Larger foraminiferal biostratigraphy of the lower Tertiary of Jaintia Hills, Meghalaya, NE India

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ABSTRACT: Larger foraminifera of the Tertiary a1 (Thanetian) to Tertiary b (Priabonian) of the Far Eastern Letter Stages are recognized in the upper Paleocene to upper Eocene limestones of Jaintia Hills, Meghalaya. The occurrence of *Pellatispira* preceded both occurrences of *Lepidocyclina* spp. and *Nummulites fabianii.* Three new genera and species, *Meghalayana indica,* n. gen., n. sp., *Raoia indica,* n. gen., n. sp., and *Protogypsina indica,* n. gen., n. sp. are described after *Orbitosiphon tibetica,* Paleocene orbitoidal foraminifera as a group with *Orbitosiphon.*

INTRODUCTION

The upper Cretaceous to the lower Tertiary (Paleogene) shelf sediments of Meghalaya Province, NE India are well exposed Garo Hills in the west through Khasi Hills to Jaintia Hills in the east. Especially the Paleogene larger foraminiferal fauna occurring in the south Shillong Front, eastern Khasi Hills exhibits the fauna between the Tethys and Indo-Pacific Regions (Nagappa 1959; Matsumaru and Jauhri 2003). The stratigraphy of the upper Cretaceous to Paleogene sequences of eastern Khasi and Jaintia Hills, Meghalaya has been provided the objective lithostratigraphic classification such as Mawsmai, South Shillong and North Cachar Groups in ascending order (Samanta and Raychaudhuri 1983). The biostratigraphy and systematics of larger foraminifera were announced to be presented in a separate paper by Samanta and Raychaudhuri, but have never been published. The purpose of the present paper is to describe larger foraminiferal biostratigraphy of the Paleogene of Jaintia Hills, Meghalaya (Text-figure 1). This provides the framework for the international correlation of larger foraminiferal bioevents, and may assist in the development of a biozonation for the Far Eastern Letter Stages.

STRATIGRAPHY, LITHOLOGY, FAUNAL SUCCESSION AND CORRELATION

The stratigraphy of the eastern Khasi and Jaintia Hills by Samanta and Raychaudhuri (1983) is as follows: the upper Cretaceous Mawsmai Group, which rests on the basal Pre-Cambrian metamorphic and igneous rocks, is unconformably overlain by the Paleogene South Shillong Group, which is constituted by the Lama, Umium and Prang Formations. The Prang Formation is overlain by the Kopili Formation of the North Cachar Group. From the stratigraphic correlation of the previous workers, the Lama Formation is equivalent of the Therria and Lakadong Stages by Nagappa (1959), which are further subdivided into the Therria Limestone, Therria Sandstone, Lakadong Limestone and Lakadong Sandstone by Das Gupta (1977). The Umium Formation is equivalent of the Narpuh Stage with basal Umlatdoh Limestone by Nagappa (1959), which is subdivided into the Umlatdoh Limestone and Narpuh Sandstone by Das Dupta (1977). The Prang Formation is regarded as the Prang Stage (Nagappa 1959) and Prang Limestone (Das Gupta 1977). In the Paleogene shelf sequences in the Khasi Hills and Jaintia Hills, there exists four sedimentary cycles of limestone and sandstone from the Therria to Prang Stages, although there is lack of sandstone after the Prang Limestone. The stratigraphic horizon is difficult to trace laterally. The rocks are tectonically highly disturbed by folding and faulting in this area. The present study is the first fundamental introduction for the larger foraminiferal zonation of this area.

The greater part of the Paleogene succession in the studied area is made up of larger foraminifera and calcareous algae debris in a matrix of carbonate gravel, sand, and mud (Text-figs. 2a-c). It is, lithologically, called as calcirudite, calcarenite and calcilutite. Larger foraminifera constitute especially the dominant faunal elements in the Paleogene succession. Coral and algal debris, occasionally fossil debris including mollusks and echinoids, and intraclasts are present in many samples in measured sections. The limestone for study contains very few planktonic foraminifera.

The faunal assemblage zonations based on larger foraminifera were difficult to interpret except for the Lakadong Limestone, because species contamination occurred by the influence of tectonic event. The distribution chart is, therefore, more complex than usual, and all the species of each sample were indicated irrespective (Text-fig. 3). Nevertheless, six faunal assemblage zonations based on larger foraminiferal species were recognized in measured sections as following explanations of sample materials and studied sections with spot sampling locations.

SAMPLE MATERIALS AND STUDIED SECTIONS

The southern part of the Jaintia Hills District, known as the South Shillong Front and/or its equivalent front is investigated for the present study. In there, the cliff-forming and fossiliferous limestones constitute the most significant and recognizable lithostratigraphic features, and are selected as measured sections. Their stratigraphic orders of the South

Shillong Group and North Cachar Group can be discriminated in order to collect rock samples in measured sections. The northern part of the Jaintia Hills District is not investigated the area for the present study, because of lack fossiliferous sedimentary rocks.

The following 10 sections and 5 stations of supplemental spot samples are treated for the present study. Judging from the geological structure of folding axis extending east-west direction, the light to dark gray coloured Lakadong Limestone of the middle part of the South Shillong Group, which overlies the light grey to greyish white or light pink coloured Terria Sandstone, is exposed around Mynkree village along the National Highway No. 44 (NH-44) route, betweem Shillong City in the northwest and Silchar City in the southeast, and around Nongtalang village, 30km west far from Mynkree Village. Two sections are selected in Mynkree village as Mynkree section A and B (Text fig. 1-5 and 6, Text-fig. 2a). One section is selected in Nongtalang Village (Text-fig. 1-7, Text-fig. 2a). The next geological development of the folding structure is extended in the Nongkhlieh village of Shnongrim area, about 14km northeast from Mynkree village. In there, the bluish grey coloured and large sized foraminifera bearing Umlatdoh Limestone, which overlies conformably the coal bearing Lakadong Sandstone, can be seen in Nongkhlieh ridge section A, but the basal Umlatdoh Limestone cannot be seen in Nongkhlieh ridge section B (Text-fig. 1-8A and B, Text-fig. 2b). In Nongkhlieh ridge section C, the light to dark gray coloured Prang Limestone overlies the Lakadong Sandstone with unconformity, and is overlain by the brownish shale with ferruginous sandstone of the Kopili Formation, carrying limestone lens (Text-fig. 1-8C, Text-fig. 2b).

The bluish grey to dark grey coloured Prang Limestone, which overlies conformably the Narpuh Sandstone, are exposed widely around and along NH-44 road between Lumsnong village, 6km south of Mynkree village, and Sonapur village. 4 sections are selected such as NH-44 section 1 to NH-44 section 4 (Text-fig. 1-1 to 1-4, Text-fig. 2c)

In order to reinforce the space and time distribution of species, and to search the distribution of limestone carrying the faunal assemblage, supplemental samples were collected near Musianglamare village between Mynkree sections and NH-44 sections (Text-fig. 1-9 and 10, Text-fig. 3); near the mid-point between Lumsnong village and Sonapur village along the north-south NH-44 road (Text-fig. 1-11 and 12, Text-fig. 3); and near Kharkhana village, about 16km far western extension of NH-44 sections (Text-fig. 1-13, Text-fig. 3). However, the authors couldn't trace the same biostratigraphical horizon in Kharkhana limestone samples in the western extension of the east-west direction of NH-44 Sections, because a great fault with a general strike of north-south direction is judged to have been formed after deposition between them.

Mynkree section A

Text-figure 1-5, Text-figure 2a-left column

A cliff of about 40mthickness on the western side of the National Highway No. 44 (NH-44) near Mynkree village. A total of 9 samples of the Lakadong Limestone were collected. The lower part (samples Myn/Lkd/101 to Myn/Lkd/103) of the sequence is composed of calcirudite and calcilutite; the middle part (samples Myn/Lkd/104 to Myn/Lkd/105), of crystalline calcarenite; and the upper part (samples Myn/Lkd/106 to Myn/Lkd/109), of calcilutite. Calcareous algae are common. The species are *Aberisphaera gambanica* Wan, *Daviesina khatiyahi* Smout, *Idalina sinjarica* Grimsdale, *Kathina selveri* Smout, *Lockhartia diversa* Smout, *L. haimei* (Davies), *L. tipperi* (Davies), *Miscellanea globularis* Rahaghi, *M. miscella* (d'Archiac and Haime), *M. primitiva* Rahaghi, *Orbitosiphon tibetica* (Douville), *Ranikothalia nuttalli* (Davies), *Pseudochrysalidina* spp., *Pseudolituonella* spp., *Rotalia trochidiformis* (Lamarck), and *Smoutina cruysi* Drooger. This fauna correlated to the Lakadong Limestone from samples 86/LKd/DR4 to 86/LKd/DR10 in the Um Sohryngkew River section, East Khasi Hills (Matsumaru and Jaxuhri 2003; text-fig. 1), due to the occurrence of *Lockhartia haimei, Ranikothalia nuttalli* and *Miscellanea miscella.* This fauna is regarded as a typical one from the Ranikot Stage (Nagappa 1959), and is similar to the Ranikot.

Mynkree section B

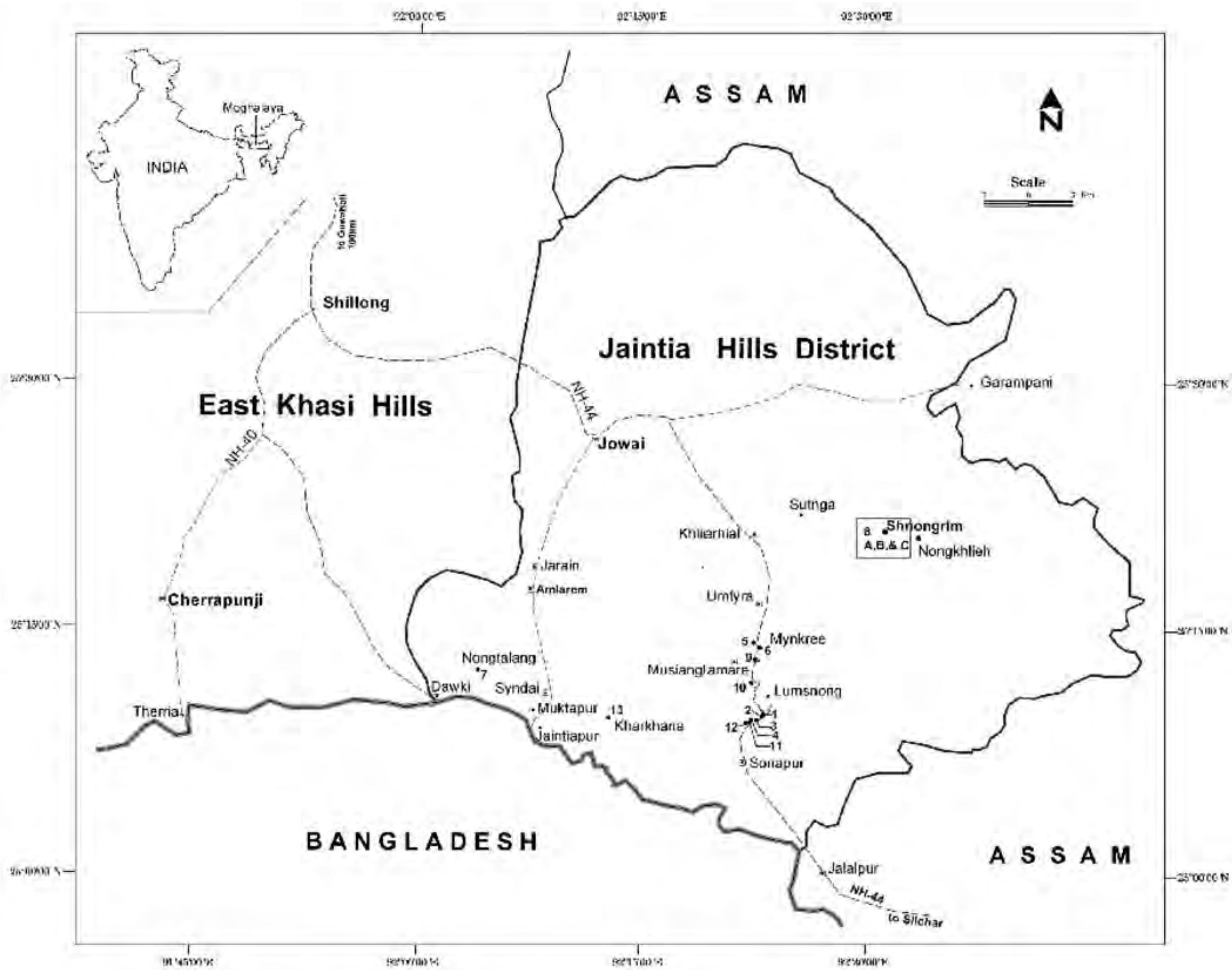
Text-figures 1-6, Text-figure 2a-middle column

A roadside cliff on the eastern side of NH-44 near Mynkree village. A total of 8 samples of the lakadong Limestone were collected. The lower part (samples LL1.1 to LL1.4) of the sequence is composed of skeletal calcarenite and the upper one (samples LL1.5 to LL1.8) is composed of calcilutite. The lowermost part about 5m thick from samples LL1.1 to LL1.2 is characterized by the occurrence of *Daviesina khatiyahi, Idalina sinjarica, Kathina selveri, Lockhartia conditi* (Nuttall), *L. diversa, Miscellanea miscella, M. primitiva, Pseudolituonella* spp., *Rotalia trochidiformis,* and *Smoutina cruysi* in addition to *Raoia indica,* n. gen., n. sp. Further 6 samples from LL1.3 to LL1.8 contain a fauna which includes *Aberisphaera gambanica, Daviesina khatiyahi, Idalina sinjarica, Kathina selveri, Lockhartia conditi, L. diversa, L. haimei, Miscellanea miscella, M. primitiva, Orbitoclypeus ramaraoi* (Samanta), *Orbitosiphon tibetica, Raoia indica,* n. gen., n. sp., *Pseudocrysalidina* spp., *Pseudolituonella* spp., *Ranikothalia nuttalli, Rotalia trochidiformis,* and *Smoutina cruysi*. This fauna except for samples LL1.1 to LL1.2 is regarded as the same fauna as shown in the Lakadong Limestone from samples Myn/Lkd/101 to Myn/Lkd/109 in Mynkree section A. Therefore, two faunal assemblages based on the lack or presence of both *Ranikothalia nuttalli* and *Lockhartia haimei.* In Um Sohryngkew River section, East Khasi Hills, Meghalaya it is clearly discriminated into two assemblages, i. e. lower assemblage, without *Ranikothalia nuttalli* and *Lockhartia haimei,* recognized from samples 86/LKd/DR 1 to 86/LKd/DR4, and upper one, with both two species, recognized from samples 86/LKd/DR5 to 86/Lkd/DR10 (Matsumaru and Jauhri 2003). As such, in Mynkree B Section, the former is correlated to the lower assemblage in Um Sohryngkew River section, and is assigned to Assemblage 1. The latter is correlated to the upper assemblage in Um Sohryngkew River section, and is assigned to Assemblage 2. Both assemblages are described later. Both assemblages are regarded and correlated with the fauna of the Ranikot (Nagappa 1959).

Nongtalang section

Text-figure 1-7, Text-figure 2a-right column

A cliff on a roadside at Nongtalang village. A total of 5 samples of the Lakadong Limestone were collected. The lowermost part (sample Nong/Lkd/B-01) is composed of calcilutite, while the middle part (samples Nong/Lkd/B-02 to Nonh/Lkd/B-04) is composed of recrystalized sparry calcite sement. The upper-



TEXT-FIGURE 1
Map showing locations of the study area and sampling stations in Jaintia Hills, Meghalaya, NE India. 1. NH-44 section 1, 2. NH-44 section 2, 3. NH-44 section 3, 4. NH-44 section 4, 5. Mynkree section A, 6. Mynkree section B, 7. Nongtalang section, 8.Nongkhlieh ridge sections A, B and C in Shinongrim area, 9. Spot samples LL2 and LL3, 10. Spot samples UL4.1 and UL6.1, 11. Spot sample 131/PL/St.2, 12. Spot samples NH-44/KL1-2 and KL1-3, and 13. Kharkhana.

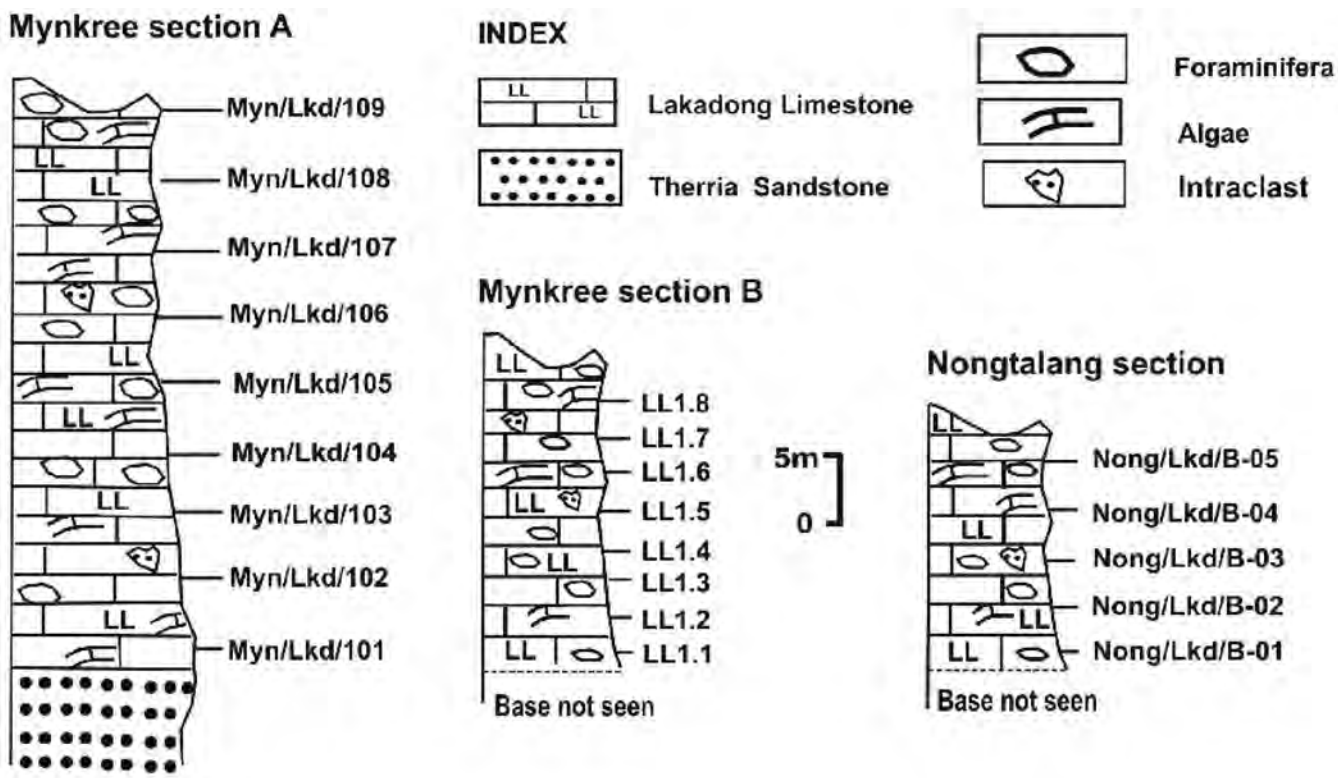
most (sample Nong/Lkd/B-05) is composed of skeletal calcarenite. The Nong/Lkd/B-01 yields *Daviesina khatiyahi, Idalina sinjarica, Kathina major* Smout, *K. selveri, Lockhartia diversa, L. haimei, Miscellanea globularis, M. primitiva, Raoia indica,* n. gen., n. sp., *Pseudolituonella* spp., *Ranikothalia nuttalli, Rotalia trochidiformis,* and *Smoutina cryuysi.* The similar fauna is in sample Nong/Lkd/B-05 again.

Spot samples LL2 and LL3
Text-figures 1-9

Both samples LL2 and LL3 of the Lakadong Limestone were collected from the NH-44 roadside, 4km SSW from Mynkree Section B. They yield *Glomalveolina primaeva* (Reichel), *Lockhartia conditi, Opertorbitolites douvillei* Nuttall, *Orbitoclypeus ramaraoi, Orbitosiphon tibetica, Protogypsina indica,* n. gen., n. sp., *Pseudolituonella* spp., *Raoia indica,* n. gen., n. sp., *Rotalia trochidiformis, Ranikothalia nuttalli,* and *Smoutina cruyisi,* correlated to the middle to upper Lakadong Limestone from samples LL1.3 to LL1.8 in the Mynkree section B.

Nongkhlieh ridge section A
Text-figure 1-8A, Text-figure 2b-left column

A cliff of a roadside of Shnongrim area, west Nongkhlieh Village. A total of 6 samples from L251 to L236 of the Umlatdoh Limestone, which conformably covered the Lakadong Sandstone carrying typical coal beds, and overlying 6 samples from L2C31 to L2C39 of the Prang Limestone were collected, respectively. There are two covered areas in the section. The lower is the cover zone between samples L241 and L234. It seems to be a series of the Umlatdoh Limestone due to the common occurrence of *Assilina laxispira* de la Harpe from both



TEXT-FIGURE 2a
Map showing columnar sections of Mynkree sections A and B, and Nongtalang section of the Lakadong Limestone with sampling stations in Jaintia Hills, Meghalaya, NE India.

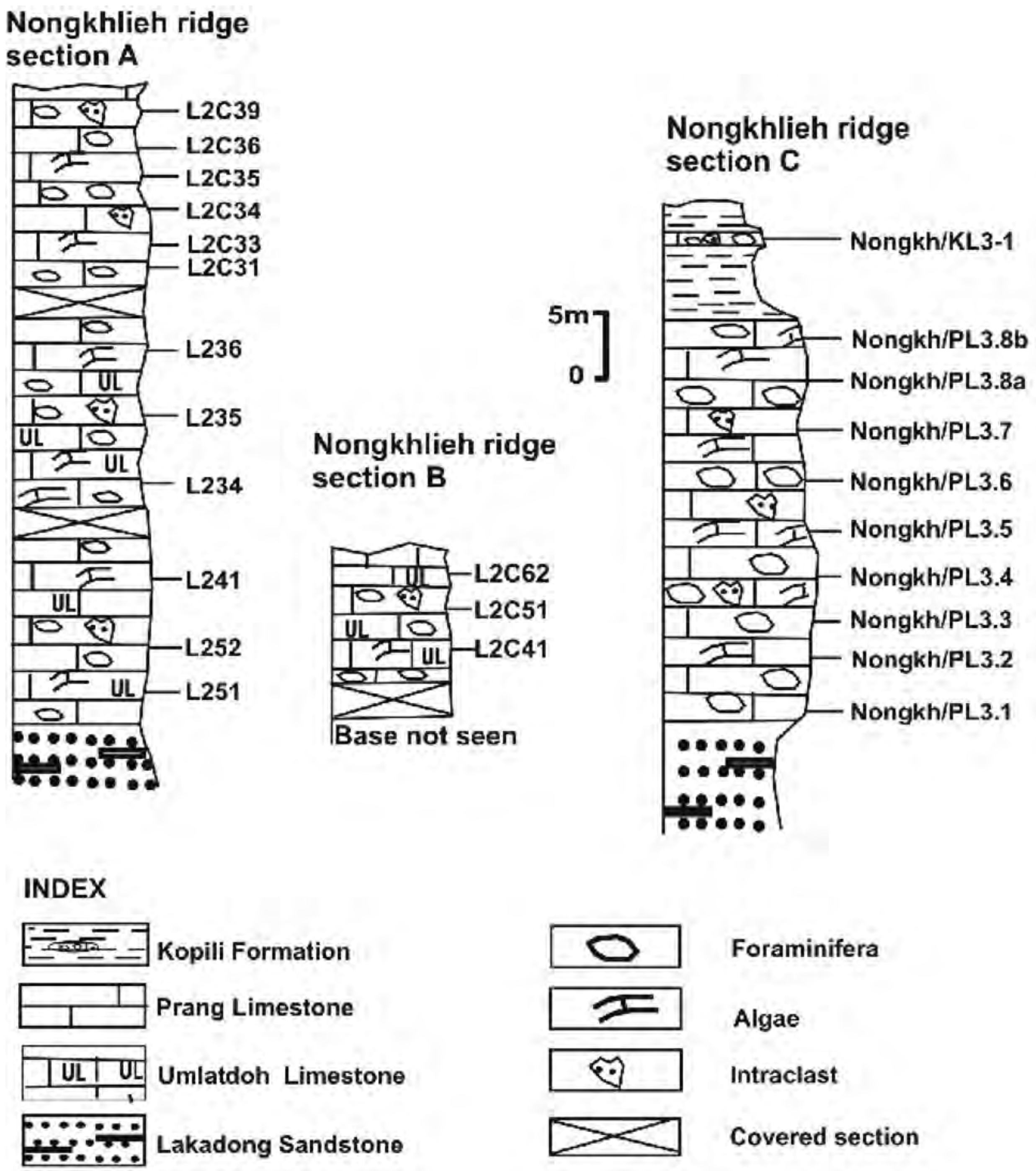
samples. The upper area is the cover zone between samples L236 and L2C31. It seems to be a great hiatus by the absence of strata, and there is the different occurrence of foraminiferal species (Text-fig. 3). Namely, the Narpuh Sandstone above the Umlatdoh Limestone of sample L236 is not present in this zone. In addition, sample L236 yields only *Nummulites atacicus* Leymerie, while sample L2C31 yields *Chapmanina* spp., and *Fabiania cassis* (Oppenheim), although *Nummulites atacicus, N. burdigalensis* (de la Harpe), and *N. globulus* Leymerie are recognized as fragmental debris. This means that the Prang Limestone (sample L2C31) above the upper hiatus zone may be bounded by the fault contact with the below Umlatdoh Limestone (sample L236).

The lower part (samples L251 to L241) of the Umlatdoh Limestone is composed of calcirudite and calcarenite, and is characterized by the occurrence of *Alveolina oblonga* d'Orbigny, *A. schwageri* Checchia-Rispoli, *Assilina laxispira* and *A. placentula* (Deshayes). The upper part (samples L234 to L236) of the Umlatdoh is composed of calcarenite, and is characterized by the occurrence of *Nummulites atacicus, N. globulus,* and *Discocyclina* spp. The former is assigned to Assemblage 3-1 and the latter is assigned to Assembalge 3-2. *Alveolina oblonga, Nummulites atacicus,* and *Assilina granulosa,* which seems to be *A. laxispira,* occurred from the Meting and Laki Limestones, both of the Laki Stage (Nuttall 1925; Nagappa 1959). Both assemblages 3-1 and 3-2 are then correlated with the fauna of the Laki Stage (Nagappa 1959).

The foraminiferal species from the Prang Limestone (sample L2C31) is stated above. Sample L2C33 yields *Pellatispira orbitoidea* (Provale) in association with *Dictyoconoides cooki* (Carter), *Discocyclina* spp., and *Operculina subformai* (Provale). Then it is discriminated into two assemblages, based on the fauna recognized in the Prang limestone, due to the lack of *Pellatispira,* and the presence of *Pellatispira*. The former is assigned to Assemblage 4, although it is the fauna without diagnostic species except *Chapmanina,* and the latter is assigned to Assemblage 5. In Rakhi section, Sulaiman Range, Eames (1952) has found the stratigraphic relationships between non-occurrence of *Pellatispira* and occurrence of *Pellatispira* from the Khirthar Stage. Therefore the upper prang Limestone in Nongkhlieh ridge section A seems to be correlatable to the Khirthar Stage.

Spot samples UL4.1 and UL6.1
Text-figures 1-10

A roadside exposure of the Umlatdoh Limestone near Musianglamare Village along NH−44 route, about 2km south from the location of samples LL2 and LL3. Both samples UL4.1 and UL6.1 are composed of calcarenite, and calcareous algae are common. They yield *Alveolina oblonga, A. schwageri, A. globosa* (Leymerie), *Discocyclina llarenai* Ruiz de Gaona, *Nummulites gizehensis* (Forskål), *N. globulus, N.* spp., *Operculina subformai,* and *Orbitolites complanatus* Lamarck. Whiles *Idalina sinjarica, Lockhartia conditi, L. haimei, L. hunti* Ovey, *Orbitoclypeus ramaraoi, Rotalia trochidiformis,* and



TEXT-FIGURE 2b
Map showing columnar sections of Nongkhlieh ridge sections A to C of the Umlatdoh Limestone, Prang Limestone and limestone bed in the Kopili Formation with sampling stations in Jaintia Hills, Meghalaya, NE India.

Smoutina cruysi, which are not necessarily in situ, can be seen. As a whole an association of *Alveolina oblonga* and *A. schwageri* from samples UL4.1 and UL6.1 indicates that the Umlatdoh Limestone of both samples is correlated with the lower part (samples L251 to L241) of the Umlatdoh Limestone in Nongkhlieh ridge section A.

Nongkhlieh ridge section B
Text-figure 1-8B, Text-figure 2b-middle column

A roadside cliff of Shnongrim area, 5km west from Nongkhlieh Village. A total of 3 samples (L2C41, L2C51 and L2C62) of the Umlatdoh Limestone, which is composed of skeletal calcarenite, were collected. *Assilina laxispira, Alveolina* spp., *Discocyclina* spp., *Nummulites atacicus, N. burdigalensis,* and *N. globulus* have been seen in the samples with *Lockhartia diversa,* which is not seen in situ. This fauna is assigned to Assemblage 3-1.

Nongkhlieh ridge section C
Text-figure 1-8C, Text-figur 2b-right column

A roadside cliff of Shnongrim area, 4km west from Nongkhlieh Village. A total of 9 samples composed on calcarenite of the Prang Limestone, and one sample of a purple coloured detrital limestone intercalated in the Kopili Formation, which covered the Prang Limestone, were collected for study. The lower three samples with gravel and intraclasts of Nongkh/PL3.1 to Nongkh/PL3.3 are collected from the lower part of the Prang Limestone, and are characterized by the occurrence of *Linderina brugesi* Schlumberger, *Nummulites beaumonti* d'Archiac and Haime, *N. gizehensis, N. perforatus* (Montfort), and *Orbitolites complanatus,* in addition to *Alveolina* spp, and *Discocyclina* spp. Reworked species are *Daviesina khatiyahi, Kathina selveri, Lockhartia diversa, Miscellanea miscella, Nummulites globulus,* and *Rotalia hensoni* Smout. The middle and upper part of the Prang Limestone from samples Nongkh/PL3.4 to Nongkh/PL3.8a contain a fauna which includes *Alveolina* spp., *Discocyclina dispansa* (Sowerby), *D.* spp., *Nummulites acutus* (Sowerby), *N. beaumonti, N. gizehensis, N. millecaput* Boubée, and *N. perforatus.* Reworked species such as *Miscellanea miscella* can be seen. The former fauna from the lower Prang Limestone is assigned to Assemblage 4-1, based on the association of *Nummulites beaumonti, N. gizehensis* and *N. perforatus.* The latter from the middle to upper Prang is assigned to Assemblage 4-2, based on the association of *N. beaumonti, N. gizehensis, N. millecaput,* and *N. perforatus.* These species typify the Khirthar Stage (Davies 1940; Nagappa 1959). The topmost Prang Limestone of sample Nongkh/PL3.8b is characterized by the occurrence of *Discocyclina dispansa, Nummulites acutus, N. perforatus,* and *Pellatispira orbitoidea.* The other species of *Operculina subformai. Kathina selveri, Nummulites beaumonti,* and *N. globulus* may be regarded as reworked species. From a viewpoint of the occurrence of *Pellatispira orbitoidea,* the topmost Prang Limestone (sample Nongkh/PL3.8b) in this section is correlated with the upper Prang Limestone from samples L2C33 to L2C39 in Nongkhlieh ridge section A, and is assigned to Assemblage 5. As a whole, the Prang Limestone is correlated with the Khirthar Stage, due to the occurrence of *Nummulites beaumonti, N. gizehensis, N. perforatus,* and/or *Pellatispira.*

Sample Nongkh/KL3-1 from a brownish coloured limestone bed intercalated between dark grey to black coloured shales of the Kopili Formation occurs *Discocyclina augustae* van der Weijden, *D. dispansa, D. javana* (Verbeek), *Lepidocyclina* spp., *Nummulites incrassatus* de la Harpe, *N. perforatus, N. striatus* (Bruguiere), *Operculina subformai, O. schwageri* Silvestri, *Pellatispira orbitoidea,* and *Sphaerogypsina globulus* (Reuss). Whiles *Nummulites globulus, Orbitosiphon tibetica,* and *Rotalia trochidiformis* can be seen as reworked species. *Lepidocyclina* spp. is the first finding from Jaintia Hills, and occurs very few. The fauna of Nongkh/KL3-1 is assigned to Assemblage 6, based on the reason of the occurrence of Eocene *Lepidocyclina* spp. and *Nummulites striatus* (which is here regarded as a senior synonym of *N. pengaronensis* Verbeek). This limestone may be correlatable to the top Khirthar Stage, due to the occurrence of *Nummulites striatus.*

NH-44 (National Highway No.44) section 1
Text-figure 1-1, Text-figure 2c-left column)

A roadside cliff along NH-44, about 6km south from Lumsnong village. It represents about 40mthick exposure of the Prang Limestone, which covered the Narpuh Sandstone, and composed of calcirudite through calcarenite to calcilutite in upwards. Two samples of 129/PL6-3 and 129/PL6-4 of calcarenite were collected, and are characterized by the occurrence of *Alveolina elliptica* (Sowerby), *A. elliptica nuttalli* Davies, *A.* spp., *Nummulites atacicus,* and *Orbitolites complanatus.* Whiles *Daviesina khatiyahi, Idalina sinjarica, Glomalveolina primaeva, Lockhartia conditi, L. haimei, Opertorbitolites douvillei, Orbitosiphon tibetica, Raoia indica,* n. gen., n. sp., *Protogypsina indica,* n. gen., n. sp., and *Rotalia trochidiformis* have been seen in these samples, and they are regarded as reworking from the lower horizons. The present fauna is similar to faunal assemblage 4-1 from the lower part of the Prang Limestone in Nongkhlieh ridge section C.

NH-44 section 2
Text-figure 1-2, Text-figure 2c-middle left column

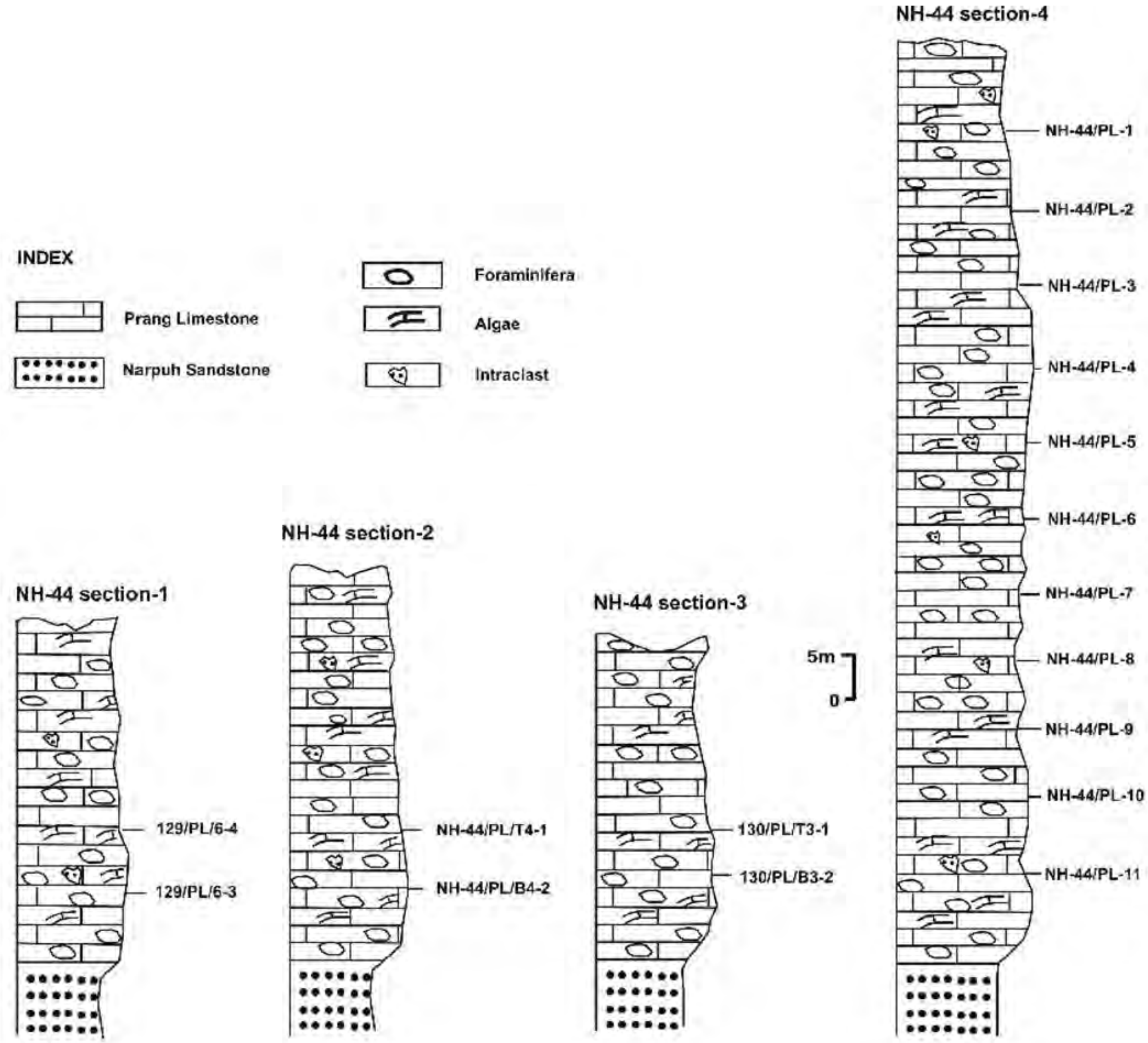
A roadside cliff along NH-44, about 0.5km south from NH-44 section 1. The large *Nummulites-* bearing Prang Limestone with 45mthick above the Narpuh Sandstone is exposed, and composed of calcilutite. Two samples of NH-44/PL/B4-2 and NH-44/PL/T4-1 are characterized by the occurrence of *Alveolina elliptica, A. elliptica nuttalli, Assilina laxispira, A. placentula, Nummulites atacicus, N. beaumonti, N. gizehensis, N. millecaput,* and *Orbitolites compalnatus.* Reworked species of *Alveolina oblonga, Lockhartia diversa,* and *Orbitoclypeus ramaraoi* can be seen. The present fauna is assigned to faunal assemblage 4-1, due to the similar fauna of *Alveolina elliptica nuttalli, Nummulites atacicus,* and *Orbitolites complanatus* from the Prang Limestone in NH-44 section 1.

NH-44 section 3
Text-figures 1-3, Text-figure 2c-middle right column

A roadside cliff along NH-44, 0.3km further southwest from NH-44 section 2. The large *Nummulites* and *Discocyclina-* bearing Prang Limestone is exposed over the Narpuh Sandstone, and is estimated to be about 35mthick. Two samples 130/PL/B3-2 and 130/PL/T3-1 are composed of calcilutite, and are characterized by the occurrence of *Discocyclina augustae, D. dispansa, D. javana, Nummulites atacicus, N. beaumonti, N. gizehensis,* and *N. millecaput.* Reworked species of *Nummulites globulus,* and *Ranikothalia nuttalli* can be seen. The present fauna is assigned to faunal assemblage 4-1, due to the similar fauna from the Prang Limestone in NH-44 sections 1 and 2.

NH-44 section 4
Text-figures 1-4, Text-figure 2c-right column

A huge cliff of the Prang Limestone over the Narpuh Sandstone is exposed along NH-44, 1km further west from NH-44 Section 3, and is estimated to be about 90mthick. The lower part (samples NH-44/PL-11 and NH-44/PL-10) of the Prang Limestone is composed of skeletal calciltite of broken specimens of *Discocyclina* and *Nummulites*. They contain a fauna which includes *Discocyclina augustae, D. dispansa, D. javana, D. llarenai, Nummulites acutus, N. atacicus, N. beaumonti, N.*



TEXT-FIGURE 2c
Map showing columnar sections of NH-44 sections 1 to 4 of the Prang Limestone with sampling stations in Jaintia Hills, Meghalaya, NE India.

ptukhiani Kacharava, *N. gizehensis,* and *N. perforatus.* Planktonic and reworked foraminifera can be seen. The present fauna is also similar to faunal assemblage 4-1 from the lower Prang Limestone in NH-44 Sections 1 to 3. The middle part (samples NH-44/PL-9 to NH-44/PL-7) of the Prang Limestone is composed of calcilutite, and yields *Discocyclina augustae, D. dispansa, D. llarenai, Nummulites acutus,* and *N. perforatus.* This fauna is similar to faunal assemblage 4-2 from the middle to upper part of the Prang Limestone in Nongkhlier ridge section C, based on the occurrence of *Nummulites perforatus.* The upper Prang Limestone from samples NH-44/PL-6 to NH-44/PL-1 is composed of algal biolithite (sample NH-44/PL-6), calcarenite to calcilutite (samples NH-44/PL-5 to NH-44/PL-2) and *Pellatispira* biolithite (sample NH-44/PL-1) in ascending order. The fauna from the upper Prang Limestone is dominated by the occurrence of *Nummulites perforatus, Pellatispira orbitoidea, P. madaraszi* (von Hantken), and *Operculina subformai.* The present fauna is similar to faunal assemblage 5 found from the upper Prang Limestone (samples L2C33 to L2C39) in Nongkhlieh ridge section A.

Spot sample 131/PL/St.2
Text-figures 1-11

A roadside exposure of the Prang Limestone along NH-44 route, 0.2km southwest from NH-44 section 4 stated above, on the western side of the road, Jaintia Hills, Meghalaya. Sample St.2 is composed of algal biolithite, which occur *Fabiania cassis, Operculina subformai,* and *Pellatispira orbitoidea.*

Whiles *Nummulites globulus,* which has not been found in situ, can be seen. This is assigned to faunal assemblage 5, recognized from the upper Prang Limestone (samples NH-44/PL-6 to NH-44/PL-1) in NH-44 section 4.

Spot samples NH-44/KL1-2 and NH-44/KL1-3
Text-figures 1-12

A roadside exposure of a limestone bed of the Kopili Formation along NH-44 route, 1km southwest from sample 131/PL/St.2. Two samples NH-44/KL1-2 and NH-44/KL1-3 were collected from the purple coloured calcarenite. They yield *Discocyclina augustae, D. dispansa, D. javana, Linderina brugesi, Meghalayana indica,* n. gen., n. sp., *Nummulites fabianii* (Prever)*, N. incrassatus, N. striatus, Pellatispira glabra* Umbgrove*, P. madaraszi,* and *P. orbitoidea.* The fauna is assigned to faunal assemblage 6, recognized from the limestone (sample KL3-1) of the Kopili Formation in Nongkhlieh ridge section C, due to the occurrence of *Nummulites incrassatus, N. striatus,* and *Pellatispira orbitoidea.* The stratigraphical horizon between both limestones of samples NH-44/KL1-2 and NH-44/KL1-3, and those of Nongkhlieh ridge section C (sample Nongkh/KL3-1) is obscure, because of about 30km distance between localities. In this study, the important fact became, nevertheless, clear that the stratigraphic occurrence of *Pellatispira* preceded both occurrences of Eocene *Lepidocyclina* spp., and *Nummulites fabianii* in the Jaintia Hills, Meghalaya.

Kharkhana
Text-figures 1-13

The exposure at Kharkhana village. One sample of calcilutite was collected for preliminary study. It yields *Idalina sinjarica, Lockhartia diversa, L. hunti,* and *Pseudochrysalidina* spp. This limestone is correlated with the fauna of sample UL4.1, due to the occurrence of *Lockhartia hunti.*

FAUNAL ASSEMBLAGE ZONATIONS AND THEIR GEOLOGICAL AGES

The six faunal assemblage zonations based on the larger foraminifera in the Jaintia Hills, Meghalaya have been recognized from the biostratigraphical occurrences of larger foraminiferal species from the best described selected sections and samples in the region at present from the Lakadong Limestone to limestone beds of the Kopili Formation, which are representative carbonate sequences of reef to fore-reef environment of deposition. The larger foraminifera shown in Text-figure 3 indicative of the Tertiary a1 (Thanetian) to Tertiary b (Priabonian) Stages of the East Indian Letter Classification at stage level (Van der Vlerk and Umbgrove 1927; Leupold and Van der Vlerk 1931; Adams 1965, 1970; Matsumaru 1996; Govindan 2003). It is, however, difficult to correlate strata exactly within a stage, because a stratigraphical and paleontological information at and near of the stage boundary is inadequately known until present, and the present study will contribute the stage to be better known. In addition, it is difficult to correlate strata with other region, because the ranges of individual genera and species of larger foraminifera, which make up the faunal assemblages, will remain fairly unstable and/or will change by environmental facies and regional differences. However, these ranges will be useful when they can be dated accurately from the associated faunal assemblages and they are checked by the reference to the carbonate sequences.

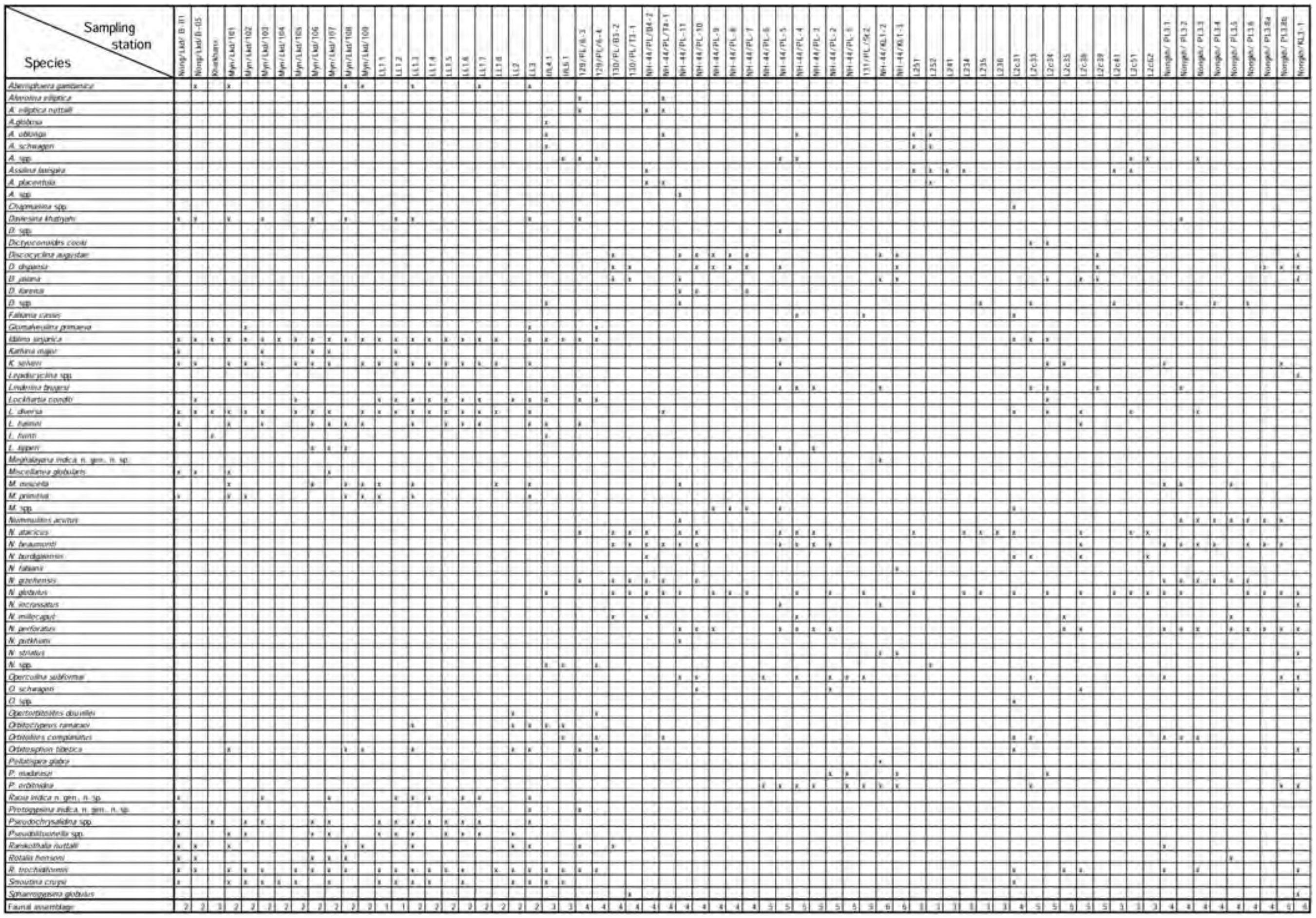
1. *Idalina sinjarica – Miscellanea primitiva – M. miscella – Kathina selveri – Lockhartia diversa* Assemblage (Assemblage 1).

This faunal assemblage zonation is defined by the biostratigraphic occurrence of the above five species. The common occurrence typifies this assemblage: *Daviesina khatiyahi, Kathina major, Lockhartia conditi, Raoia indica,* n. gen., n. sp., *Rotalia trochidiformis, Smoutina cruysi, Pseudochrysalidina* spp., and *Pseudolituonella* spp. This assemblage is seen in the lower Lakadong Limestone (samples LL1.1 and LL1.2; LL1.1, type material) in the Mynkree section B, and here is the type of this assemblage. Further, this assemblage exists in the lower Lakadong Limestone from samples 86/LKd/DR1 to 86/LKd/DR4 in the Um Sohryngkew River Section, East Khasi Hills, Meghalaya (Matsumaru and Jauhri 2003; Text-fig. 2). This assemblage can be correlated with the upper Ranikot Beds of Sind succession after Vredenburg (1909), and Dhak Pass Beds of the basal Ranikot Stage of Punjab Salt Range after Gee (1944), based on the occurrence of *Miscellanea miscella.* In addition, the Assemblage 1 may be at least correlatable with "Shallow benthic zones" (SBZ) 3 to 4 by Serra-Kiel et al. (1998) from the common range of *Idalina sinjarica, Miscellanea primitiva,* and *Miscellanea miscella,* and with the fauna of the Thanesian Limestone of Dolenja Vas, NW Dinarides (Drobne et al. 1988) due to the common occurrence of *Idalina sinjarica* and *Kathina selveri*. Further, the present Assemblage 1 in the Lakadong Limestone can partial be correlated with the basal LFA (larger foraminiferal assemblage) 1 (*Miscellanea miscella* and *Ranikothalia nuttalli*) in Indian Bassin as Tertiary a1 lower (upper Paleocene, Thanetian) of Letter Stages by Govindan (2003).

Geological age: Late Paleocene (Thanetian), and Tertiary a1 lower (Thanetian) of Letter Stages.

2. *Aberisphaera gambanica – Daviesina khatiyahi – Lockhartia haimei – Miscellanea miscella – Ranikothalia nuttalli* Assemblage 2.

This assemblage is defined by the biostratigraphic occurrence of the above five species. The common species is *Idalina sinjarica, Kathina selveri, Lockhartia conditi, L. diversa, Orbitoclypeus ramaraoi, Orbitosiphon tibetica, Pseudochrysalidina* spp., *Pseudolituonella* spp., *Raoia indica,* n. gen., n. sp., *Rotalia trochidiformis,* and *Smoutina cruysi.* This assemblage can be seen the upper Lakadong Limestone in Mynkree Section A (samples Myn/Lkd/101 to Myn/Lkd/109; Myn/Lkd/101, type material), as the type of faunal assemblage 2, Mynkree section B (samples LL1.3 to LL1.8), and Nongtalang section (samples Nong/LKd/B-01 to Nong/LKd/B-05). The Lakadong Limestone carrying Assemblage 2 is correlated with the upper Lakadong Limestone from samples 86/LKd/DR5 to 86/LKd/DR10 in the Um Sohryngkew River Section, East Khasi Hills (Matsumaru and Jauhri 2003) based on the occurrences of *Aberisphaera gambanica, Lockhartia haimei*, *Miscellanea miscella,* and *Ranikothalia nuttalli.* This limestone is correlated with the upper Ranikot Stage of Sind area (Vredenburg 1909) and Khairabad Limestone of Punjab Salt Range (Gee 1944). In addition, it is correlated with the basal part of the Zongpu Group or the Zhepure Shale Formation (Member IV), Zongpu Group in Kampa Area, Tibet (Shixuan 1987; Willems and Zhang 1993), which yields *Sphaerogypsina globulus* (=*Aberisphaera gambanica* by Wan 1991), *Miscella-*



TEXT-FIGURE 3
Distribution chart of larger foraminifera from the Lakadong, Umlatdoh, Prang Limestones and limestone beds of the Kopili Formation in Jaintia Hills, Meghalaya, NE India.

nea miscella, Lockhartia haimei, and *Operculina canalifera.* The last species is here regarded as *Ranikothalia nuttalli,* because of their base data by Ho et al. (1976, p. 62, pl. 22, figs. 15-16). The present assemblage can partial be correlated to the LFA 1 as Tertiary a1 (Thanetian) (Govindan 2003). The assemblage may be correlated to SBZ 5 and 6 due to the occurrences of *Ranikothalia nuttalli,* and *Idalina sinjarica.* However, the range of *Ranikothalia bermudezi* of the Caribbean species and *R. sindensis* of the Tethys species can be seen in the stratigraphic distribution chart of SBZ 3 to 5(?).

Geological age: Late Paleocene (Thanetian), and Tertiary a1 upper (upper Paleocene, Thanetian) of Letter Stages.

3. Two assemblages from the lower to upper Umlatdoh Limestone may be regarded as following.

3-1. *Alveolina oblonga – A. schwageri – Assilina laxispira – A. placentula* Assemblage (Assemblage 3-1).

This assemblage is defined by the stratigraphic occurrence of above four species, and can be seen in the lower part of the Umlatdoh Limestone in Nongkhlieh ridge section A (samples L251 to L241; L252, type material), as the type of this assemblage, Nongkhlieh section B (samples L2C41 to L2C62), and spot samples UL4.1 and UL6.1. This assemblage also contains *Nummulites globulus, N. atacicus, N. burdigalensis, Alveolina globosa,* and/or *Orbitolites complanatus.* The Umlatdoh Limestone carrying this assemblage can be correlated with the Laki Limestone of Laki Stage of Sind area by Nagappa (1959), which includes *Nummulites atacicus.* The underlying Meting Limestone of Laki Stage yields *Nummulites atacicus, N. mamilla* (=*N. globulus*), *Assilina granulosa, A. leymeriei, Flosculina globosa* (=*Alveolina globosa*), *A. subpyrenaica, A. oblonga,* and *Orbitolites complanata* by Nuttall (1925) and/or Nagappa (1959). Then the Umlatdoh limestone carrying Assemblage 3-1 can also be correlated with the Meting Limestone. Generally, the Assemblage 3-1 in the Umlatdoh Limestone can be correlated to the assemblage of Laki Stage by Nagappa (1959) or partly correrated with Govindan's LFA 2 (*Nummulites atacicus-N. globulus*) and LFA 3 (*Nummulites burdigalensis-Assilina major*) in Indian Basins as equivalent to Tertiary a2. The Assemblage 3-1 can partial be correlated with SBZ 7 to 11 based on the composite ranges of *Alveolina globosa, Nummulites atacicus, N. burdigalensis, N. globulus, A.oblonga, A. schwageri, Assilina laxispira, and A. placentula,* except for .the range of *Orbitolites complanatus* of SBZ 12(?) to

16(?). The last species can be found from the sample UL6.1 (Text-fig. 3). According to the range of *Nummulites atacicus* and *N. globulus* (s.l.) by Serra-Kiel et al. (1998), they are limited into SBZ 8 and/or SBZ 8 to 9, which is correlatable to plankton foraminiferal zone of P6b zone. However, considering the biostratigraphy from other areas, both *Nummulites atacicus* and *N. globulus* occur within P4-6? to P8 zones in the Eocene of Corbieres Septentrionales (Aude) by Massieux (1973). Further both species occur from Ilerdian to Biarritzian (Bartonian?) in the Flysh (Paleogene deposits) of Moldova Basin by Ionesi (1971), although *Nummulites burdigalensis* occur from Ilerdian to Cuisian. According to Bieda (1963), *Nummulites atacicus* occur from Ypresian to lower Bartonian of the Tatra Eocene, while *Orbitolites complanatus* occur from Ypresian to Lutetian of the Tatra Eocene. Apart from this problem, the lower Umlatdoh Limestone carrying Assemblage 3-1 can be correlated with the Eocene (Cuisian) upper Zhepure Shale Formation (Member V), Tibet (Willems and Zhang 1993), which yields *Alveolina, Nummulites,* and *Orbitolites*. In addition, the Assemblage 3-1 in the Umlatdoh Limestone can partial be correlated to Govindan's LFA 2-3 in Indian Basins as Tertiary a2 (Ypresian)

Geological age: Early Eocene (Ypresian), and Tertiary a2 (Ypresian) of Letter Stage.

3-2. *Nummulites atacicus – N. globulus* Assemblage (Assemblage 3-2).

This assemblage is defined by the stratigraphic occurrence of above two species. It can be seen in the upper Umlatdoh Limestone (samples L234 to L236; L234, type material) in Nongkhlieh ridge section A, and this section is the type of the assemblage. The associated taxa are poor, but it contains *Assilina laxispira* in sample L234, and *Discocyclina* spp. in sample L235. This faunal assemblage can be correlated with the fauna of Laki Stage in Punjab Salt Range (Gee 1944; Nagappa 1959). They can be correlatable to SBZ 8 to 11 based on the total range of *Nummulites atacicus, N. globulus* and *Assilina laxispira* (Serra-Kiel et al. 1998). Both assemblages (3-1 and 3-2) can be correlatable with Govindan's lower Eocene (Ypresian) LFA 2 and 3 as Tertiary a2 (Ypresian), due to the occurrence of *Assilina laxispira, Nummulites atacicus, N. globulus,* and *N. burdigalensis.*

Geological age: These assemblages suggest early Eocene (Ypresian), and Tertiary a2 (Ypresian) of Letter Stages.

4.Two assemblages exist in the lower and middle parts of the Prang Limestone.

4-1. *Alveolina elliptica nuttalli – Nummulites beaumonti – N. gizehensis – N. perforatus – Orbitolites complanatus* Assemblage (Assemblage 4-1).

This assemblage is defined by the stratigraphic occurrence of above five diagnostic species, and in the lower Prang Limestone in Nongkhlieh ridge section C (samples Nongkh/PL3.1 to Nongkh/PL3.3), NH-44 section 1 (samples 129/PL/6-3 and 129/PL/6-4), NH-44 section 2 (samples NH-44/PL/B4-2, type material, and NH-44/PL/T4-1), as the type of the assemblage, NH-44 section 3 (samples 130/PL/B3-2 and 130/PL/T3-1) and NH-44 section 4 (samples NH-44/PL-11 to NH-44/PL-10). This assemblage 4-1 contains *Discocyclina dispansa*. Further, *Nummulites globulus* and *N. atacicus* exist until this assemblage, due to rather abundant occurrences and few damegad tests. The following diagnostic species can be seen, i.e. sample NH-44/PL-11 occurs *Nummulites ptukhiani,* and both samples NH-44/PL/B4-2 and 130/PL/B3-2 occur *Nummulites millecaput.* This assemblage 4-1 is correlated with the fauna of the Khirthar Stage of Sind (Vredenburg 1909) based on the occurrence of *Nummulites gizehensis, N. perforatus, N. obtusus,* which is very similar to *N. perforatus,* and *Discocyclina dispansa.* This assemblage can partial be correlated with SBZ 12 (?) to 17, based on the total range of above five diagnostic species (Serra-Kiel et al. 1998). Further this assemblage can partial be correlated with Middle Eocene (Lutetian to Bartonian) LFA 4 to 6, based on the occurrence of *Alveolina elliptica, Nummulites obtusus,* and *N. perforatus* (Govindan 2003).

Geological age: Middle Eocene (Lutetian), and Tertiary a2 upper (Lutetian?) of Letter Stages.

4-2. *Nummulites acutus - N. beaumonti – N. gizehensis – N. millecaput – N. perforatus* Assemblage (Assemblage 4-2).

This assemblage is defined by the stratigraphic occurrence of above five species. *Discocyclina* spp. can be seen in the assemblage. This assemblage is recognized in the middle Prang Limestone in Nongkhlieh ridge section C (samples Nongkh/PL3.4 to PL3.8a; Nongkh/PL3.5, type material), as the type of the assemblage, and NH-44 section 4 (samples PL9 to PL7). This assemblage 4-2 can be correlated to the fauna of Khirthar Stage of Sind (Vredenburg 1909) by the occurrence of *Nummulites gizehensis* and *N. perforatus*. They can partial be correlated with Govindan's LFA 4 to 6, due to the occurrence of *Nummulites perforatus, N. acutus,* and *N. beaumonti.* This assemblage can be correlated with SBZ 15-17, based on the total range of above five diagnostic species (Serra-Kiel et al. 1998). The Assemblages 4-2 can be correlatable with *Nummulites aturicus – N. gizehensis – N. millecaput* Assemblage, Assemblage I, and *Nummulites pengaronensis – N. perforatus – Alveolina elliptica* Assemblage, Assemblage II of Tertiary a3 (Lutetian to Bartonian) of Haha-Jima, Ogasawara Islands (Matsumaru 1996), due to the common occurrence of species. The Yusan Formation, carrying Tertiary a3 (Ta3) in Haha-Jima, Ogasawara Islands, yields *Nummulites aturicus, N. gizehensis, N. millecaput, N. pengaronensis, N. perforatus,* and *Nummulites* sp. (which can be seen as *Nummulites acutus* Sowerby from pl. 27, fig. 4; Text-fig. 5 of p. 8) by Matsumaru (1996). The Assemblage I in Haha-Jima is confirmed from the Yusan Formation between the contemporary basalt of radiometric age of 42.5 Ma (Kaneoka et al. 1970) and the Okimura Formation, carrying the Assemblage II and P13 planktonic foraminiferal zone, which yields the type species of *Orbulinoides* (= *Porticulisphaera*) *beckmanni* Saito (1962). The spira-daigram of *Nummulites acutus* in the present Assemblage 4-2 (Plate 4, figure 8) is similar to that of *N. acutus* (Saraswati et al. 2000). The Assemblage 4-2 can partial be correlated with SBZ 15-17, based on the total range of above *Nummulites* species. Further both present Assemblages 4-1 and 4-2 can be correlated with Govindan's middle Eocene (Lutetian and Bartonian) LFA 4 to 6, due to the occurrence of *Alveolina elliptica, Nummulites perforatus, N. acutus,* and *N. beaumonti.*

Geological age: Middle Eocene (Lutetian to Bartonian), and Tertiary a3 (Lutetian to Bartonian) of Letter Stages.

Time (Ma) ICS,2004	Time (Ma) Berggren et al., 1995	Stage	Plankton. Foram. Zones (Berggren et al., 1995)	Larger Foraminiferal Zones: Shallow Benthic Zones (Serra-Kiel et al.,1998)	Jaintia Hills, Meghalaya, India (this study)	Indian Basins (Govindan, 2003)	Haha Jima, Japan (Matsumaru, 1996)	Letter Stages
		Priabonian	P17	SBZ 20	Assemblage 6	LFA 7		
37.2	Ca.37		P15	SBZ 18	Assemblage 5		Assemblage III	Tb
		Bartonian	P14	SBZ 17	Assemblage 4	LFA 4-6	Assemblage II	
					(4-2)		Assemblage I	Ta3
40.4	Ca.41.5	Lutetian		(SBZ 15)				
			P10					
48.6	Ca.49	Ypresian	P9	SBZ 12	(4-1)			
				SBZ 11	Assemblage 3	LFA 2-3		Ta2
				(SBZ 9)	(3-2)			
			P6	SBZ 7	(3-1)			
55.8	Ca.55	Thanetian		SBZ 6	Assemblage 2	LFA 1		Ta1
			P5	SBZ 5				
			P4	SBZ 4	Assemblage 1			
58.7	Ca.58	Selandian		SBZ 3				

TEXT-FIGURE 4
Correlation chart between the larger foraminiferal assemblages of Jaintia Hills, Meghalaya, NE India, and the Paleocene-Eocene Time scale (official website of ICS, 2004 under www.stratigraphy.org and Berggren et al. 1995) of planktonic zones (Berggren et al. 1995) and larger foraminiferal zones such as Shallow Benthic Zones (Serra-Kiel et al. 1998), Indian Bassins assemblages (Govindan 2003), Haha-Jima assemblages, Japan (Matsumaru 1996) and Letter Stages (Matsumaru 1996; Govindan 2003).

5. *Nummulites perforatus – Operculina subformai – Pellatispira madaraszi – P. orbitoidea* Assemblage (Assemblage 5)

This assemblage is defined by the stratigraphic occurrence of above four species. This assemblage contains *Discocyclina dispansa,* and can be seen in the upper Prang Limestone in Nongkhlieh ridge section A (samples L2C33 to L2C39), Nongkhlieh ridge section C (sample PL3.8b), NH-443 section 4 (samples PL-6 to PL-1; NH-44/PL-2, type material), as the type of the present assemblage, and spot sample 131/PL/St.2. This assemblage is correlated to the fauna of the upper Prang Stage and Kopili Stage of Central Assam after Wilson and Metre (1953) or upper Khirthar Stage of Nagappa (1959), due to the occurrence of *Discocyclina dispansa* and *Pellatispira.* The Assemblage 5 can be correlated with SBZ 18 to 20 due to the range of *Pellatispira madaraszi* (Serra-Kiel et al. 1998). The present assemblage can be correlated with *Biplanispira absurda – Pellatispira provalei* Assemblage (Assemblage III) from the Tertiary b Sekimon Limestone, Haha-Jima, Ogasawa Islands, Japan (Matsumaru 1996), due to the occurrence of *Pellatispira orbitoidea, Nummulites perforatus,* and *Operculina subformai.* The present assemblage can partial be correlated with upper Eocene (Tertiary b) LFA 7, due to the occurrence of *Pellatispira madaraszi* and *Discocyclina dispansa* (Govindan 2003).

Geological age: Late Eocene (Priabonian), and Tertiary b lower (Bartonian) of Letter Stages.

6. *Nummulites incrassatus – N. striatus – Pellatispira orbitoidea* Assemblage (Assemblage 6).

This assemblage is defined by the startigraphic occurrence of above dominant three species, and is associated with *Discocyclina augustae, D. dispansa, D. javana,* and *Lepidocyclina* spp. from a limestone bed of the Kopili Formation in Nongkhlieh ridge section C (sample KL3.1), as the type of the present assemblage. *Lepidocyclina* spp. (Plate 3, figure 11) from the upper Eocene Kopili Formation is especially important. This species have multiple nucleoconch; large, attaining 1.12mm in breadth and 0.63mm in height; discoidal and rather irregular in outline; multilocular comprising about 6 chambers, and subequal in size, 0.322, 0.323, and 0.416mm and others; wall of the nucleoconch, thin and about 0.2 to 0.4mm thick; equatorial chambers, spatulate, 72 micron tangential diameter and 88 micron radial diameter; lateral chambers, subreniform to subrectangular in axial section, more or less spaceous, and 72 to 82 micron broad and 16 to 21 micron high; number of lateral chambers per tier over the nucleoconch, 6 to 7 layers; thickness of roofs and floors, 8 to 12 microns; chamber walls perforated by stolons. This species seem to be similar to *Lepidocyclina pustulosa* H. Douvulle (s. l.) or *Lepiudocyclina* (*Neolepidina*) *pustulosa* (H. Douville 1917) by Brönnimann (1946) known widely in the Caribbean region. Further a limestone (samples KL1-2 and KL1-3) of the Kopili Formation yields *Nummulites fabianii, N. incrassatus, N. striatus, Pellatispira madaraszi,* and *P. orbitoidea,* but not *Lepidocyclina* spp. The present assemblage (Assemblage 6) is correlated to *Biplanispira absurda – Pellatispira provalei* Assemblage (Assemblage III) from the Sekimon Limestone, Haha-Jima, Ogasawara Islands (Matsumaru 1996), due to the occurrence of *Pellatispira orbitoidea*. Both assemblages 5 and 6 can be correlatable with Govindan's upper Eocene (Priabonian) LFA 7, due to the occurrence of *Nummulites striatus* and *Pellatispira madaraszi.* Both assemblages can be correlated with SBZ 18 to 20 due to the total range of *Nummulites incrassatus* and *N. striatus* (Serra-Kiel et al. 1998).

Geological age: Late Eocene (Priabonian), and Tertiary b upper (Priabonian) of Letter Stages.

SYSTEMATIC DESCRIPTION

The present study was carried out by studying random thin sections of limestone samples, supplemented by a few oriented sections that were especially made to be able to study the embryonic configuration of diagnostic species. Most specimens in thin sections were ill preserved and fragmented by tectonic effect and weathering, after deposition of specimens. Special attention is given to *Lakadongia indica* Matsumaru and Jauhri 2003 in order to review the only Paleocene orbitoidal foraminifera from the Tethys region. Thereafter three new species, *Meghalayana indica, Protogypsina indica,* and *Raoia indica* discovered from the Paleogene of Jaintia Hills, Meghalaya are described, although enough specimens couldn't be collected for the present study. They are the type species of new genera.

Family ORBITOSIPHONIDAE Matsumaru and Jauhri 2003 supplement

This family comprises Paleocene orbitoidal foraminifera with both symmetrical test, composed of well developed lateral chambers arranged in regular tiers over equatorial layer, and asymmetrical test, composed of well developed lateral chambers in regular tiers in concave side over equatorial layer, and low to slit-like lateral chambers among stout pillars on convex side over equatorial layer; biloculine embryonic apparatus, followed by one or two principal auxiliary chamber(s), other nepionic arcuate chambers and symmetrical chamber(s), all of the chambers being planispiral or sometimes low trochospiral in early stage; after then the neanic stage, consisting of ogival or rhombic shaped equatorial chambers, arranged in intersecting curves to polygonal in shaped chambers, arranged in rough circles towards the periphery, or open arcuate, ogival, polygonal to spatulate shaped equatorial chambers, tending to be arranged in inconsistent radial rows or rough annular rows, and sometimes crude equatorial chambers between main equatorial chambers in the same row or successive rows, developed; stolons and canals present.

Genus ***Orbitosiphon*** Rao 1940 emend
Type species: Lepidocyclina (*Polylepidina*) *punjabensis* Davies 1937, which is a junior synonym of *Lepidorbitoides tibetica* H. Douville 1916.

Generic description: Test, symmetric to asymmetric; embryonic apparatus, biloculine of protoconch and deuteroconch; followed by one or two primary auxiliary chamber(s), two or four initial spires, and sometimes multiple spires like *Nephrolepidina* (Family Lepidocyclinidae) (Davies 1937, pl. 7, figure 8?; Plate 1, figure 3); arcuate, ogival or rhombic, polygonal to spatulate equatorial chambers, arranged in intersecting curves through inconsistent radial rows to annular rows, and well-developed layers of tired lateral chambers over equatorial layer (Davies 1937, pl. 7, figs. 5, 16; Plate 1, figures 7 right, 8) and/or well- developed layers of tired lateral chambers over equatorial layer on concave side of test, and the presence of tired lateral chambers among thickened lateral walls and/or vacuoles among stout pillars over equatorial layer on the other convex side of test (Davies 1937, pl. 7, fig. 6; Plate 1, figure 7 left); stolons and canals are present.

Orbitosiphon tibetica (Douville 1916)
Plate 1, figures 1–8

Lepidorbitoides tibetica DOUVILLE 1916, p. 34–35, pl. 14, figs. 1–4.
Lepidorbitoides polygonalis DOUVILLE 1916, p. 35, pl. 14, figs. 5–6; pl. 15, figs. 1–3.
Lepidocyclina (Polylepidina) punjabensis DAVIES 1937, p. 53–55, pl. 7, figs. 1–8, 14, 16, text–fig. 3.
Orbitocyclina punjabensis (Davies). – TAN SIN HOK 1939, pl. 71–72, 75–78, 80, pl. 2, figs. 1–3. – BRONNIMANN 1944, p. 15, 18, 20, 38–40. – Hanzawa 1965, p. 248, pl. 35, fig. 4b.
Orbitosiphon punjabensis (Davies). – RAO 1940a, p. 414–415, fig. 1. – Adams 1987, p. 310. – FERRANDEZ–CANADELL 2002, p. 5–7, pl. 1, figs. 1–26, text–figs. 3–4.
Lepidocyclina (Polylepidina) birmanica RAO 1942, p. 6–8, pl. 1, figs. 1, 4–6; pl. 2, figs. 3, 7.
Orbitosiphon tibetica (Douville). – RAO 1944, p. 95–99, pl. 1, figs. 2–3, text–figs. 1–3.– WAN 1991, p. 20, pl. 3, figs. 15–16. – MATSUMARU and JAUHRI 2003, p. 278, 280, pl. 2, figs. 4, 7; pl. 4, figs. 1–6.
Discocyclina (Discocyclina) polygonalis (Douville). – RAO 1944, p. 99–100, pl. 1, figs. 1, 4, text–figs. 4, 5.
Actinosiphon tibetica (Douville). – SMOUT and HAQUE 1956, p. 52, pl. 11, fig. 6. – HO et al., 1976, p. 67, pl. 11, figs. 7–12. – MATSUMARU 1991, p. 894, 896, figs. 12–2a–c – 3a–b.
Bolkarina aksarayi SIREL 1981, p. 80–82, pl. 1, figs. 1–3; pl. 2, figs. 1–4; pl. 3, figs. 1–6.
Orbitosiphon praepunjabensis ADAMS 1987, p. 310–311, pl. 4, figs. 7–12.
Bolkarina sp. – Ogorelec and Drobne, in DROBNE et al. 1988, p. 154–162, pl. 25, figs. 1–2.
Setia tibetica (Douville). – Ferrandez-Canadell 2002, p. 9–11, pl. 2, figs. 1–29; pl. 3, figs. 1–11; text–figs. 3–4.
Setia primitiva Ferrandez-Canadell 2002, pl. 11–13, pl. 4, figs. 1–14.
Lakadongia indica Matsumaru and Jauhri 2003, p. 281–282, pl. 1, figs. 1–7; pl. 2, figs. 1–3, 5–6; pl. 3, figs. 1–5; text-fig. 4.

Description: The microspheric test is flat lenticular to discoidal in shape, and sometimes undulated concavo-convex test, with a form ratio of diameter (with maximum half diameter about 9mm) to thickness (up to 0.8mm) up to about 23. The surface of test is ornamented with slender to thin pillars, and regular outline polygonal shaped lateral chambers, which are seen as low and spaceous and are arranged in regular tiers over both sides of equatorial layer in axial section. The entire picture is the same to that of a microspheric specimen of *Lepidorbitoides tibetica* Douvillè 1916, pl. 14, figs. 1 left, 2, 4; *Actinosiphon tibetica* (Douvillè) (Matsumaru 1991, fig. 12-2a); and *Lepidocyclina* (*Polylepidina*) *punjabensis* Davies 1937, pl. 7, figs. 1–2, 5, 7, 14, 16; (Plate 1, figures 7 right, 8). The same form can be seen in *Lepidocyclina* (*Polylepidina*) *birmanica* Rao, 1942, pl. 2, figs. 3, 7; *Bolkarina aksarayi* Sirel, 1981, pl. 2, figs. 1–4; pl. 3, figs. 1, 6; *Orbitosiphon punjabensis* (Davies) (Ferrandez-Canadell 2002, pl. 1, figs. 1–6, 12–17); and *Lakadongia indica* Matsumaru and Jauhri 2003, pl. 1, figs. 1, 3–6; pl. 2, fig. 6; pl. 4, fig. 5. Some bilaterally asymmetric microspheric test is covered with coarse and porous pillars, and irregular outline or vermiform shaped lateral chambers in convex side of test in tangential and oblique sections, which are seen as low and slit-like space or often vacuole cavity and are roughly arranged in tiers or among stout pillars over equatorial layer. The concave side of test is ornamented with slender pillars and/or often stout pillars, and outline polygonal shaped lateral chambers arranged regularly in vertical tiers in oblique and axial sections. The entire picture is the same to that of a microspheric specimen of *Lepidorbitoides polygonalis* Douvillè 1916, pl. 14, figs. 5–6; pl. 15, figs. 1–3; *Lepidocyclina* (*Polylepidina*) *punjabensis* Davies 1937, pl. 7, figs. 3–4, 6, 8; *Discocyclina* (*Discocyclina*) *polygonalis* (Douvillè) (Rao 1944, pl. 1, figs. 2, 4); *Bolkarina aksarai* Sirel 1981, pl. 3, figs. 4–5; *Orbitosiphon praepunjabensis* Adams 1987, pl. 4, figs. 11–12; *Setia tibetica* (Douvillè) (Ferrandez-Canadell 2002, pl. 2, figs. 1–21; pl. 3, figs. 1–3), and *Lakadongia indica* Matsumaru and Jauhri 2003, pl. 1, figs. 2; pl. 2, figs. 1–5, 7; pl. 4, fig. 6; text-fig. 4 upper two; (Plate 1, figure 7 left). The initial chambers are spirally arranged; and equatorial chambers are large, initially arcuate, becoming ogival or rhombic, elongated rectangular or polygonal, sometimes spatulate, and are arranged in successive cycles. In some specimens, crude equatorial chambers are seen in equatorial layer doubles formed by interlocking of the extremities of layers of lateral chambers in axial, tangential and oblique sections (Plate 1, figure 8). This picture can be seen to a microspheric specimen of *Bolkarina* sp. from the Dolenja Vas Section (Dv 5/6964 and Dv 5/4647) (Drobne et al. 1988, pl. 25, figs. 1–2). Equatorial chambers are communicated adjacent chambers by basal, annular, diagonal and radial stolons in equatorial and axial sections or cannals in oblique and axial sections. Lateral chambers of symmetrical test, high and spaceous; of dimension, 58 x 12, 60 x 12, 70 x 16, 78 x 18 and 110 x 20 micron in inner length and height, arranged in regular tiers over central equatorial zone; thickness of finely perforated roofs and floors, 6 to 12 micron; and number of lateral chambers per tier over the same zone, 8 to 12 layers. Lateral chambers in convex side of asymmetrical test, low and slit-like or vacuole cavity; of dimension, 38 x 6, 40 x 6, 50 x 8 and 60 x 16 micron in inner length and height, arranged in tiers or among stout pillars (90 to 100 micron in thickness); lateral chambers in concave side, similar to all aspects and size in symmetrical test. There are obvious transitional tests between symmetrical and asymmetrical tests (Matsumaru and Jauhri 2003, pl. 1, figs.1-6).

The megalospherioc test is lenticular to discoidal, more or less concavo-convex with a diameter of 2.3 to 3.0mm, and a form ratio of diameter to thickness of up to 4.0 to 7.5. The embryonic apparatus consists of two chambers, a subspherical protoconch, measuring 56 x 52, 60 x 52, 88 x 48, 112 x 96 and 120 x 100 microns in 5 specimens and a reniform deuteroconch, 92 x 64, 66 x 44, 56 x 40, 112 x 68 and 128 x 92 microns, respectively. Protoconch varies from much larger than deuteroconch (*Actinosiphon* – type; *Orbitosiphon tibetica* (Douvillè). Rao 1944, text-fig. 2; *Actinosiphon tibetica* (Douvillè). Smout and Haque 1956, pl. 11, fig. 6? ; Ho Yen et al. 1976, pl. 11, fig. 8; *Lakadongia indica* Matsumaru and Jauhri 2003, pl. 3, fig. 2; Plate 1, figure 2) through equal sized (*Lepidocyclina* (*Polylepidina*) – type; *Lepidocyclina* (*Polylepidina*) *punjabensis* Davies 1937, fig. 3; pl. 7, figs. 7, 14; *Orbitosiphon tibetica* (Douvillè). Rao 1944, text-fig. 3; *O. punjabensis* (Davies). Ferrandez-Canadell 2002, pl. 1, figs. 7–9, 18–20, 24–26; *Setia primitiva* Ferrandez-Canadell 2002, pl. 4, figs. 2, 5–6, 7–11, 13–14; *Lakadongia indica* Matsumaru and Jauhri 2003, pl. 4, figs, 2, 4; Plate 1, figures. 4–5) to smaller than deuteoconch (*Nephrolepidina* – type; *Lepidocyclina* (*Polylepidina*) *punjabensis* Davies 1937, pl. 7, fig. 8; *Orbitosiphon tibetica.* Rao, 1944, text-fig. 1; *Orbitosiphon praepunjabensis* Adams, 1987, pl. 4, figs. 7–10; *Actinosiphon tibetica.* Matsumaru 1991, figs. 2b–c, 3; *Setia tibetica.* Ferrandez-Canadell 2002, pl. 2, figs. 22–29; *Lakadongia indica.* Matsumaru and Jauhri 2003, pl. 3, figs. 1, 3–5; pl. 4, fig. 1; Plate 1, figures. 1, 3). The bilamellar embryonic wall measures

8 to 16 microns thick. In biserial megalospheric specimens, the third principal auxiliary chamber, PAC, having a tubelike aperture with deuteroconch is formed in the early nepionic planispiral or sometimes low trochospiral and is followed by usually 6 or 8 asymmetric imbricate chambers or open arcuate chambers extending along the protoconch on one side and along deuteroconch on the opposite side (Plate 1, figures. 4–5). These biserial nepionic chambers meet at a symmetric closing chamber. The total number of nepionic chambers is usually 8 to 10. In quadriserial megalospheric specimens, there are two PAC, usually smaller than the protoconch and deuteroconch (Plate 1, figures 1, 3) or sometimes larger than the embryonic apparatus (Plate 1, figure 2). The embryonic apparatus and 2PAC together are arranged so as to form a cross and quadriserial nepionic stage (Plate 1, figures 1–2) or rarely multiserial nepionic stage (Plate 1, figure 3). The nepionic chambers connected with both adjacent nepionic and main equatorial chambers by stolons. The neanic stage in biserial megalospheric specimens consists of rhombic or ogival to polygonal shaped equatorial chambers, arranged in intersecting curves to rough circles towards the periphery, which have 4 and advanced 6 stolon-system with basal and radial or diagonal stolons, and canals in chamber walls, where the walls are more than 4 microns thick. The neanic stage in quadriserial megalospheric specimens consists of open arcuate, ogival, polygonal, short hexagonal to spatulate chambers, tending to be arranged in inconsistent radial rows and/or rough annular rows, and connected with basal, radial, diagonal, and annular stolons or canals (Plate 1, figures 1–3, 5–6). In some specimens, there are crude equatorial chambers or cavities between mature equatorial chambers in the same row in successive cycle. The intraseptal canals can be seen in the main equatorial chamber walls gained thickness more than 4 microns (Plate 1, figures 1–3, 5–6). Lateral chambers of symmetrical test, low rectangular in axial section; of dimension 20 x 6, 28 x 8, 30 x 10 and 42 x 8 micron in inner length and height, arranged in regular tiers over embryonic apparatus. Thickness of roofs and floors is 6 to 8 micron, and number of lateral chambers per tier over embryonic apparatus is 8 to 12 layers. Lateral chambers in convex side of asymmetrical test, low and slit-like or vacuole cavity; of dimension 18 x 4, 20 x 6, 26 x 6 and 30 x 8 micron in inner length and height, arranged in tiers or among stout pillars over embryonic apparatus. Thickness of roofs and floors among stout pillars (60 to 90 micron in thickness) is 8 to 20 micron, and number of lateral chambers per tier over embryonic apparatus is 3 to 5 layers.

Stratigraphic horizon: This species occurs in samples Myn/Lkd/101, 108 and 109 in Mynkree section A, sample LL1.3 in Mynkree section B, and spot samples LL2 and LL3 of the Lakadong Limestone. The others from samples, 129/PL/6-3 and 6-4, L2C31 and Nongkh/KL3-1, are regarded as reworked intraclasts from the Lakadong Limestone.

Geological age: Late Paleocene (Thanetian), and Tertiary a1 upper (Thanetian) of Letter Stages by the co-occurrence of *Miscellanea miscella, Ranikothalia nuttalli, Lockhartia haimei, Kathina selveri,* and *Idalina sinjarica* (Matsumaru and Jauhri 2003).

Remarks: Orbitosiphon tibetica (Douvullè) has been known as the only Paleocene orbitoid foraminifera, after the mass extinction of the Cretaceous – Tertiary (K-T) event (Tan Sin Hok 1939; Brönnimann 1944; Rao 1944; Van Gorsel 1978; Adams

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PLATE 1

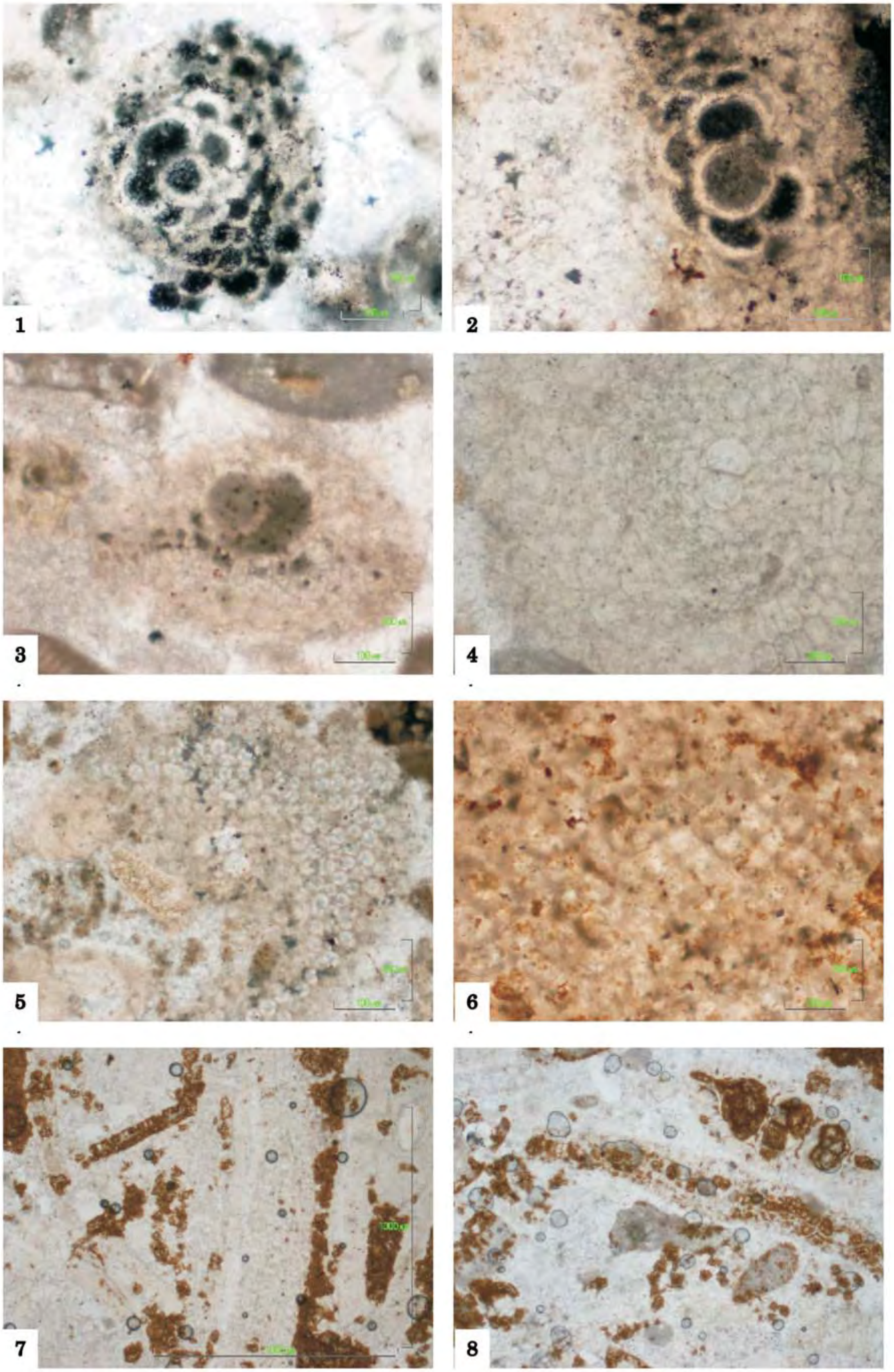
Orbitosiphon tibetica (Douville). Thanetian (Tertiary a1), Meghalaya, NE India.

1,4 Equatorial sections of megalospheric form, showing biloculine embryonic apparatus (protoconch, I, smaller than deuteroconch, II) with 1 or 2 primary auxiliary chambers (1 or 2PAC) arranged so as to form a cross for figure 1 or lepidocycline-type emryo (I = II) with 1PAC for figure 4. The equatorial chamber of arcuate, ogival and polygonal shape of figure 1 is arranged in roughly concentric rings. That of figure 4 is arranged in intersecting curves of ogival and rhombic chambers in early stage and spatulate shaped chambers in later stage, arranged in roughly concentric rings. The former is carryng basal, diagonal and radial stolons and canals in chamber walls, but the latter may be carrying stolons and canals, but we may not observe them due to thinner walls. Locality Myn/lkd/101. 1. ×115, 4. ×110. (scale bar, 100µm)

2-3,5 Centered oblique sections of megalospheric form, showing actinosiphon-type embryo (I, much larger than II) with 2PAC to form a cross for figure 2, nephrolepidine-type embryo (I, much smaller than II) with 2PAC for figure 3, and lepidocyclina-type embryo (I = II) with 1 PAC for figure 5. The equatorial chamber of figures 2 and 3 is arranged in the same as that of figure 1. That of figure 5 is arranged in intersecting curves of ogival and rhombic shaped chambers, and sometimes crude small equatorial chambers present in the same rows. Locality 2, 5. Myn/Lkd/101, 3. LL2. 2. ×115, 3, 5. ×110.(scale bar, 100µm)

6 Oblique section, showing ogival and rhombic chambers, carrying stolons and cannals and arranged in intersecting curves. Locality Myn/Lkd/101. ×110. (scale bar, 100µm)

7-8 Axial sections, showing asymmetric form with well developed lateral chambers on one side of test (figure 7 left), symmetric form with well developed lateral chambers on both sides of test (figure 7 right), and rather intermediate form of *Lakadongia indica* Matsumaru and Jauhri with duplication of equatorial chambers in equatorial layer (figure 8). Locality 7. Myn/Lkd/101, 8. Myn/Lkd/109. ×44. (scale bar, 100µm)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1987; Matsmaru 1991; Matsumaru and Jauhri 2003). Many authors have examined this species from a limited rock samples and many synomym species listed above have been described based on microspheric and/or megalospheric specimens in random thin sections. Douvillè (1916, p. 34–35) has originally described both microspheric and megalospheric generations of *Lepidorbitoides tibetica* from the *Operculina* limestone (Coll. H. Hayden) of Kampa Dzong, Tibet, which was referred to the Danian Stage. Later Davies (1937, p. 54) regarded *Lepidocyclina* (*Polylepidina*) *tibetica* to occur from the upper Ranikot (probably Thanetian). Douvillè described *Lepidorbitoides polygonalis* as a different species for large developed microspheric specimen, in stead of *L. tibetica.* Davies (1937, p. 53–55) described *Lepidocyclina* (*Polylepidina*) *punjabensis* from the Ranikot Stage, Punjab Salt Range, in stead of *L.* (*P.*) *subtibetica* with both reasons of minor morphological variation and far location from Tibet. He showed megalospheric specimens with 1 PAC (Davies 1937, pl. 7, figs. 7, 14; text-fig. 31) and obscure 2 PAC (Davies op. cit., pl. 7, fig. 8). Both forms are confirmed in *Orbitosiphon tibetica* from the Lakadong Limestone, Jaintia Hills (Plate 1, figures 4–5 and Plate 1, figures 1–3). Unfortunately Davies (1937, p. 53–55) didn't show the Douvillè's megalospheric specimen of "cross" type, quadriserial form with 2 PAC, although he has found two megalospheric types in association with the same microspheric form. However, Adams (1987, pl. 4, fig. 8) showed "cross" type form as holotype of *Orbitosiphon praepunjabensis* in the L. M. Davies collection (BM (NH) P51968). Further the senior author (1991, fig. 3a) showed the same form as *Actinosiphon tibetica* from the Davies collection (BM (NH) P34987). Rao (1940, 1944) described *Orbitosiphon tibetica* from the Khairabad Limestone, which underlies the Patala Shales in the type locality of *L.* (*P.*) *punjabensis.* Rao (1940, fig. 1; 1944, pl. 1, fig. 3, text-figs. 1–2) showed a megalospheric specimen of "cross" type with 2 PAC (A1 form) of *O. tibetica,* and a megalospheric specimen with 1 PAC (A2 form) (Rao 1944, text-fig. 3), equivalento to Davies (1937, pl. 7, figs. 7, 14; text-fig. 3). Rao's A2 form and Davies's figs.7 and 14 of Plate 7 forms have equatorial chambers arranged in both intersecting curves of rhombic or ogival shaped chambers and probably inconsistent radial rows of open arcuate to polygonal shaped chambers, which carries sometimes crude equatorial chambers in the same rows. This form can be seen *O. tibetica* from the Lakadong Limestone, Jaintia Hills (Plate 1, figures 4–5). Rao (1942) described *L.* (*P.*) *birmanica* from the upper Eocene Yaw Shales near Yeshin, Burma. However according to Cotter (1938), the lower Eocene (probably including the Paleocene) Laungshe Shales, but not Yaw Shales was exposed near Yeshin location. In addition, *L.* (*P.*) *birmanica,* which showed a megalospheric form of embryonic-nepionic stage arranged to form a "cross" type was nothing but *Orbitosiphon tibetica* of his A1 form. Rutten (1950) concluded *L. birmanica* and *L. zeijlmansi* Tan Sin Hok 1936 from the Eocene of northern central Borneo to be closely related. Some specimens of the latter (Tan Sin Hok 1936, pl. 1, figs. 3–5, 7, 9–10, 14–15) seems to be similar to *O. tibetica,* but the other (Tan Sin Hok op. cit., pl. 6, 12–13, 16) of thick lenticular test are uncertain. Recently the senior author found *O. tibetica* from the upper Paleocene Paunggi Formation at locality 93 (coll. T. Nishizuka), 250km SSE from Yeshin, Myanmar (Burma) at his disposal. This is similar to *Lakadongia indica,* illustrated by Matsumaru and Jauhri (2003, pl. 3, fig. 5). *Bolkarina aksarayi* Sirel 1981 was found from Thanetian limestone, Aksaray and other localities, central Turkey. This species is characterized by a planispiral involute coiled periembryonic chambers with arcuate or subrectangular in shape, followed by annuli of equatorial chambers with polygonal to spatulate in shape and by differentiated lateral chambers. In the senior author's topotype specimes have stolons and canals. As such this species is nothing but *Orbitosiphon tibetica,* except for the description of a megalospheric form (A form). Sirel's A form (pl. 3, figs. 2, 4–5) is similar to a microspheric form, which carrys plannispirally involute early stage, followed by equatorial chambers with polygonal or spatulate in shape and by differentiated lateral chambers. Sirel (p. 81, pl. 2, fig. 3; pl. 3, fig. 6) found the equatorial chambers of *B. aksarayi* to be arranged in irregular horizontal plane from center to periphery, which is the typical character of crude equatorial chambers in the same row in successive cycles or cavities between inflated and/or adjacent mature equatorial chambers in the same row in *Lakadongia indica. Setia tibetica* (Douville) and *S. primitiva* Ferrandez-Canadell 2002 are nothing but *Orbitosiphon tibetica,* and the former is assigned to Rao's A1 form and the latter is assigned to Rao's A2 form. *Setia primitiva* and *Orbitosiphon punjabensis* are assigned to Rao's A2 form, and the former is discriminated

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PLATE 2

1-3. *Meghalayana indica* Matsumaru and Sarma, n. gen., n. sp.

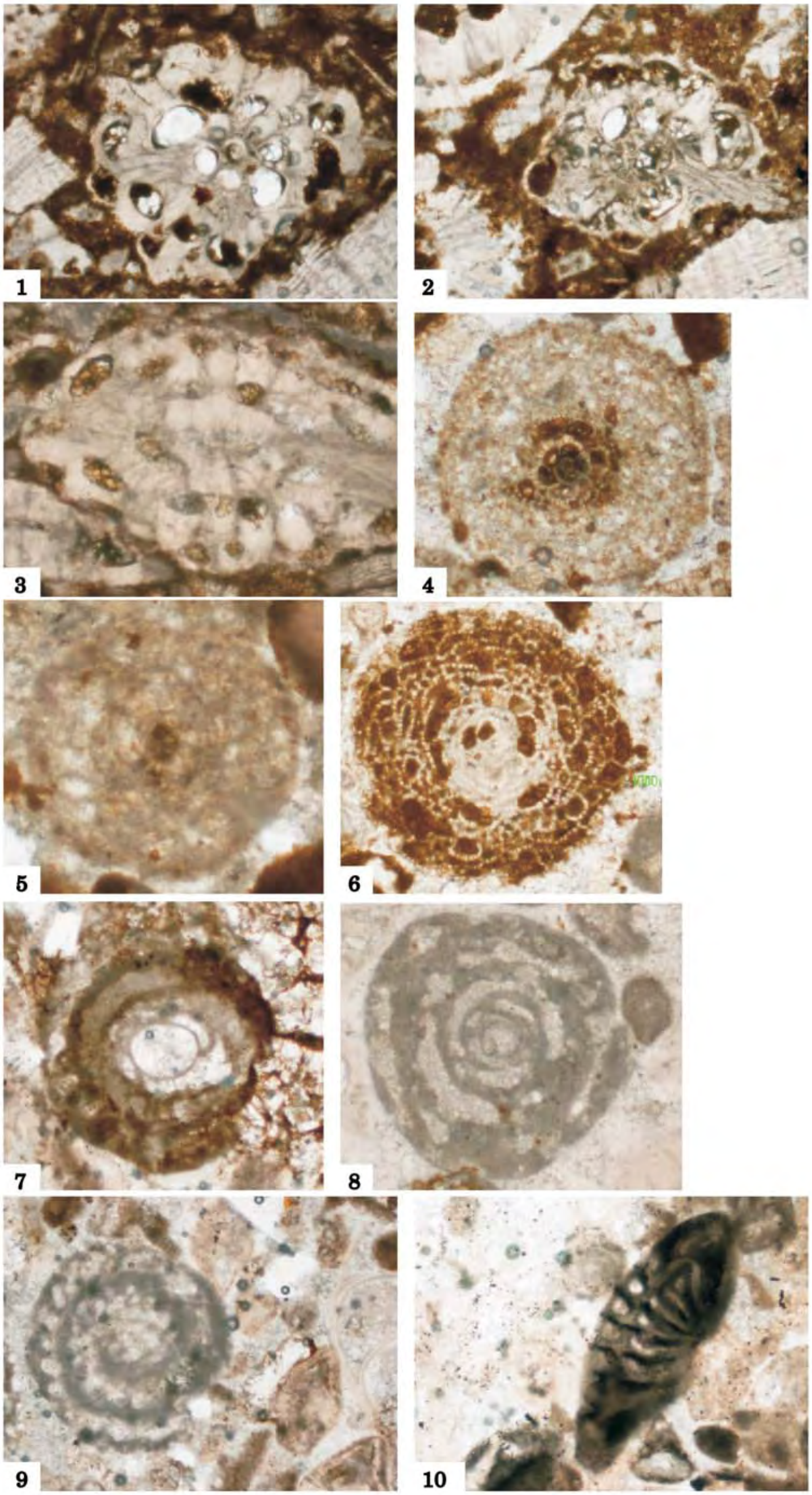
1 Equatorial section of megalospheric form, showing proloculus and nepionic chambers in raspbery-like arrangement, and spines arise from each whorls of chambers. Holotype, Saitama Univ. Coll. No. 8865. 2. Tangential section of megalospheric form. 3. Axial section of microspheric form. Locality NH-44/KL1-2. ×38.

4-6. *Protogypsina indica* Matsumaru and Sarma, n. gen., n. sp.

4 Equatorial section of megalospheric form, showing embryonic apparatus, helicostegine large chambers arranged in low trochospiral coil, later ones subdivided ventrally to form small chamberlets, and main acervuline chambers. Holotype, Saitama Univ. Coll. No. 8866. 5. Tangential section of megalospheric form. 6. Axial section of microspheric form. Locality LL3. 4. ×70, 5. ×62, 6. ×78.

7-10. *Raoia indica* Matsumaru and Sarma, n. gen., n. sp.

7 Equatorial section of megalospheric form. Holotype, Saitama Univ. Coll. No. 8867. 8-9. Tangential sections of megalospheric form. 10. Oblique section. Locality 7, 9-10. Nong/LKd/B-01. 8. Myn/LKd/103. 7. ×46, 8. ×62, 9-10. ×38.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from the latter by the presence of canals. However Davies's stout specimen of *Lepidocyclina* (*Polylepidina*) *punjabensis,* which is assigned to the same form in the present specimen (Plate 1, figure 7 right), can be seen stolons and canals. The diameter of diagonal and radial stolons and canals in the specimen is 4, 7 to 8 and 2 microns, respectively. Although Ferrandez-Canadell (2004, p. 397) regarded the canal systems to be primary importance rather than the structure and arrangements of the embryo – nepionic stages, the consideration is, however, taken it the other way round, and the embryo in foraminifera may control the morphogenesis.

The conclusion as to the very narrowly related or similar relationships of several species stated above is in accordance with *Orbitosiphon tibetica* (Douville), except for thick lenticular of *Lepidocyclina zeijlmansi*. *Orbitosiphon tibetica* has a very wide variation and seems to be diversifying into compound morphology during the late Paleocene after the K-T event.

Family CALCARINIDAE Schwager 1876

Meghalayana Matsumaru and Sarma, **n. gen.**

Name: This genus is named after the Meghalaya State, NE India, where the material for study was collected.

Type species: Meghalayana indica Matsumaru and Sarma, n. gen., n. sp.

Diagnosis: Test, ovoidal to ellipsoidal form; early megalospheric generation, thick walled globular proloculus and four or more thin and thick walled chambers in raspbery-like arrangement, and microspheric generation, small globular proloculus followed by low trochospiral and involute coil, later both generation followed by arcuate shaped acervuline chambers; eight to nine long and short coarse spines arise from the early to late whorls of chambers in some planes in coils; canal system consists of distinct canals in the umbilical side of test that connect to the longitudinal and ramifying spine canals; wall calcareous, thickly lamellar, perforate, surface ornamented solid pustules and lamellar covering the test.

Remarks: This genus resembles *Siderolites* Lamarck 1801 in general shape, but is different from the latter in having the raspberry-like arrangement in early stage in megalospheric generation. *Meghalayana* resembles *Silvestriella* Hanzawa 1952 in having raspberry type embryonic-nepionic stages, but is different from the latter of tetrahedral form throughout in having ovoidal to ellipsoidal test, and lateral chambers irregularly arranged. The microspheric form of *Silvestriella* is not known until present. As such the authors will call it the *Meghalayana*: megalospheric form is possessing the raspberry-like megalospheric apparatus and nepionic stages of a reduced spirals as Küpper (1954) has indicated, and microspheric form is possessing low trochospirals and tightly coiled whorls; both forms having irregularly arranged lateral chambers.

Meghalayana indica Matsumaru and Sarma, **n. gen., n. sp.**
Plate 2, figures 1–3.

Material and type specimen: Specimens of limestone rock sample NH-44/KL1-2 in the Kopili Formation exposed along National Highway No. 44 between Lumsnong and Sonapur (Fig. 1–12). Holotype, a megalospheric specimen in equatorial section of thin section KL1-2-2, Saitama University Coll. no. 8865 (Plate 2, figure 1).

Description: Test large, ovoidal to ellipsoidal; 0.94 to 2.40mm in diameter, and 0.60 to 1.28mm in thickness; form ratio of diameter to thickness, 1.53 to 1.63; megalospheric generation, spherical proloculus, measuring internal diameter 83 x 83 micron, and microspheric generation, globular proloculus, measuring internal diameter 30 x 30 micron; wall of proloculus 16 and 3 micron thick in both generation, respectively; following the proloculus, both generation having main acervuline chambers of three or four whorls and covering the whole test; whorls are round in equatorial section throughout, but not polygonous in the same section in the later growth in *Silvestriella tetrahedra*

PLATE 3

1 *Idalina sinjarica* Grimsdale. Longitudinal section of megalospheric form. Locality LL3. ×84.

2 *Glomalveolina primaeva* (Reichel). Axial section of megalospheric form. Locality 129/PL/6-4. ×68.

3-4 *Daviesina khatiyahi* Smout. 3. Tangential section. 4. Axial section. Locality 129/PL/6-3. ×32.

5 *Rotalia trochidiformis* Lamarck. Axial section. Locality LL1.6. ×32.

6 *Lockhartia haimei* (Davies). Axial section. Locality Myn/LKd/106. ×32.

7 *Lockhartia conditi* (Nuttall). Axial section. Locality LL2. ×32.

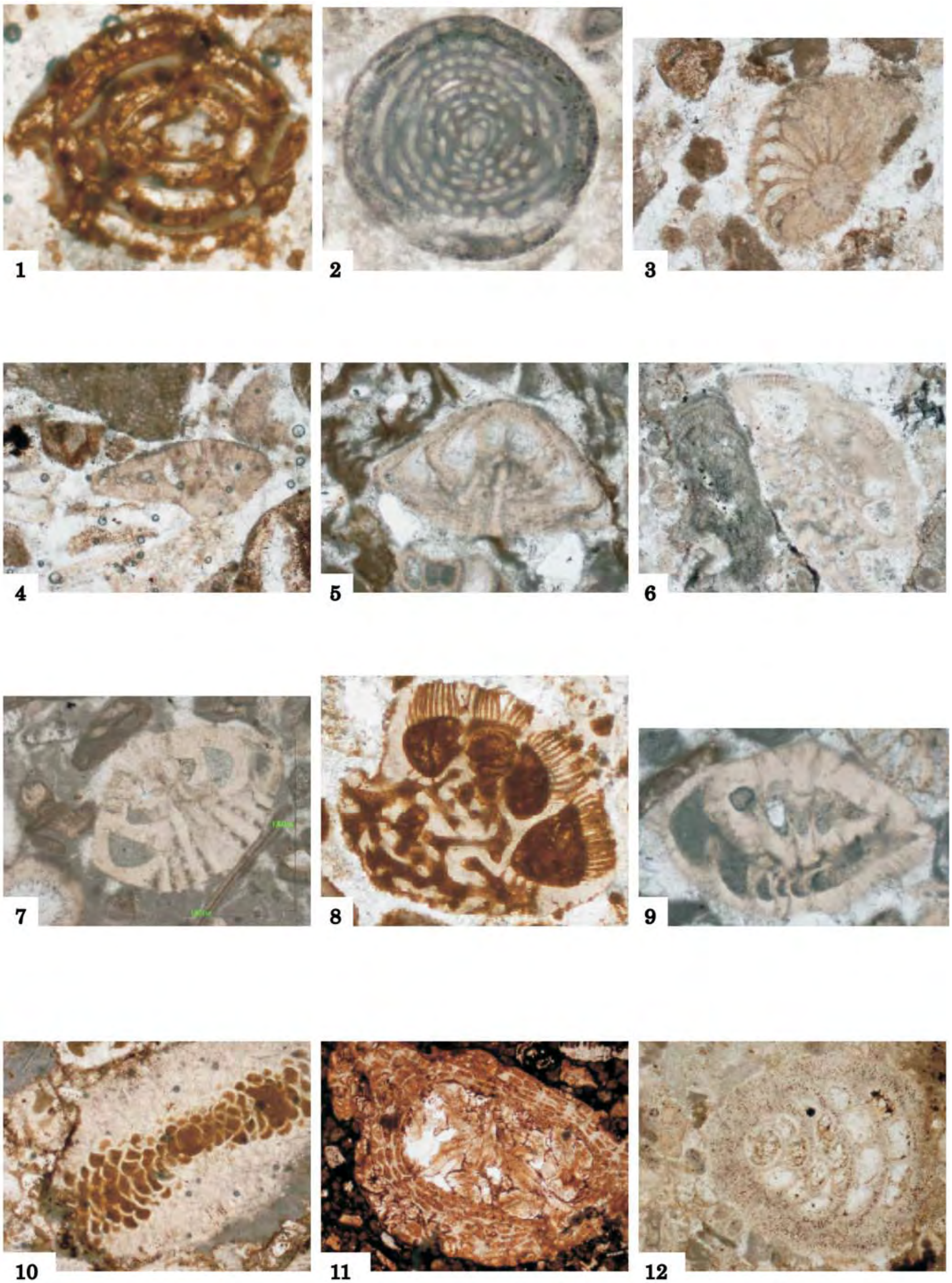
8 *Lockhartia diversa* Smout. Axial section. Locality LL3. ×56.

9 *Smoutina cruysi* Drooger. Axial section. Locality LL1.6. ×44.

10 *Linderina brugesi* Schlumberger. Oblique section. Locality NH-44/PL-3. ×34.

11 *Lepidocyclina* spp. Axial section. Locality Nongkh/KL3-1. ×32.

12 *Chapmanina* spp. Oblique section. Locality L2C31. ×32.



(Von Gumbel 1870); dimension of acervuline chambers in the periphery, measuring 216 x 120 to 260 x 160 micron in tangential and radial diameter in equatorial section, and 146 x 104 to 240 x 160 micron in width and height in axial section; roofs and floors of acervuline chambers, 120 to 140 micron thick; radial spines arise from the early to late whorl of chambers, length of spines from their origin to tips, measuring 504 to 1,600 micron and width of spines, 280 to 400 micron; wall calcareous, and perforate.

Associated fauna: Discocyclina augustae, D. javana, Nummulites incrassatus, N. striatus, Pellatispira glabra, and *P. orbitoidea.*

Stratigraphic horizon: Limestone in the Kopili Formation.

Geological age: Late Eocene (Priabonian), and Tertiary b of Letter Stages.

Family ACERVULINIDAE Schultz 1854

Protogypsina Matsumaru and Sarma, **n. gen.**

Name: This genus is named for the first occurrence of the gypsinid foraminifera from the Paleocene of Jaintia Hills, Meghalaya, NE India.

Type species: Protogypsina indica Matsumaru and Sarma, n. gen., n. sp.

Diagnosis: Test small, spherical or subspherical; multi-chambered; embryonic apparatus of megalospheric form, composed of spherical to subspherical protoconch and kidney-shaped deuteroconch; following helicostegine large ovoidal chambers, involute and low trochospiral about a short axis, and other later coil of small and large arc shaped chambers developed ventrally; later lateral chambers, almost elliptical, irregularly superposed in radial lines or in tiers radiating outwards from the center; wall calcareous, perforate, and aperture consisting of mural pores or the coarse perforating of the chambers.

Remarks: Protogypsina is similar to *Sphaerogypsina* Galloway 1933, *Wilfordia* Adams 1965, or *Orbitogypsina* Matsumaru 1996 by its sphaerical test, but the internal arrangement of embryonic, periembryonic and later chambers is different from the three genera stated above. *Sphaerogypsina* has embryonic and periembryonic chambers with raspberry structure. *Willfordia* has a short nepionic spiral in the early stage, and pseudopillars formed in walls of lateral chambers. *Orbitogypsina* has two principal auxiliary chambers and four nepionic spirals.

Protogypsina indica Matsumaru and Sarma, **n. gen., n. sp.**
Plate 2, figures 4–6

Material and type specimen: Specimens of rock samples LL2 and LL3 of the Lakadong

Limestone, exposed along the National Highway No. 44 between Mynkree and Musianglamare (Fig. 1–9), and those of rock sample 129/PL/6-3 of the Prang Limestone in the NH-44 section 1, south of Lumsnong (Fig. 1-1). Specimens for the latter sample 129/PL/6-3 are regarded to be reworked from the Lakadong Limestone, because there was no occurrence from the Umlatdoh Limestone. Holotype, megalospheric specimen of thin section LL3-1, Saitama Univ. Coll. No. 8866 (Plate 2, figure 4).

Description: Test small, spherical to subspherical form; 0.60 to 0.92mm in diameter, and 0.60 to 0.80mm in thickness; form ratio of diameter to thickness, 1.0 to 1.2; megalospheric biloculine embryonic chambers, spherical to subspherical protoconch, internal diameter 24 x 24, 43 x 36 and 44 x 48 micron in 3 speci-

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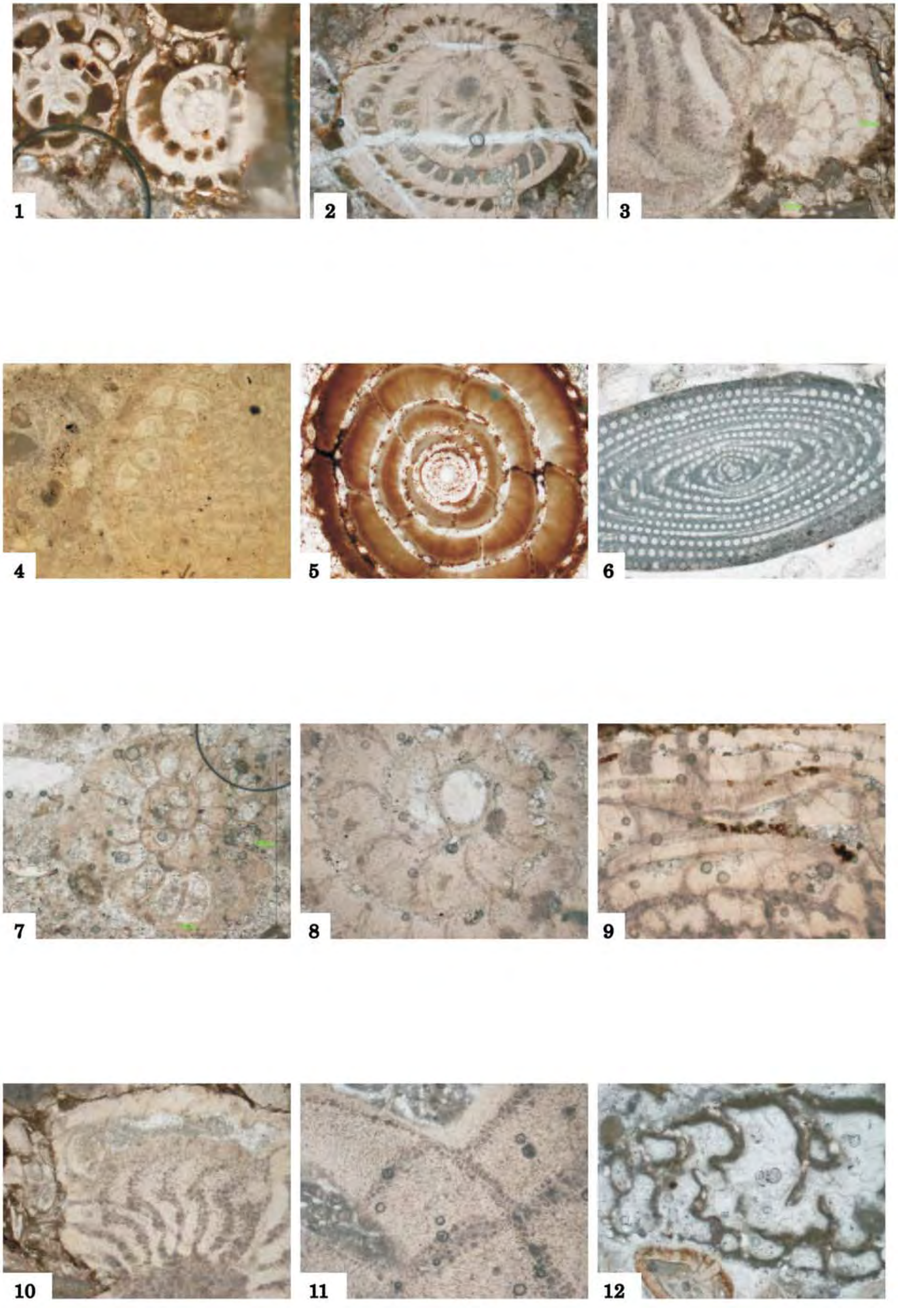
PLATE 4

1. *Nummulites globulus* Leymerie (right) and *Lockhartia* sp. probably *L. haimei* (Davies) (left). Tangential sections. The former species commonly yields from the lower Prang Limestone, but the latter species may be derived from the upper Paleocene Lakadong Limestone. Locality NH-44/Pl/T4-1. ×32.
2. *Nummulites beaumonti* d'Archiac and Haime. Oblique section. This species occurs from the lower Prang Limestone. Locality NH-44/PL/T4-1. ×32.
3. *Nummulites ptukhiani* Kacharava (right) and *N. atacicus* Leymerie (left). Oblique sections. Locality NH-44/PL-11. ×32.
4. *Dictyoconoides cooki* (Carter). Oblique section. Locality L2C34. ×30.
5. *Alveolina elliptica nuttalli* Davies. Equatorial section. Locality 129/PL/6-3. ×32.
6. *Alveolina schwageri* Checchia-Rispoli. Axial section. Locality UL4.1. ×32.
7. *Miscellanea miscella* (d'Archiac and Haime). Equatorial section. Locality LL3. ×32.
8. *Nummulites acutus* (Sowerby). Centered oblique section. Locality Nongkh/PL 3.5. ×34.
9. *Nummulites fabianii* (Prever). Axial section. Locality NH-44/KL1-3. ×32.
10. *Nummulites atacicus* Leymerie. Tangential section. Locality NH-44/PL-11. ×32.
11. *Assilina placentula* (Deshayer). Axial section. Locality NH-44/PL/T4-1. ×30.
12. *Pseudochrysalidina* spp. Longitudinal section. Locality LL1.6. ×32.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mens, and deuteroconch reniform, internal diameter 32 x 16, 38 x 36 and 52 x 44 micron, respectively; embryonic chambers 43 to 46 micron high in axial section; wall of embryonic chambers 3 to 4 micron thick; embryonic chambers followed by helicostegine large chambers, low trochospiral, and involute coil, later small subsiderary chambers formed ventral side; helicostegine chambers, internal diameter 70 x 44 to 80 x 72 micron, subsidiary chambers, internal diameter 20 x 7 to 24 x 6 micron; remainder of test, ovoidal to rectangular chamberlets arranged in irregular tiers, grading increasing in size away from center to the periphery, and their number from 6 to 8 per row; dimension of these chamberlets, inner tangential and radial diameter up to 48 x 40 micron; roofs and floors of chamberlets, 6 to 10 micron thick, and perforate; no microspheric specimens observed.

Associated fauna: Aberisphaera gambanica, Daviesina khatiyahi, Glomalveolina primaeva, Idalina sinjarica, Kathina selveri, Lockhartia conditi, L. diversa, L. haimei, Miscellanea miscella, M. primitiva, Opertorbitolites douvillei, Orbitoclypeus ramaraoi, Orbitosiphon tibetica, Raoia indica, n. gen., n. sp., *Ranikothalia nuttalli, Rotalia trochidiformis, Smoutina cruysi,* and others of Assemblage 2.

Stratigraphic horizon: Lakadong Limestone.

Geological age: Late Paleocene (Thanetian) and Tertiary a1 upper of Letter Stages.

Family Meandropsinidae Henson 1948

Raoia Matsumaru and Sarma, **n. gen.**

Name: This genus is named after Dr. S. R. Narayana Rao, who provided valuable foraminifera from India.

Type species: Raoia indica Matsumaru and Sarma, n. gen., n. sp.

Diagnosis: Test lenticular, early stage coiled in some planes, later planispiral and involute, increasing chambers from six to ten per whorl, final stage tend to uncoil; interior of chambers, rhombic to rectangular shape, not subdivided, and marginal zone of chambers subdivided by rudimentary radial septules; wall calcareous, imperforate, porcellaneous.

Remarks: This genus resembles *Hottingerina* Drobne 1975 in general test, but is different from the latter in lacking secondary septula perpendicular to primary septa. *Raoia* resembles *Scandonea* De Castro 1971 in general interior structure, but is different from the latter in having rudimentary radial septula.

Raoia indica Matsumaru and Sarma, **n. gen., n. sp.**
Plate 2, figures 7–10.

Material and type specimen: Specimens from rock samples Nong/LKd/B-01 in

Nongtalang section (Fig. 1–7), Myn/Lkd/103 and 107 in Mynkree section A (Fig. 1–5), and LL1.2, LL1.3, LL1.4, LL1.6 and LL1.7 in Mynkree section B (Fig. 1–6) of the Lakadong Limestone. Holotype, megalospheric specimen of thin section of Myn/Lkd/103-2, Saitama Univ. Coll. No. 8867 (Plate 2, figure 7).

Description: Test large, lenticular; 0.76 to 1.73mm in diameter, and 0.42 to 0.52mm in thickness; form ratio of diameter to thickness, 2.96 to 4.15; megalospheric subspherical protoconch, 208 x 206, 232 x 200 and 240 x 204 micron in 3 specimens, and microspheric proloculus, 56 x 54 micron; both embryo followed by three to four tightly coiled whorls, each whorl with six to ten rhombic to rectangular shaped chambers; dimension of adult chamber, 160 x 80 to 216 x 90 micron in width and height in equatorial section; later uncoil and flaring in the final stage, but mostly destroyed; wall calcareous, imperforate, and outer wall thick, 50 to 55 micron, and septa thin and rather massive, 8 to 20 micron; aperture multiple and may be cribriform.

PLATE 5

All figures ×34.

1 *Nummulites atacicus* Leymerie. Centered oblique section. Locality NH44/PL-3.

2 *Nummulites beaumonti* d'Archiac and Haime. Centered oblique section. Locality NH44/PL/B4-2.

3 *Nummulites gizehensis* (Forskål). Axial section. Locality NH44/PL/B4-2.

4 *Nummulites globulus* Leymerie. Centered oblique section. Locality NH44/PL-8.

5-6 *Nummulites incrassatus* de la Harpe. 5. Tangential section. Locality Nongkh/KL3-1; 6. Transverse section. Locality NH44/PL-5.

7 *Nummulites millecaput* Boubee. Equatorial section. Locality NH44/PL/B4-2.

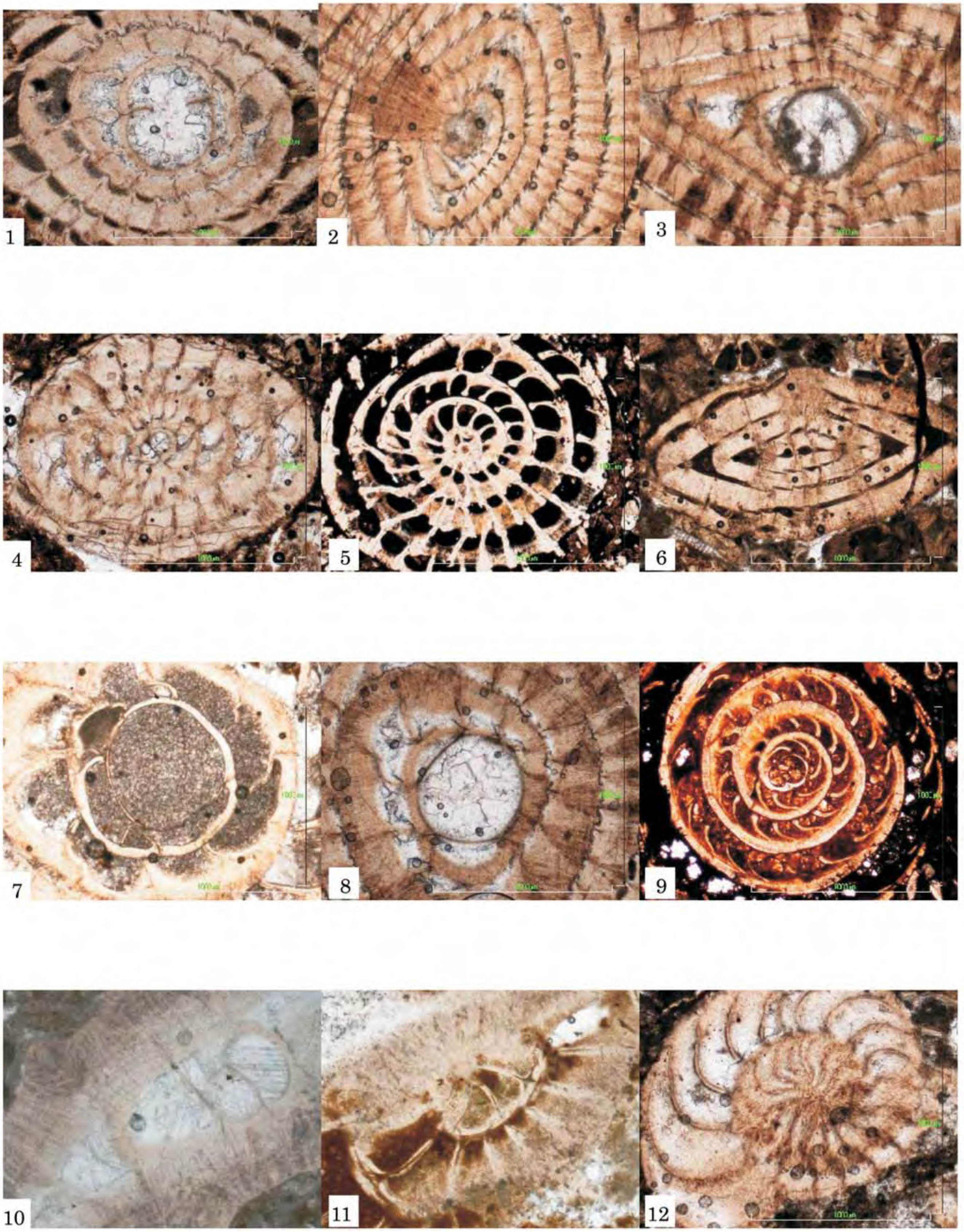
8 *Nummulites perforatus* (Montfort). Centered oblique section. Locality NH44/PL-2.

9 *Nummulites striatus* (Bruguiere). Equatorial section. Locality Nongkh/KL3-1.

10 *Assilina placentula* (Deshayes). Axial section. Locality NH44/PL/T4-1.

11 *Ranikothalia nuttalli* (Davies). Oblique section. Locality LL3-2.

12 *Operculina subformai* (Provale). Oblique section. Locality NH44/PL-1.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Associated fauna: Daviesina khatiyahi, Idalina sinjarica, Kathina major, K. selveri, Lockhartia conditi, L. diversa, L. haimei, L. tipperi, Miscellanea globularis, M. primitiva, Ranikothalia nuttalli, Rotalia trochidiformis, Smoutina cruysi, and others of Assemblages 1 and 2.

Stratigraphic horrizon: Lakadong Limestone.

Geological age: Late Paleocene (Thanetian), and Tertiary a1 of Letter Stages.

CONCLUSION

The Paleogene larger foraminifera occurring from the upper Paleocene rocks (Lakadong Limestone) through lower to middle Eocene ones (Umlatdoh and lower Prang Limestones) to upper Eocene ones (upper Prang Limestone and limestones in the Kopili Formation), Jaintia Hills, Meghalaya showed characteristic fauna of SBZ 3 to 4 (Selandian? to Thanetian) through SBZ 7 to SBZ 11 (Ypresian) and SBZ 12 to SBZ 17 (late Ypresian to late Bartonian) to SBZ 18 to SBZ 20 (late Bartonian to Priabonian). Further the present Paleogene larger foraminifera showed characteristic fauna of the Tertiary a1 (Thanetian) to Tertiary b (Priabonian) of the Far Eastern Letter Stages (Govindan 2000; Matsumaru 1996). Six significant faunal assemblages with further two subassemblages based on diagnostic species could be recognized. *Aberisphaera gambanica, Daviesina khatiyahi, Idalina sinjarica, Kathina selveri, Lockhartia diversa, L. haimei, Miscellanea primitive, M. miscella,* and *Ranikothalia nuttalli* were proved to be diagnostic species for the regional zonal value of Assemblages 1 and 2 in recognition of upper Paleocene (Thanetian) Tertiary a1 of Letter Stages. *Aberisphaera gambanica* and *Orbitosiphon tibetica* were especially proved to be important species for the correlation of upper Paleocene sediments of studied area with those of Tibet. *Alveolina oblonga, A. schwageri, Assilina laxispira, A. placentula, Nummulites atacicus,* and *N. globulus* were proved to be diagnostic species of Assemblage 3 of the lower Eocene (Ypresian) Tertiary a2. *Alveolina elliptica nuttalli, Nummulites beaumonti, N. gizehensis, N. perforatus,* and *Orbitolites complanatus* were proved to be diagnostic species for the recognition of Assemblage 4-1 of lower Middle Eocene (late Ypresian? to Lutetian) Tertiary a2. *Nummulites acutus, N. beaumonti, N. gizehensis, N. millecaput,* and *N. perforatus* were proved to be the well recognition of species for Assemblage 4-2 of upper Middle Eocene (Bartonian) Tertiary a3. *Nummulites perforatus, Operculina subformai, Pellatispira madaraszi,* and *P. orbitoidea* were diagnostic species to indicate Assemblage 5 of lower Upper Eocene (late Bartonian? to Priabonian) Tertiary b, and *Nummulites incrassatus, N. striatus,* and *Pellatispira orbitoidea* to indicate Assemblage 6 of upper Upper Eocene (Priabonian) Tertiary b. Further *Lepidocyclina* spp. and *Nummulites fabianii* have found from Assemblage 6. The first finding of late Eocene *Lepidocyclina* in Jaintia Hills, Meghalaya marks the important occurrence of it in the western area far off Borneo, Far Eastern region.

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PLATE 6

All figures ×34.

1-2 *Miscellanea primitiva* Rahaghi. 1. Centered oblique section; 2. Transverse section. Locality Myn/Lkd/101.

3 *Aberisphaera gambanica* Wan. Oblique section. Locality Nong/Lkd/B-05.

4 *Alveolina oblonga* d'Orbigny. Centered oblique section. Locality UL4.1.

5 *Kathina selveri* Smout. Transverse section. Locality Nong/Lkd/B-05.

6 *Assilina laxispira* de la Harpe. Equatorial section. Locality NH44/PL/B4-2.

7 *Orbitolites complanatus* Lamarck. Equatorial section. Locality L2C33.

8 *Orbitoclypeus ramaraoi* (Samanta). Centered oblique section. Locality LL3-1.

9-10 lower. *Pellatispira orbitoidea* (Provale). 9. Centered oblique section. Locality Nongkh/KL3-1; 10. Axial section. Locality NH44/PL-1.

10 upper. *Operculina schwageri* Silvestri. Transverse section. Locality NH44/PL-1.

11-12 *Pellatispira madaraszi* (von Hantken). 11. Equatorial section; 12. Transverse section. Locality NH44/PL-1.

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