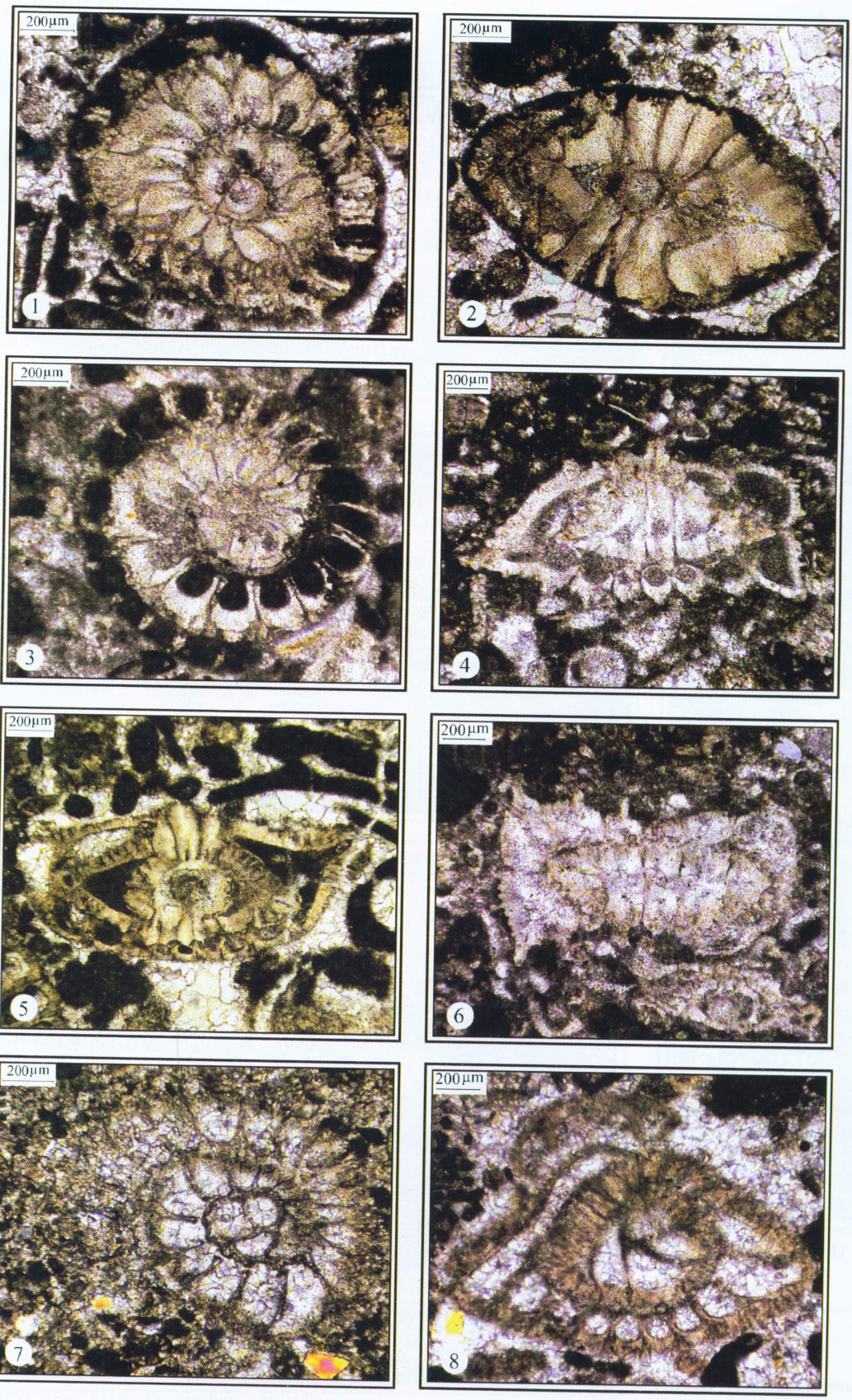
Plate I



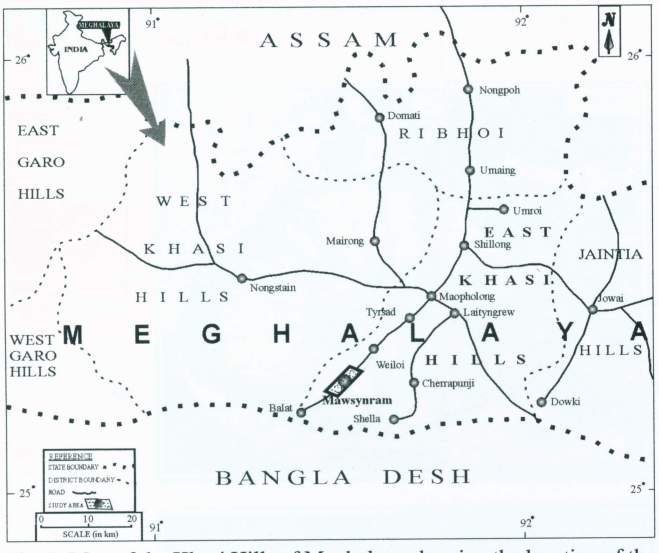


Fig. 1. Map of the Khasi Hills of Meghalaya showing the location of the study area.

juliettae. In Kurtinsiang Hills section the taxon range zone extends from sample number KPL 1 to KPL 26 (fig. 7) and in Laitmawksing Hills section from sample number LTL 0 to LTL 15 (fig. 8).

Characteristics: The *Miscellanea juliettae* Taxon Range Zone is characterised by *Miscellanea juliettae* in association with *Miscellanea yvettae, Ranikothalia sindensis, R.* sp., *Operculina* sp., *Quinqueloculina seminulum,* ? *Periloculina* sp., *Triloculina* sp., *Textularia barretti, Clavulina* sp., *Orbitosiphon punjabensis, O.* sp., *Discocyclina* sp., *Eponides* sp. in Kurtinsiang Hills section and *Miscellanea yvettae, Ranikothalia sindensis, R.* sp., *Operculina* sp., *Biloculinites paleocenica, Quinqueloculina seminulum,* ? *Periloculina* sp., *Triloculina* sp., *Textularia barretti, Clavulina* sp., *Orbitosiphon punjabensis, O.* sp., *Discocyclina* sp., *Eponides* sp. in Laitmawksing Hills section.

Age: The age of the *Miscellanea juliettae* Taxon Range Zone is Late Paleocene (Thanetian).

Miscellanea miscella Taxon Range Zone

Definition: The total stratigraphic range of *Miscellanea miscella.* In Kurtinsiang Hills section the taxon range zone is distributed from sample number KPL 28 to KPL 44 (fig. 7) and in Laitmawksing Hills section it is distributed from sample number LTL 22 to LTL 27 (fig. 8).

Characteristics: The *Miscellanea miscella* Taxon Range Zone is characterised by *Miscellanea miscella* in association with *Miscellanea yvettae, Ranikothalia sindensis, R.* sp., *Operculina* sp., *Biloculinites paleocenica, Idalina* sp., *Quinqueloculina seminulum, Triloculina* sp., *Glomalveolina primaeva, G.* aff. *levis, G. levis, Textularia barretti, Orbitosiphon punjabensis, O.* sp., *Discocyclina* sp. in Kurtinsiang Hills section and *Ranikothalia sindensis, R.* sp., *Operculina* sp., *Biloculinites paleocenica, Idalina* sp., *Quinqueloculina seminulum, Glomalveolina primaeva, G.* aff. *levis, G. levis, Orbitosiphon punjabensis, O.* sp., *Discocyclina* sp. in Laitmawksing Hills section.

Age: The age of the *Miscellanea miscella* Taxon Range Zone is Late Paleocene (Thanetian).

Miscellanea juliettae - Miscellanea miscella Concurrent Range Zone

Definition: The total stratigraphic range where both *Miscellanea juliettae* Taxon Range Zone and *Miscellanea miscella* Taxon Range Zone overlaps. In Kurtinsiang Hills section the concurrent range zone is distributed from sample number KPL 26 to KPL 28 (fig. 7) and in Laitmawksing Hills section it is distributed from sample number LTL 15 to LTL 22 (fig. 8).

Characteristics: The *Miscellanea juliettae - Miscellanea miscella* Concurrent Range Zone is characterised by occurrence of *Miscellanea juliettae and Miscellanea miscella* in association with *Miscellanea yvettae, Ranikothalia sindensis, R.* sp., *Operculina* sp., *Biloculinites paleocenica, Quinqueloculina seminulum, Triloculina* sp., *Textularia barretti, Orbitosiphon punjabensis, O.* sp., *Discocyclina* sp., *Eponides* sp. in Kurtinsiang Hills section and *Miscellanea yvettae, Ranikothalia sindensis, R.* sp., *Operculina* sp., *Biloculinites paleocenica, Idalina* sp., *Quinqueloculina seminulum,* ?*Periloculina* sp., *Triloculina* sp., *Glomalvelina primaeva, G.* aff. *levis, G. levis, Textularia barretti, Orbitosiphon punjabensis, O.* sp., *Discocyclina* sp., *Eponides* sp. in Laitmawksing Hills section.

Age: The age of the *Miscellanea juliettae-Miscellanea miscella* Concurrent Range Zone is Late Paleocene (Thanetian).

CORRELATION OF BIOZONES WITH SBZ ZONAL SCHEME

The biozones established in the present study can be closely correlated with the standard Shallow Benthic Zone (SBZ) of Serra-Kiel et al. (1998). Both the biozones *Miscellanea juliettae* Taxon Range Zone and *Miscellanea miscella* Taxon Range Zone can be placed within the SBZ 3 Zone (Early Thanetian) of Serra-Kiel et al. (1998) which is equivalent to Early P4 Zone of planktonic foraminifera of Berggren et al. (1995) (figs. 7 and 8).

SYSTEMATIC PALAEONTOLOGY

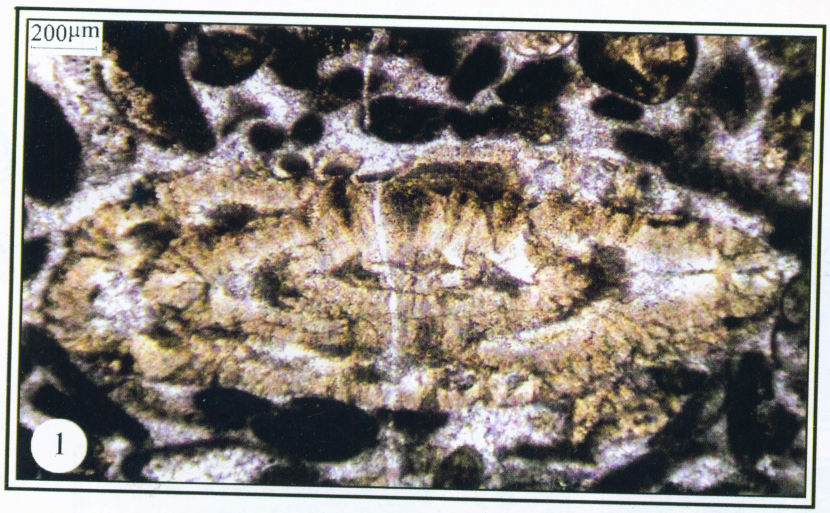
Order **Foraminiferida** Eichwald, 1830
Suborder **Textulariina** Delange and Herouard, 1896
Superfamily **Textulariacea** Ehrenberg, 1838
Family **Valvulininae** Berthelin, 1880
Genus ***Clavulina*** d' Orbingy, 1826
Clavulina sp.
(Pl. III, fig. 7)

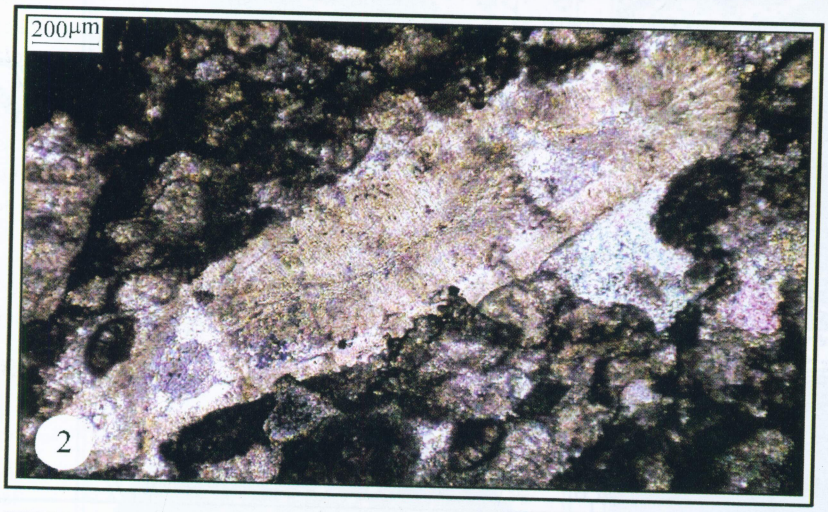
Description: Test elongate, the early stage of the test is triserial, later stage uniserial and becoming somewhat rounded, chamber simple and large. Cell wall thick, thickness reaches up to 0.08 mm. The length of the specimen observed in the sample

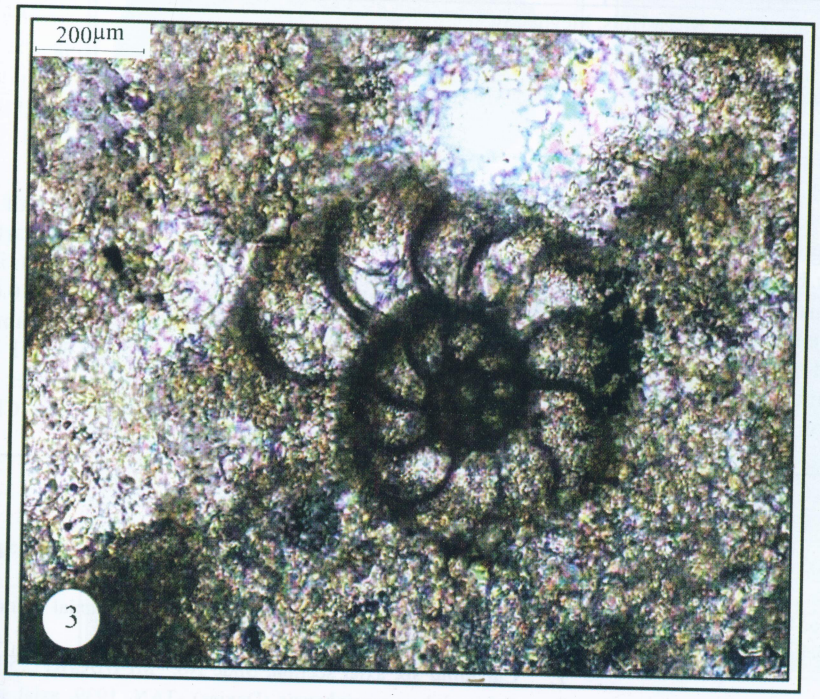
EXPLANATION OF PLATE II

1. ***Miscellanea miscella*** (d' Archiac & Haime, 1853) microspheric axial section, Slide No. MPT/BG/LTL 15.C
2. ***Ranikothalia* sp.** axial section, Slide No. MPT/BG/KPL 13.B
3. ***Operculina* sp.** equatorial section, Slide No. MPT/BG/LTL 8.D
4. ***Ranikothalia sindensis*** (Davies) Caudri, 1944), axial section, Slide No. MPT/BG/LTL 19.B

Plate II







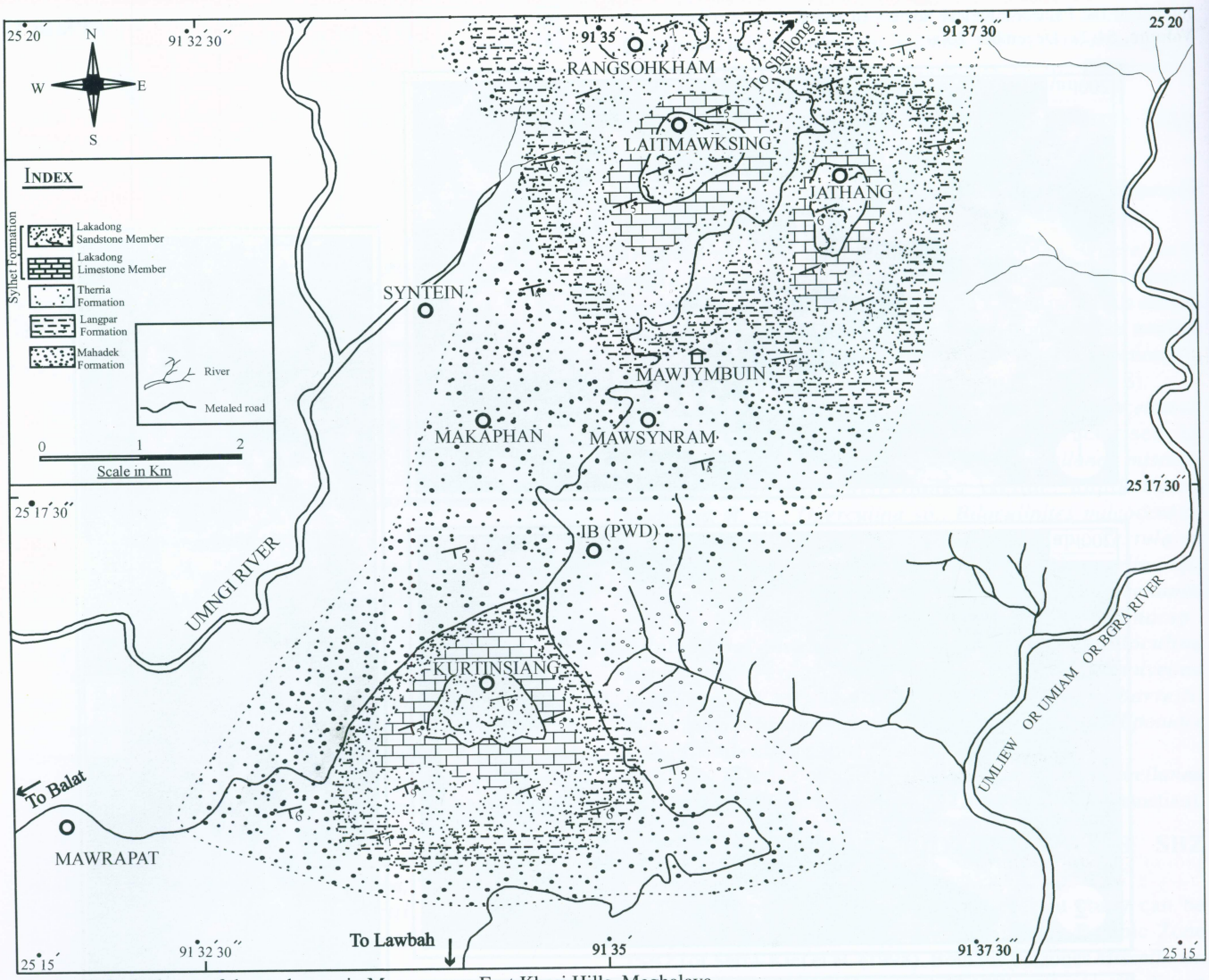


Fig. 2. Geological map of the study area in Mawsynram, East Khasi Hills, Meghalaya

KPL 5 is 1 mm and breadth in the middle part of the test is 0.7 mm.

Family **Textulariidae** Ehrenberg, 1838
Subfamily **Textulariinae** Ehrenberg, 1838
Genus ***Textularia***, Defrance, 1824
Textularia barretti Jones and Parker, 1867
(Pl. III, fig. 6)

Description: Test elongate, leaf or wedge shaped, tapering, early chambers planispirally coiled, rapidly becoming biserial, chambers simple, not labyrinthic. The measured length of the specimen observed in axial section in sample number KPL 30 is 1.04 mm and breadth is 0.68 mm at the end of the test.

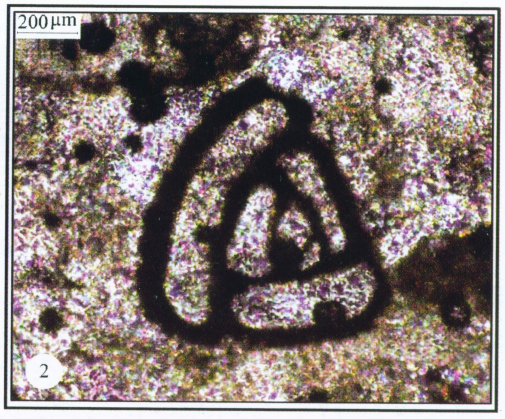
Suborder MILIOLINA Delange and Herouard, 1896
Superfamily MILIOLACEA Ehrenberg, 1839
Family HAUERINIDAE Schwager, 1876
Subfamily **Siphonapertinae** Saidova, 1975
Genus ***Quinqueloculina*** d' Orbigny, 1826
Quinqueloculina seminulum Linne, 1958
(Pl. III, fig. 1)

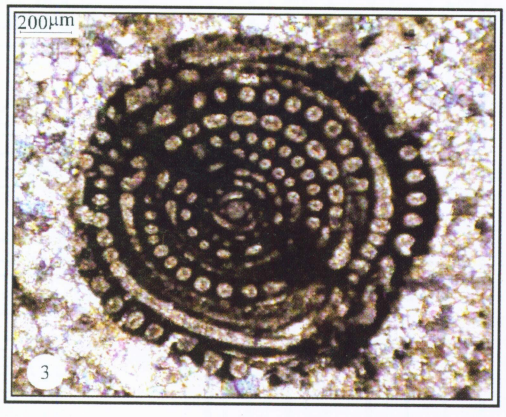
Description: The test composed of chambers a half coil in length and added successively in planes 144° apart. Five chambers completing a cycle, each chamber 72° from its next adjacent one. Inner thickness of chamber riches up to 0.08 mm and inner length riches up to 0.44 mm. Equatorial diameter of the specimen observed in the sample number LTL 11 is 1.06 mm, proloculus rounded and measured outer diameter is 0.14 mm. Test wall thick, thickness 0.02 mm to 0.14 mm. Chamber

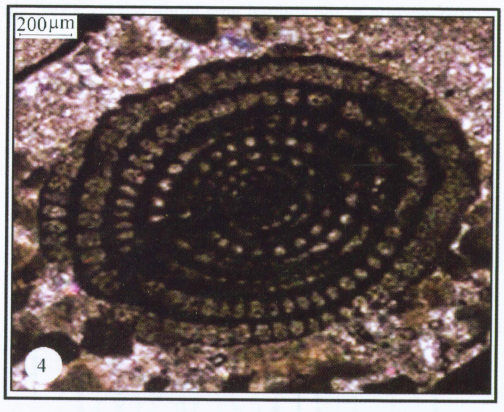
EXPLANATION OF PLATE III

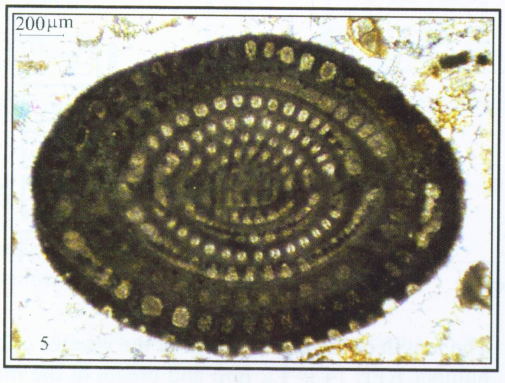
1. ***Quinqueloculina seminulum*** (Linne, 1958), equatorial section, Slide No. MPT/BG/LTL 11.A
2. ***Triloculina* sp.** equatorial section, Slide No. MPT/BG/KPL 39.C
3. ***Alveolina (Glomalveolina) primaeva*** (Reichel, 1937), equatorial section, Slide No. MPT/BG/KPL 40.E
4. ***Alveolina (Glomalveolina)* aff. *levis*** (Hottinger, 1960), equatorial section, Slide No. MPT/BG/KPL 36.B
5. ***Alveolina (Glomalveolina) levis*** (Hottinger, 1960), equatorial section, Slide No. MPT/BG/LTL 27.B
6. ***Textularia barretti*** (Jones and Parker, 1867), axial section, Slide No. MPT/BG/LTL 7.A
7. ***Clavulina* sp.** axial section, Slide No. MPT/BG/KPL 5.D
8. ***Orbitosiphon punjabensis*** (Davies) -TAN, 1939, axial section, Slide No. MPT/BG/KPL 44.C

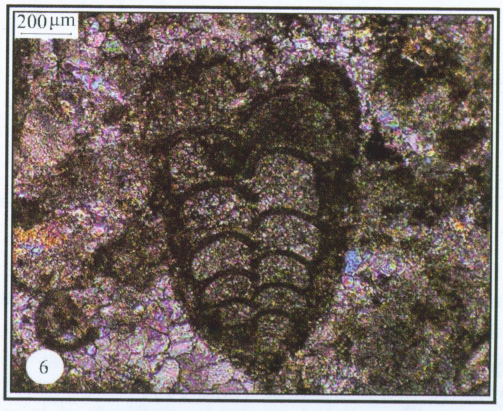
Plate III

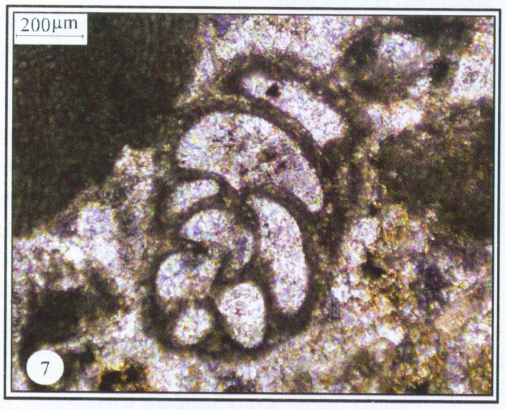


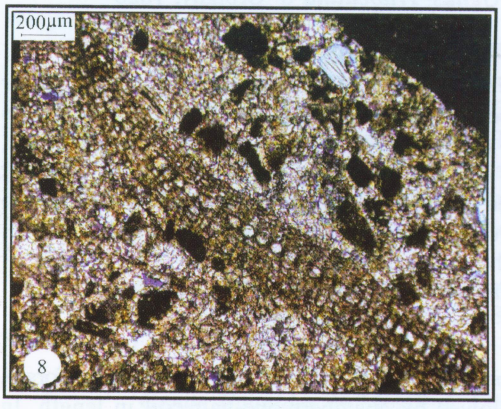












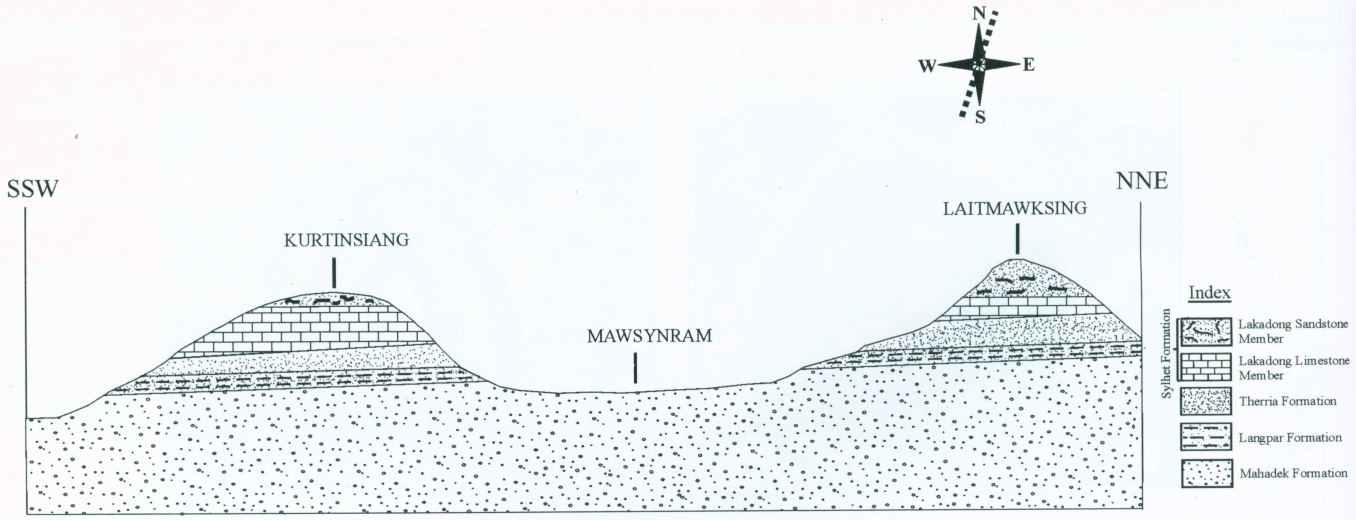


Fig. 3. Schematic cross-section of the studied area along NNE - SSW direction.

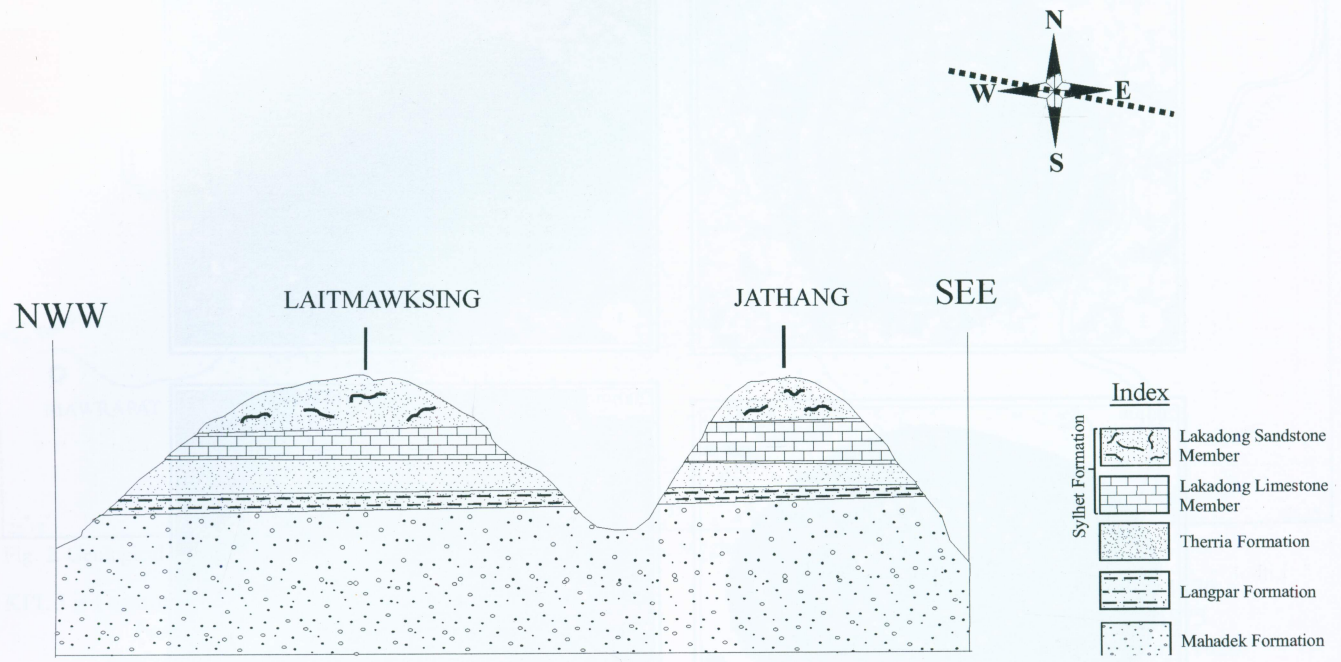


Fig. 4. Schematic cross-section of the studied area long NWW - SEE direction

simple and large.

Subfamily **Miliolinellinae** Vella, 1957

Genus ***Triloculina*** d' Orbigny, 1826

Triloculina sp.

(Pl. III, fig. 2)

Description: Early chambers quinqueloculine, later chambers placed on radial planes 120° apart, three chambers taking part in the formation of the outer surface of the test, chambers half a coil in length, the inner thickness of chamber in the specimen observed in sample number KPL 39 riches up to 0.07 mm, chambers not labyrinthic. Test wall smooth, thickness reaches up to 0.04 mm.

Genus Idalina Munier-Chalmas and Schlumberger, 1884

Idalina sp.

(Pl. IV, fig. 2)

Description: Test ovoid, wall calcareous and imperforate, proloculus followed by chambers one-half coil in length. In axial section, chambers are arranged in a biloculine manner. The length of the axial section of the species observed in sample number KPL 14 is 1.2 mm and breath at the middle part of the specimen is 0.86 mm.

Subfamily **Hauerininae** Schwager, 1876

Genus ***Periloculina*** Munier-Chalmas and Schlumberger, 1885

? *Periloculina* sp.

(Pl. IV, fig. 3)

Description: Test subcircular to ovoid in outline, wall calcareous and imperforate, proloculus followed by chambers one-half coil in length. The last formed chamber completely involute. The chambers are arranged in a biloculine manner. The length of axial section of the test observed in sample number LTL 3 is 1 mm and breath at the middle part of the test is 0.7 mm. Proloculus is ovoid and length observed is 0.14 mm and breath observed is 0.06 mm.

Superfamily **Alveolinacea** Ehrenberg, 1839

Family **Fabulariidae** Ehrenberg, 1839

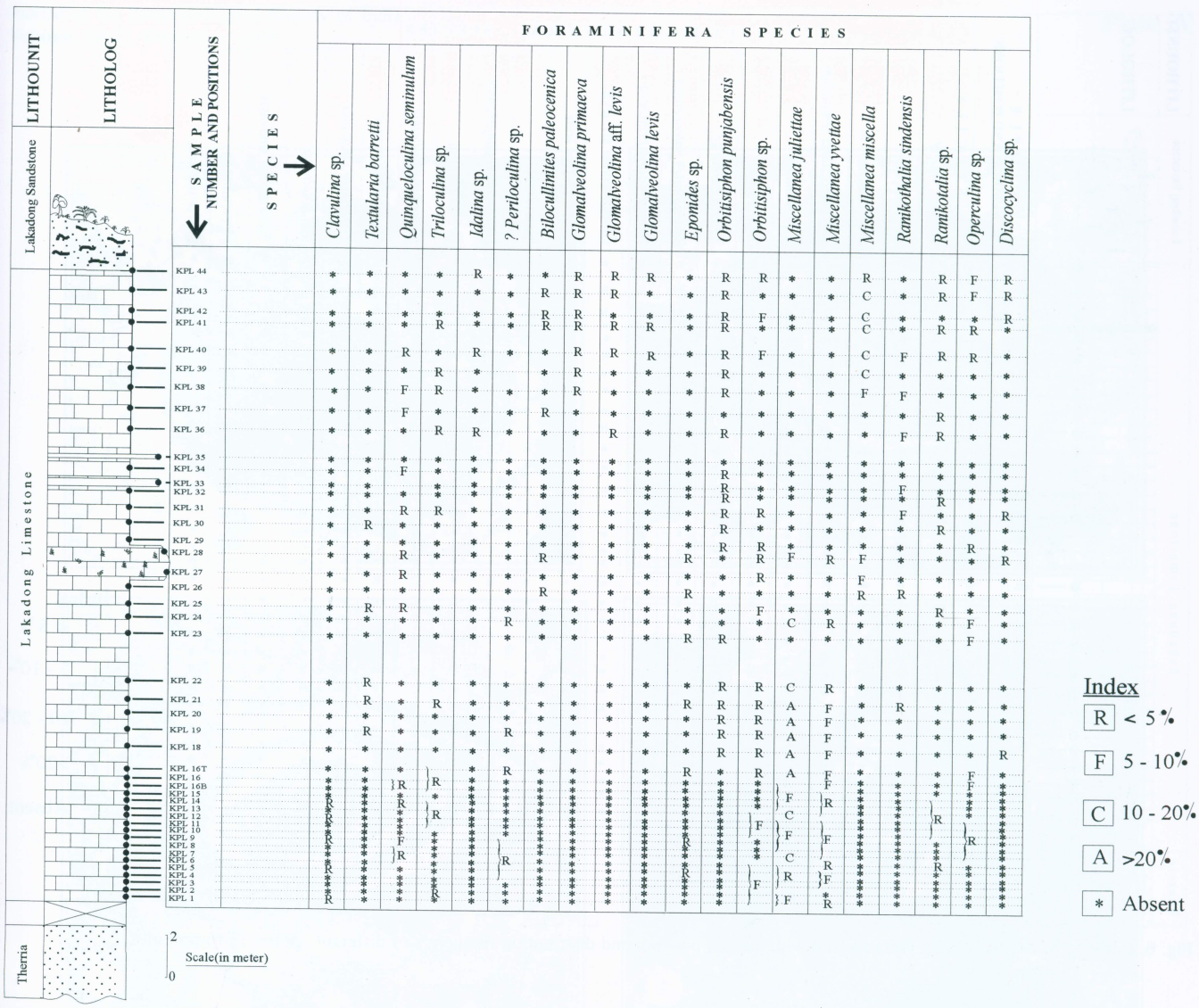


Fig. 5. Litholog of Kurtinsiang Hills section with sample position and distribution frequency of different species of foraminifera

Genus ***Biloculinites*** Rahaghi, 1983

Biloculinites paleocenica Rahagi, 1983

(Pl. IV, fig. 4)

Description: The test calcareous, surface seems to be smooth. Tests consist of eight chambers and are arranged in a biloculine manner. Wall contains subrounded vacuoles. Proloculus rounded. The diameter measured in equatorial section of specimen observed in thin section of LTL 12 is 1.2 X 0.70 mm. Thickness of wall observed is 0.05 mm. The inner diameter of proloculus is 0.15 mm.

Family **Alveolinidae** Ehrenberg, 1839

Genus ***Glomalveolina*** (Reichel, 1937)

Glomalveolina primaeva (Reichel, 1937)

(Pl. III, fig. 3)

Description: Test circular, equatorial diameter of the species is 1.3 mm. Proloculus circular and has an internal diameter of 0.07 mm. The chambers are small and subcircular. There are 9 whorls at a radius of 1.3 mm.

Glomalveolina aff. *levis* (Hottinger, 1960)

(Pl. III, fig. 4)

Description: The test is elongated, elliptical with subrounded extremities. Test diameter 1.7 X 1.42 mm. There are 9 whorls observed in the specimen. The early whorl has a circular outline with thin wall (0.04 mm) and the test becomes elongated later on with a more developed test wall. Proloculus rounded, size 0.1 mm. The chambers are small and circular or oval in the first whorls and they are large, subspherical or subquadrangular in the last whorls.

Glomalveolina levis (Hottinger, 1960)

(Pl. III, fig. 5)

Description: The test elliptical, diameter 2.06 X 1.68 mm. There are 8 whorls observed in the specimen. The whorls are elliptical in outline and wall thick (0.06 mm), septa 0.04 mm thick. Chambers are small and subspherical in the inner whorls and they are large or subquadrangular in the last whorls. Proloculus not seen.

Suborder **Rotaliina** Delage and Herouard, 1896

Superfamily **Discorbacea** Ehrenberg, 1838

Family **Eponididae** Hofker, 1951

Subfamily **Eponidinae** Hofker, 1951

Genus ***Eponides*** de Montfort, 1808

Eponides sp.

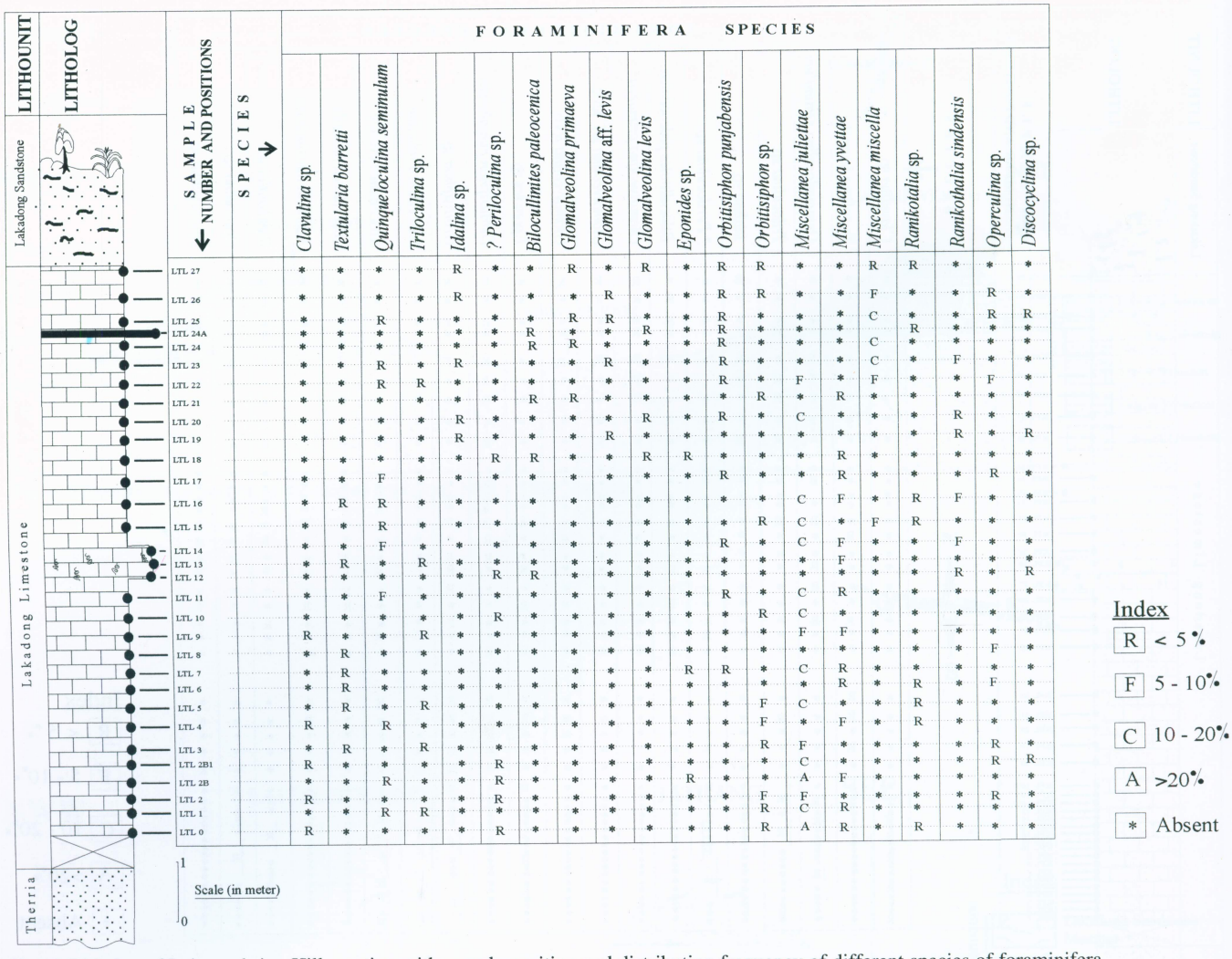


Fig. 6. Litholog of Laitmawksing Hills section with sample position and distribution frequency of different species of foraminifera.

(Pl. IV, fig. 6)

Description: Test wall calcareous, sutures distinct and depressed. The measured equatorial diameter of the specimen observed in equatorial section in the sample number LTL 8 is 0.3 mm. Number of whorl is 2.5 and number of chamber 18. The sizes of the chambers are ranges up to 0.05 mm. Thickness of cell wall is 0.02 mm. Proloculus not seen.

Superfamily: ORBITOIDACEA
Schwager, 1876

Family **Lepidorbitoididae** Vaughan, 1933
Subfamily **Lepidorbitoidinae** Vaughan, 1933
Genus ***Orbitosiphon*** Rao, 1940
Orbitosiphon punjabensis (Davies)-Tan, 1939
(Pl. III, fig. 8)

Description: Two-spired embryonic apparatus seen, protoconch is smaller than deuteroconch, equatorial chambers and well developed lateral chambers are present. Equatorial chambers are initially arcuate. Epi-auxiliary chambers are present. Tiered lateral chambers occurred on both sides of the median layer. The length of the specimen observed in megalospheric axial section of the species in sample number KPL 44 is 2.8 mm and breath at the middle part of the specimen is 0.32 mm.

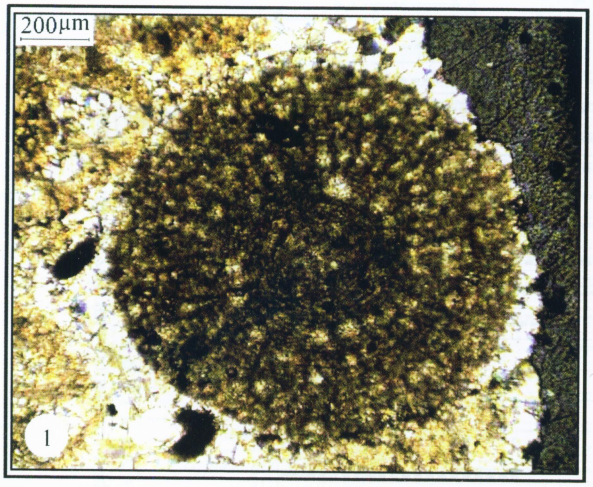
Orbitosiphon sp.
(Pl. IV, fig. 1)

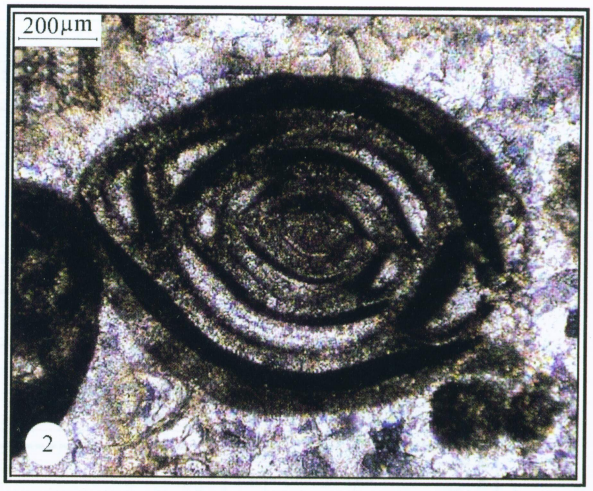
Description: Test asymmetric, embryonic apparatus bilocular, protoconch is smaller than deuteroconch, equatorial chambers and well developed lateral chambers are present. Tiered lateral chambers occurred on one side of equatorial layer and stout pillars on the other side. The equatorial diameter

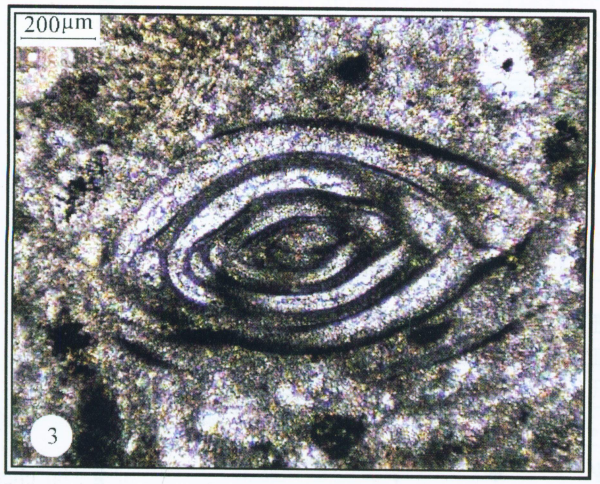
EXPLANATION OF PLATE IV

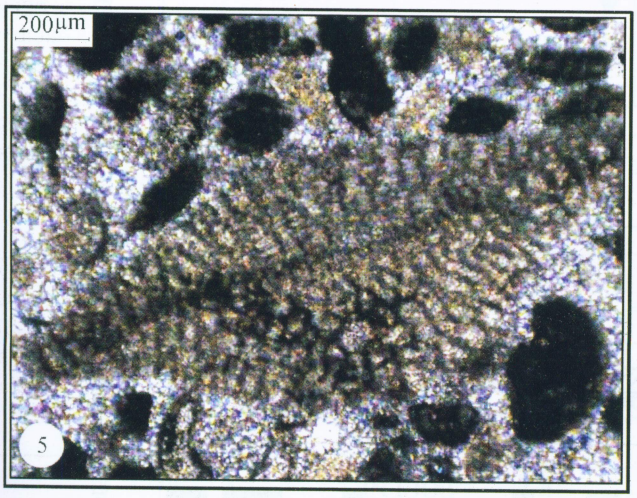
1. ***Orbitosiphon* sp**. equatorial section, Slide No. MPT/BG/KPL 38.D
2. ***Idalina* sp**. equatorial section, Slide No. MPT/BG/KPL 14.D
3. ? ***Periloculina* sp**. equatorial section, Slide No. MPT/BG/LTL 3.A
4. ***Biloculinites paleocenica*** (Rahagi, 1983), equatorial section, Slide No. MPT/BG/ LTL 12.C
5. ***Discocyclina* sp**. equatorial section, Slide No. MPT/BG/LTL 12.A
6. ***Eponides* sp**. equatorial section, Slide No. MPT/BG/LTL 8.E

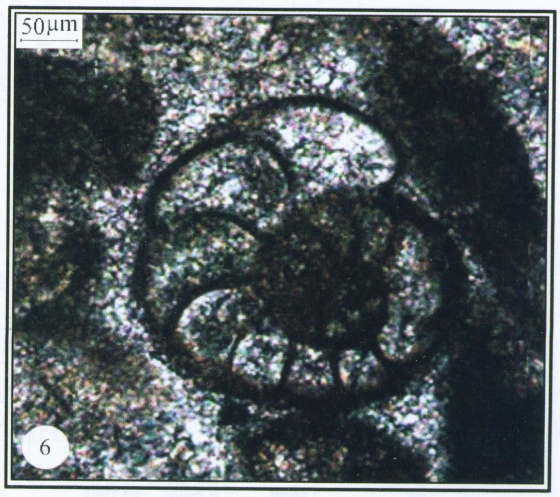
Plate IV











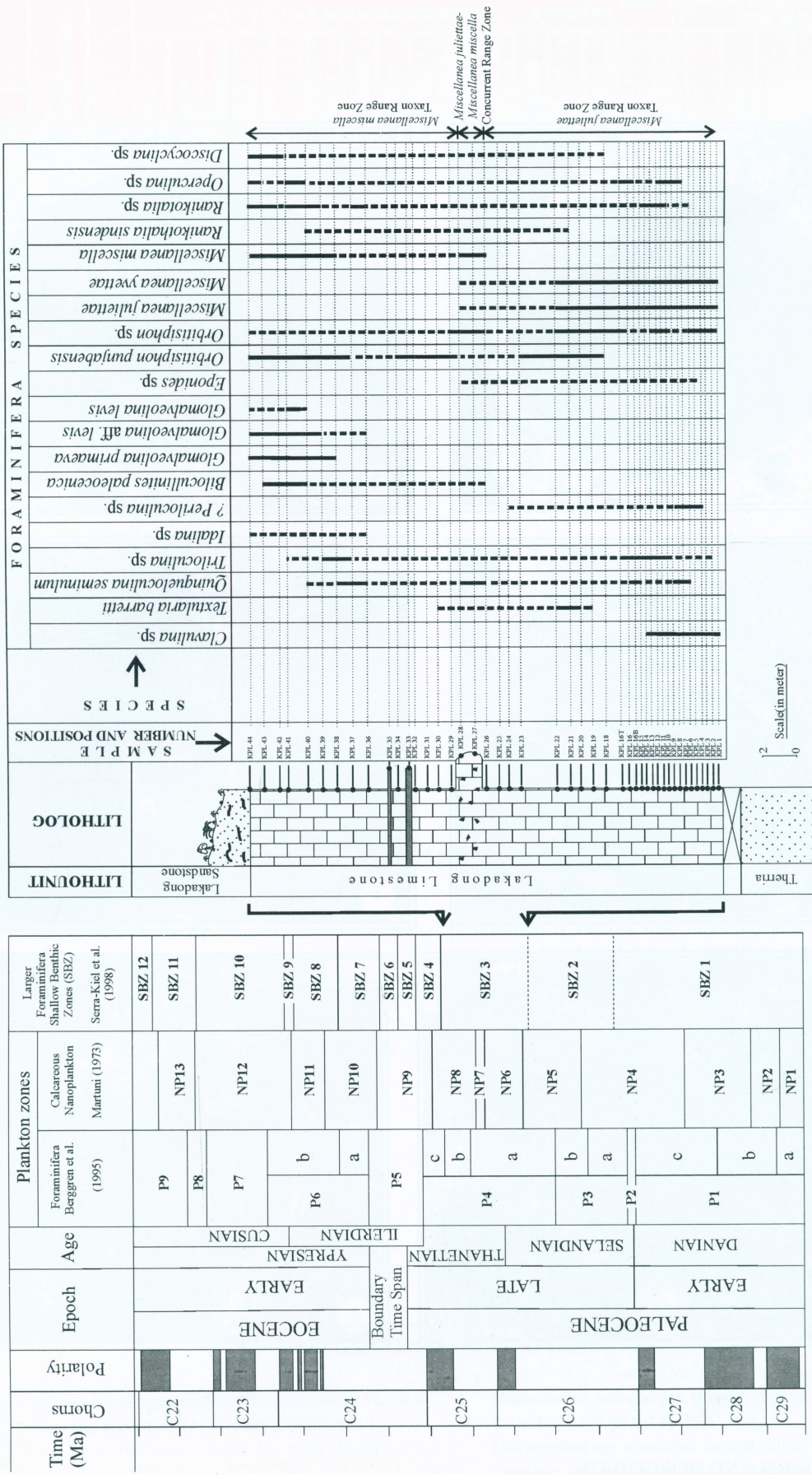


Fig. 7. Litholog of Kurtinsiang Hills section showing distribution of different species of foraminifera, established biozones and their correlation with SBZ Zonation scheme.

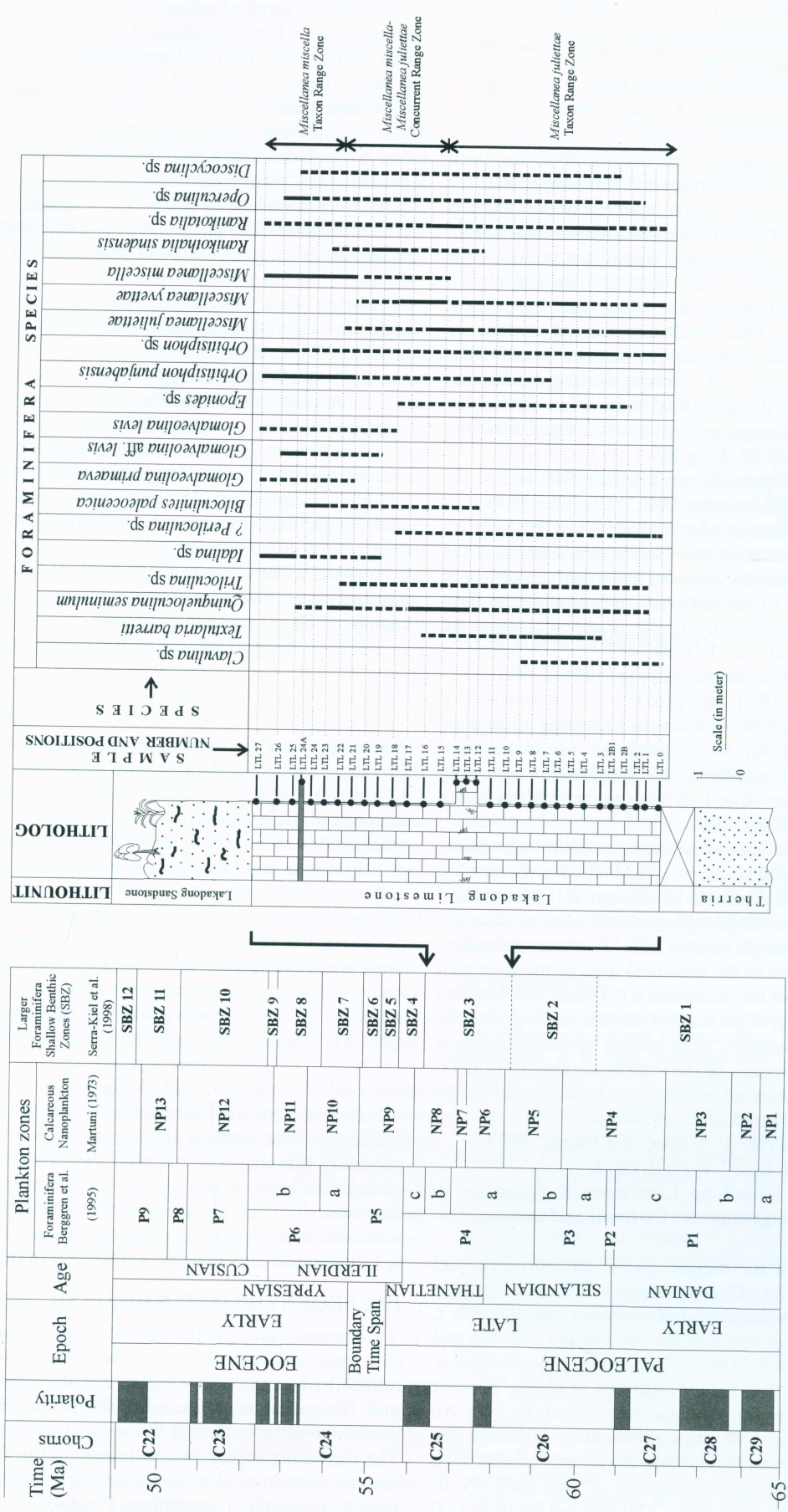


Fig. 8. Litholog of Laitmawksing Hills section shwoing distribution species of foraminifera, established biozones and their correlation with SBZ Zonation scheme.

of the test observed in the sample number KPL 38 is 1.2 mm.

Superfamily **Nummulitacea** de Blainville, 1827

Family **Pellatispiridae** Hanzawa, 1937

Genus ***Miscellanea*** Pfender, 1935

Miscellanea juliettae Leppig, 1988

(Pl. I, figs. 1, 2, 3, 4)

Description: This species is represented by both megalospheric (A-form) and microspheric (B-form) forms. The megalospheric equatorial section observed in thin sections of the sample number LTL 22 shows invaginated body whorl. Diameter of the test is 1.20 mm and size of the proloculus is 0.16 mm. Number of body whorl is 2. Sixteen and eleven chambers are observed in the last whorl and first whorl respectively (Pl. I, fig.1). The megalospheric axial sections are observed in thin sections of the sample number LTL 20. The form is strongly biconvex and involute. Strong ornamental pillars are confined to the umbilical area. Diameter of the proloculus is 0.10 mm. Length and breath of the test is 1.40 mm and 0.90 mm respectively (Pl. I, fig.2).

The microspheric equatorial sections are observed in the thin sections of the sample number LTL 5. Diameter of the test is 1.50 mm and 3.5 numbers of whorls are observed (Pl. I, fig. 3). The microspheric axial section observed in thin sections of the sample number LTL 3 are characterised by strongly invaginated peripheral margin. The length and breath measured in the form is 1.70 mm and 0.90 mm respectively. The ornamental pillars are confined to the umbilical area (Pl.I, fig. 4).

Miscellanea yvettae Leppig, 1988

(Pl. I, figs. 5, 6)

Description: *Miscellanea yvettae* in Lakadong Limestone is represented by both megalospheric (A-form) and microspheric (B-form) specimen. The specimen is occurring less commonly then the other two specimens of *Miscellanea* viz. *M. juliettae* and *M. miscella.*

The megalospheric equatorial sections of the specimens observed in the sample number LTL 6 shows invaginate peripheral margin. The diameter of the test is 1.06 mm and proloculus is 0.16 mm. Megalospheric axial section observed in the thin sections of sample number LTL 17, ornamental pillars are seen to be restricted to the umbilical area of the specimen (Pl. I, fig. 5). Diameter of megalosphere is 0.18 mm, 20 chambers in the last whorl. Length of the test is 1.40 mm and breath of the test is 0.90 mm. Microspheric axial section of the specimen is observed in the thin sections of the sample number LTL 3 (Pl. I, fig. 6). The observed length of the test is 1.50 mm and breath is 0.70 mm. Size of the proloculus is 0.03 mm.

Miscellanea miscella d' Archiac and Haime, 1853

(Pl. I, figs. 7, 8; Pl. II, fig. 1)

Description: In Lakadong Limestone this species is represented by both megalospheric (A-form) and microspheric (B-form) forms.

The proloculus of the megalospheric equatorial section observed in thin sections of sample number KPL 44 is strongly comparable with the proloculus of *Miscellanea miscella* (Pl. I, fig. 7). The equatorial diameter of the specimen is 1.50 mm and megalosphere is 0.20 mm. The slightly slanting megalospheric axial section observed in the thin sections of sample number KPL 41 is irregularly invaginate in the outer whorl (Pl. I, fig. 8). The length of the test is 1.90 mm and breadth is 1.08 mm. The microspheric axial section observed in the sample number LTL 15 irregularly invaginate in the periphery of their shell (Pl. II, fig. 1). The length of the specimen is 2.50 mm and breath is 1.00 mm. The ornamental pillars are not only restricted to the umbilical area, but also scattered over the lateral shell surface. *Miscellanea miscella* is different from its older species such as *Miscellanea yvettae* and *Miscellanea juliettae* by virture of its larger size.

Family **Nummulitidae** de Blainville, 1827

Genus ***Ranikothalia*** Caudri, 1944

Ranikothalia sp.

(Pl. II, fig. 2)

Description: The test compressed and involute. The axial section showing long, thin alar prolongations (comparatively thicker than *Ranikothalia sindensis*), but continue to umbilicus. Wall calcareous and structure is not coarsely perforate except at the marginal cord. Marginal cords thick and perforate. Proloculus not seen. Length of the specimen is 2.52 mm and width 0.60 mm.

Ranikothalia sindensis (Davies) Caudri, 1944

(Pl. II, fig. 4)

Description: The test compressed and involute. The axial section showing very long, thin alar prolongations, but continue to umbilicus. Wall calcareous and structure is not coarsely perforate except at the marginal cord. Marginal cords thick, swollen and coarsely perforate. The length of the test is 6.1 mm and breath measure is 0.98 mm to 0.32 mm. The umbilical portions have a thickness of 0.66 mm. Inner length of the initial chamber 0.30 mm and with 0.10 mm.

Genus ***Operculina*** d' Orbigny, 1826

Operculina sp.

(Pl. II, fig. 3)

Description: Test wall calcareous, lamellar, body whorl expanding rapidly, number of body whorls counted in the equatorial section of the specimen observed in sample number LTL 8 is 2.5, equatorial diameter of the test is 1.02 mm, inner diameter of the proloculus is 0.08 mm. The length measured in axial section of the specimen observed in sample number LTL 6 is 2.04 mm and breadth observed in the middle part of the specimen is 0.49 mm. The inner diameter of the proloculus of the specimen is 0.14 mm. Suture strongly curved, back at the periphery. Usually all coils visible from the exterior, earlier coils involute, periphery with a thickened marginal cord with numerous superposed marginal canals.

Family **Discocyclinidae** Galloway, 1928

Genus ***Discocyclina*** Gumbel, 1870

Discocyclina sp.

(Pl. IV, fig. 5)

Description: Test bilaterally symmetrical, discoidal and lenticular. The form is thicker at the central portion and gradually thinning towards both the ends. Pillars radially arranged in between rows of lateral chambers, thicker towards the outer side, end in surface papillae. The length of the test measured in the specimen observed in sample number LTL 12 is 1.76 mm and breath in the central part of the test is 0.84 mm.

PALAEOENVIRONMENT

Foraminifera in the limestoneshow variable vertical distribution. Their abundance is confined to the lower and middle part of the unit while rare at the top sandy part of the unit. This may be attributed to the prevalence of favourable marine conditions during the deposition in the initial stage. The increasing supply of clastic material to the basin towards the end deposition of of the Lakadong Limestone inhibited the thriving of benthic foraminifera. Presence of mud free water in

basin of deposition and predominance of larger foraminifera and calcareous algae in the Lakadong Limestone assemblage are indicative of low energy warm shallow water environment of deposition.

The Lakadong Limestone larger foraminiferal assemblage is associated with rich assemblage of calcareous algae. In recent seas, this kind of assemblage is common in shallow water tropical environment of carbonate deposition. The dominant elements of calcareous algae belong to *Distichoplax biserialis, D. raoi, Corallina* sp., *Mesophyllum meghalayensis, Lithoporella melobesioides, Amphiroa* sp. etc. (Kalita and Gogoi, 2006).

The association of *Miscellanea* and *Ranikothalia* occurs in sediments of an outer shelf and imperforate form such as *Glomalveolina* prefer restricted shelf condition of deposition (Hottinger, 1973). Arni (1965) suggested that Nummulitids occur in sediments of bioherm or sand bank facies. Nummulitic reefs, commonly developed in neritic shallows whereas operculines and discocylines characterize bioclastic deposits of fore - reef facies and Orbitoidacea and *Glomalveolina* are found in abundance in back - reef facies of a protected shelf.

Miscellanea miscella indicates shallow warm water environment (Ghose, 1976; Hottinger, 1983; Reiss and Hottinger, 1984). *Ranikothalia* and *Operculina* found in the Palaeocene sequences have been interpreted as characteristic of low water energy, carbonate environments ranging from 10 to 40 meter depth (Hottinger, 1983). Orbitoididae and *Glomalveolina* occur in back–reef facies typically developed in a lagoonal type environment (Arni, 1965; Ghose, 1976; Beckmann, 1982).

The occurrence in abundance of Nummulitids (*Miscellanea, Ranikothalia* etc.) and calcareous algae with glomalveolines and discocyclines in the limestone of Mawsynram area suggests that the Lakadong Limestone was deposited in shallow shelf areas of carbonate sedimentation with influx of material from both fore-reef and back - reef environments.

The dominance of Miliolidae is typical of a shoal - reef environment with depths between twelve and twenty meter or even less (Arni, 1965) where as the *Glomalveolina primaeva* and *Distichoplax biserialis* association is indicative of back–reef environment with low water energy and depths between twenty and forty meters in deeper Inner – shelf (Hottinger, 1983).

The *Discocyclina–Ranikothalia* association is interpreted as characteristic of fore–reef environment with low to moderate water energy with firm substrates at shallow depths in shallower inner shelf (Jauhri 1994).

From the above observation, it can be suggested that both the back-reef and fore-reef environment was prevalent during the deposition of the Lakadong Limestone unit. As such it can be concluded that these limestones are reef deposits.

CONCLUDING REMARKS

1. On the basis of species association of foraminifera in Lakadong Limestone, two Taxon Range Zones viz. *Miscellanea juliettae* Taxon Range Zone and *Miscellanea miscella* Taxon Range Zone and one Concurrent Range Zone (*Miscellanea juliettae - Miscellanea miscella* Concurrent Range Zone) have been identified.
2. The lower part of the limestone is characterized by *Miscellanea juliettae* Taxon Range Zone and is followed upward by development of *Miscellanea juliettae - Miscellanea miscella* Concurrent Range Zone and *Miscellanea miscella* Taxon Range Zone, respectively.
3. The age of these identified biozones can be assigned as Late Palaeocene (Thanetian).
4. Correlation of biozones reveals that they can be placed within the SBZ 3 Zone (Early Thanetian) of Serra-Kiel et al. (1998) which is equivalent to early P4 Zone of Berggren et al. (1995).
5. Palaeoenvironmental interpretation of the Lakadong Limestone suggests that both the back–reef and fore–reef environments were prevalent during deposition of these limestones and as such it can be concluded that these limestones are reef deposits.
6. The limestone was deposited in a marine condition and during the deposition of lower and middle parts of the deposits the water was mud free and clear which helped the larger foraminiferal population to thrive in the basin.
7. Presence of mud free water in the basin of deposition, and predominance of larger foraminifera and calcareous algae assemblage are indicative of low energy warm shallow water environment of carbonate deposition. But the increasing supply of clastic materials to the basin towards the end of the limestone deposition phase inhibited the benthic of marine population.

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REFERENCES

Arni, P. 1965 L'evolution des Nummulitinae en tant que facteur de modification des depots littoraux: *Mem. B. R. G. M.*, Paris, **32**: 7-20.

Beckmann, J. P. 1982 Displaced Late Cretaceous and Palaeocene Microfossils, p. 120-141. In: *Micropalaeontology and Biostratigraphy of the Campanian to Palaeocene of the Monte Giglio Bergamo Province* (Eds. Beckmann, J. P., Bolli, H. M., Kleboth, P. and Proto Decima, F.), Italy. Memoire Di Scienze Geologic. **35**.

Berggren, W. A., Kent, D. V., Swisher, C. C. and Aubry, M. P. 1995 A revised Cenozoic geochronology and chronostratigraphy. In: W. A. Berggren, Kent, D. V, Aubry, M. P. and Hardenbol, J. (eds.), geochronology, time scale and global correlations: an unified temporal framework for an historical geology. *Society of Economic Paleontologists and Mineralogists, Special Publication*, **54:** 129-212.

Evans, P. 1932 Explanatory notes to accompany a Table showing the Tertiary Succession in Assam. *Transactions Mining & Geological Institute of India*, **27:** 155-260.

Garg, R. and Khowaja-Ateequzzaman 2000. Dinoflagellate cysts from the Lakadong Sandstone, Cherrapunji area; biostratigraphical and palaeoenvironmental significance and relevance to sea level changes in the Upper Palaeocene of the Khasi Hills, South Shillong Plateau, India. *Palaeobotanist*, **49**, 461-484.

Ghose, B. K. 1976 Palaeogene reef rockcomplex of Meghalaya and its oil potentialities. *Science and. Culture.*, **42:** 248-253.

Gogoi, B., Borgohain, R. and Kalita, K. D. 2003 Petrography,

palaeontology and depositional environment of Lakadong Limestone of Mawsynram area, Meghalaya. *Journal of Indian Association of Sedimntologsts*, **22** (1&2): 133-149.

Hottinger, L. 1973 Selected Palaeogene larger foraminifera, p. 443-452. In: "*Atlas of Palaeobiogeogeography*"(Ed. Hallam, A.).

Hottinger, L. 1983 Processes determining the distribution of larger foraminifera in space and time. *Utrecht Micropalacontological Bulletin*, **30**: 239-235.

Jauhri, A. K. 1988 Observations on the foraminiferal fauna of the basal part of Sylhet Limestone Group (Lakadong Limestone) from Therria Ghat, South Shillong Plateau, Meghalaya, p.34-42. In: *Palaeocene of India,* (Ed. Maheshwari, H. K.), published by Indian Association of Palynostratigraphers, Lucknow, Publ. No. **4**.

Jauhri, A. K. 1994 Carbonate buildup in the Lakadong Formation of the south Shillong plateau, NE India: A micropalaeontological perspective, p. 157-169. In: *Studies on Ecology and Palaeoecology of benthic Communities* (Eds. Matteucci, R., Carboni, M.G. and Pignatti J. S.). Bolletina Societe Palaeontologia Italiana, **2**.

Jauhri, A. K. 1996 *Ranikothalia nuttali* (Davies), a distinctive early Ilerdian marker, in the Shillong Plateau, p. 209-218. In: *Contribution to XV Indian colloquium on Micropalaeontology and Stratigraphy*, (Eds. Pandey, J., Azmi, R. J., Bhandari, A. K. and Dave, A.). Dehra Dun.

Jauhri, A. K. 1998 *Miscellanea* Pfender, 1935 (Foraminiferida) from the south Shillong region, N. E. India. *Journal of the Palaeontological Society of India*, **43:** 73-83.

Kalita, K. D. and Gogoi, B. 2002 Calcareous algae from Lakadong Limestone of Mawsynram area, Meghalaya. Abstracts Vol. of *National Conference on biodiversity – Past and Present*, organized by the Palaeobotanical Society, Lucknow: 25.

Kalita, K.D. and Gogoi, B. 2003 Foraminifera from Late Palaeocene to Early Eocene of Mawsynram area, Meghalaya. *Gondwana Geological Magazine.*, **18**(1): 59-66.

Kalita, K. D. and Gogoi, B. G. 2006 First report of coralline algae in the Late Palaeocene Lakadong Limestones of Mawsynram area, Meghalaya, NE India *Journal Geological Society of India*, **68**(5): 779-783.

Leppig, U. 1988 Structural analysis and taxonomic revision of *Miscellanea*, Palaeocene larger foraminifera. *Eclogae Geologicae Helvetiae*, **81**(3): 689-721.

Matsumaru, K. and Jauhri, A.K. 2003 *Lakadongia*, a new Orbitoidal foraminiferal genus from then Thanetian (Paleocene) of Meghalaya, NE India. *Micropaleontology*, **49:** 277-291.

Medlicott, H.B. 1869. Geological Sketch of the Shillong Plateau in north-eastern Bangal. *Memori of the Geological Survey of India* **7**: 151-207.

Misra, P. K., Jauhri, A. K., Kishore, S. and Singh, S. K 2002 Calcareous algae from the Lakadong Formation of the South Shillong Plateau, *Revue De Paleobiologie*, **21**(2): 717-734.

Nagappa, Y. 1956 A note on H. C. Dasgupta's collection from the Nummulitic Limestone of Cherrapunji, Khasi Hills, Assam. *Quarterly Journal Geological Mining Metallurgical Society of India*, **23**(4): 181-182.

Nagappa, Y. 1959 Foraminiferal biostratigraphy of Cretaceous-Eocene succession in the India - Pakistan-Burma region. *Micropaleontology*, **5(2):** 145-192.

Oldham, T. 1859 On geological structure of a part Khasi Hills. *Memoirs Geological Society of India*, **1:** 99-210.

Pal, A. K. and Dutta, S. K. 1979 A study of fossil algae from Sylhet Limestone Formation of Meghalaya and Mikir Hills. *Geophytology*, **9**(1-2): 144-154.

Pandey, J. 1981 Palaeocene smaller foraminifera of Um Sohryngkew River, Meghalaya, p.70-152. In: *Proceedings of the VII Indian Colloquium of Micropalaeontology & Stratigraphy* (Ed. Rashid, D. A.), Madras. India.

Prasad, V., Garg, R., Khowaja-Ateequzzaman, Singh, I.B. and Joachimski, M.M. 2006 Apectodinium Acme and Palynofacies Characteristics in the Latest Palaeocene-Earliest Eocene of Northeastern India: Biotic Response to the Palaeocene-Eocene Thermal Maxima (PETM) in Low Latitude. *Journal of the Palaeontological* Society of India, **51**(1): 75-91.

Reiss, Z. and Hottinger, L. 1984 *The Gulf of Aquaba: Ecological Micropaleontology*. Ecological Studies, **50**, Springer – Verlag, Berlin.

Serra-Kiel, J., Hottinger, L., Caus, E., Drobne, K., Ferrandez, C., Jauhri, A. K., Less, G., Pavlovec, R., Pignatti, J., Maria Samso, J., Schaub, H., Sirel, E., Strougo, A., Tambareau, Y., Tosquella, J. and Zakrevskaya, E. 1998 Larger Foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene. *Bulletin de la société Géologique de France*, **169**(2): 281-299.

Wilson, G.F. and Metre, W.B. 1953. Assam and Arakan, p.119-123. In: *The World's Oilfields*: *The Eastern Hemisphere*, The Science of Petroleum, 6 (Ed. Illing, V.C.). London, Oxford University Press.

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