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PALAEOGENE LARGER FORAMINIFERAL CORRELATION OF ASSAM-SHILLONG SHELF-AN EXAMPLE OF HIGH RESOLUTION BIOSTRATIGRAPHY

SUDHIR SHUKLA[1], J. BEGUM[2], S.K. VYAS[3] and J. BARUA[2]

KDMIPE, ONGC, DEHRADUN. (CORRESPONDING AUTHOR)
[2]ASSAM ASSET, ONGC, NAZIRA
[3]NRBC, ONGC, DEHRADUN
E-mails: shukla_sudhir@ongc.co.in

ABSTRACT

The Assam–Arakan Basin covering north-eastern India and the adjoining areas is one of the hydrocarbon producing sedimentary basins with great thickness of the Cenozoic sediments. The lower Palaeogene shelf carbonate and intermittent clastic facies over the Assam-Arakan shelf signifies marine sedimentation of the Tethyan realm. Recent oil finds in the pre-Barail sediments in Assam has pointed to the enhanced stratigraphic exploration of the pre-Barail sediments in future by bringing in new concepts and high impact biostratigraphic tools, being developed world over. One such scheme followed have is that of shallow benthic zones [SBZ] proposed by Serra-kiel *et al.* (1998). This biostratigraphic zonation comprises twenty zones covering the Palaeocene-Eocene time span (32 M.A) and represents faunal assemblages of both concurrent and mutually exclusive species from the key-levels and key-localities. The SB zones are largely "Oppel zones" with key foraminifera along with the association of other taxa spread over vast areas in the Tethyan region.

Twenty three wells spread over the Assam-Arakan shelf were analyzed to propose a framework of biostratigraphic correlation on the lines of IGCP-286 scheme. Several other wells were also studied for supportive micropalaeontological data. Indian equivalent species for each SBZ have been worked out. They include both the Tethyan key foraminifera and concurrent shallow larger benthic species acting as the local reference. Recognition of Indian equivalent species to the European and far-Tethyan taxa is primarily aimed to make the SBZ scheme directly useful to the biostratigraphic correlations in our sedimentary basins. These of local bio-events in chronostratigraphic mapping is expected to provide robust framework to the sequence stratigraphic models in the area. Integration of SBZ data with other geological information would also be immensely useful in the stratigraphic exploration.

Keywords: Larger foraminifera, shallow benthic zones [SBZ], Paleogene, Assam-Arakan shelf. The views expressed in the paper are of authors only and may not necessarily be of the organization to which they belong.

INTRODUCTION

The Assam–Arakan Basin covering northeastern India and the adjoining areas is one of the hydrocarbon producing sedimentary basins with great thickness of the Cenozoic sediments. It is also one of the oldest basins where the hydrocarbon exploration started as early as 1889 (Digboi). In the upper Assam shelf, a great sedimentary thickness has been postulated north of Brahmaputra, around Lakhimpur, so also in the Nazira, Dimapur and Safrai lows. The present study is confined to the first two areas as most of the hydrocarbon exploration activities are concentrated there. The Assam-Shillong shelf has also been significant in exhibiting marine lower Palaeogene and non-marine younger sequences, in several wells and surface sections. The lower Palaeogene carbonates and finer clastics have preserved considerable amount of correlatable biota. As the hydrocarbon occurrences were mostly concentrated in the Barail and post-Barail sequences of paralic or non-marine origin, more emphasis was given to the study of post Oligocene sediments. Now, with the advent of encouraging leads in the pre-Barail sections in many parts of Dhansiri valley and Upper Assam, the marine sediments belonging to Tura [or equivalent], Sylhet and Kopili formations have come into exploration focus. It is a matter of common observation that similar facies in the Dhansiri valley area, have provided abundant larger foraminifera with good diversity. The problem, however, exists in the vertical demarcation of smaller zones, by the study of ditch cuttings, which are often mixed with the caved in foraminifera too. Identification of various useful datums, based on the age boundaries / zonal boundaries or the first down hole occurrence of index foraminifera and tracing the lateral extent of the zones has helped demarcate finer biostratigraphic zones and assign these zones to the shallow benthic zones [SBZ] proposed by Serra Kiel *et al.* (1998). Their biostratigraphic zonation comprises twenty zones covering the Palaeocene-Eocene time-span (32 M.A) and represent faunal assemblages of both concurrent and mutually exclusive species from key-levels and key-localities. The Indian subcontinent's input to Serra-Kiel *et al.*'s scheme is from the South Shillong outcrop areas, mostly representing the Palaeocene zonation (SBZ 2-4) and Salt Range, Pakistan including to SBZ 4 -8. The SBZ zones are largely the "Oppel zones" with key foraminifera along with the association of other taxa spread over vast areas in the Tethyan region (Hottinger,1998; Pignatti,1998). Summarization of the Indian equivalents to the non-representative species in different SBZ was essential and has also been done, to make the application of SBZ scheme easy and focused in our sedimentary areas.

The main objective of the study is to develop a viable biostratigraphic tool for stratigraphic trap exploration. In the process, the use of local bio-events and their mapping across the shelf to create stratigraphic framework became an essential aspect of the study. In order to study and propose Palaeogene larger foraminiferal zonation for the selected wells from Assam-Shillong shelf and correlate with the International Geological Correlation Programme (IGCP-286 and 393) scheme, twenty three wells spread over the entire shelf area were analyzed (Fig.1) to present a framework for biostratigraphic correlation. The present study is the first attempt at the precise biozonation of the sediments and provides a framework for

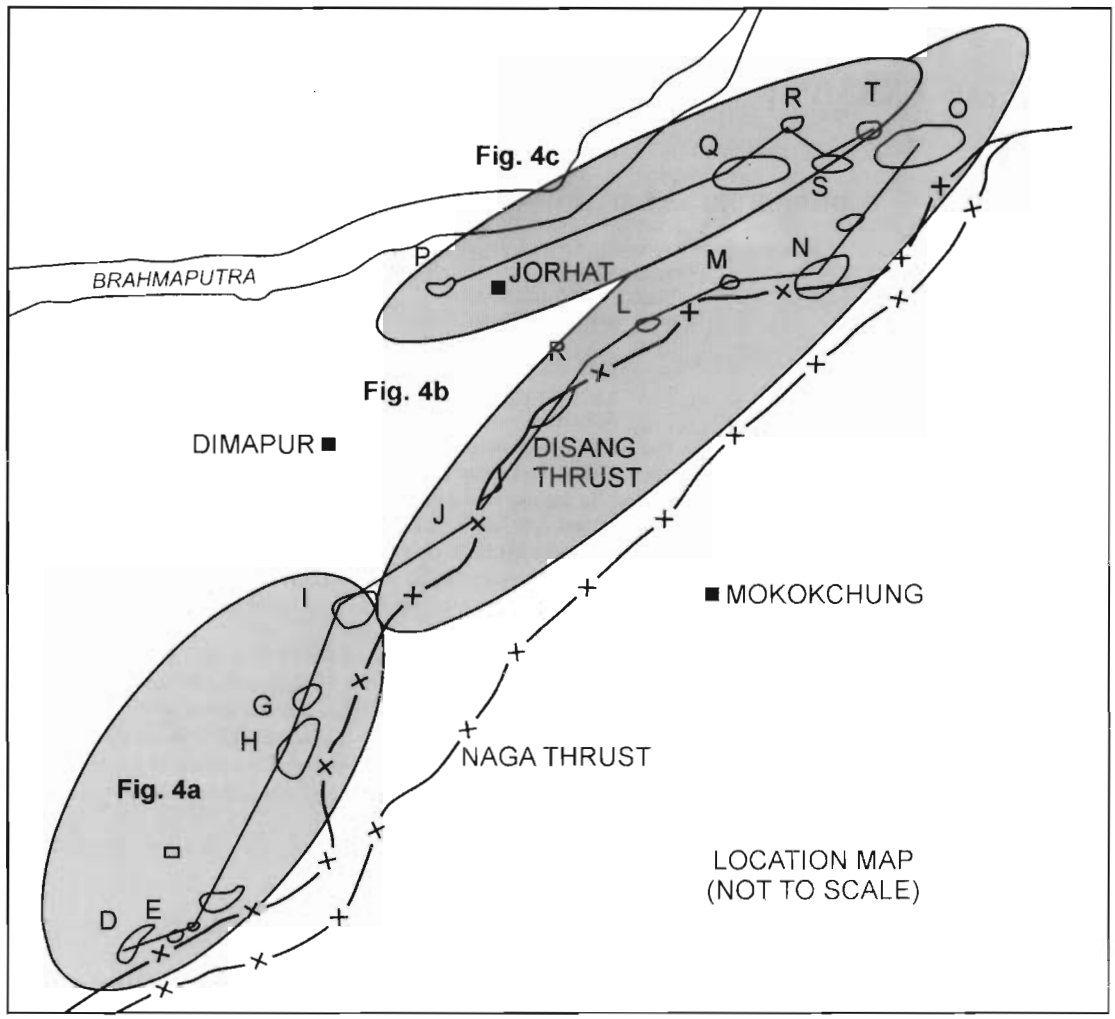


Fig. 1. Location map.

future studies with the help of working zonation referable to SBZ scheme (Table 1).

MATERIALS AND METHODS

Standard laboratory methods were used for collection, processing and preparation of the samples. Selected cuttings/ SWC or conventional core samples were wet processed and/ or thin sectioned for foraminiferal study under the binocular microscopes. Larger benthic foraminifera are studied for their external and internal features (in oriented or split sections) for taxonomic determinations, age, palaeoecological assignments and correlation. Initially, micropaleontological data from a large cross-section of wells was screened for foraminiferal occurrence, possible biostratigraphic controls and suitability for shallow benthic zonation. The foraminiferal ranges, associations, appearance/disappearance in the well sections help in the assignment of shallow benthic zones, and correlation in the nearby areas. Two correlation lines along the general strike direction [NE-SW] were taken and the formation tops and electrologs superimposed to observe similarity / trends across the shelf.

STRATIGRAPHY

The generalised lithostratigraphy of the area, right from the South Shillong shelf to the upper Assam, is well known and followed after Deshpande *et al.* (1993) (Figs.2-3). The Jaintia Group is divided into three formations, i.e. Tura Formation, Sylhet Formation and Kopili Formation, in stratigraphic order of superposition; The Tura Formation unconformably overlies Mahadeo Formation of Upper Cretaceous age. In the south eastern Khasi and Jaintia hills, the Jaintia group is again divided into three formations, i.e. Therria Formation, Sylhet Formation and the Kopili Formation. The Therria Formation conformably overlies Langpar Formation [Khasi Group] of Paleocene age, and comprises lower limestone and upper sandstone members. The Sylhet Formation comprises five members, i.e. Lakadong limestone being the oldest and Prang limestone being the youngest. The Kopili Formation conformably overlies the Sylhet Formation

BIOSTRATIGRAPHY

A brief summary of various foraminiferal and faunal biozones reported by earlier workers is presented below. The occurrence/non occurrence of a particular zone or part of it in a particular well/area largely depends on the presence or absence of age diagnostic index taxa and inferences/interpretations drawn from the gross foraminiferal assemblages. The total biozones observed in different areas and relevant to the present study are mentioned as follows:-

South Shillong shelf

Garo and West Khasi hills: Most of the biozones are based

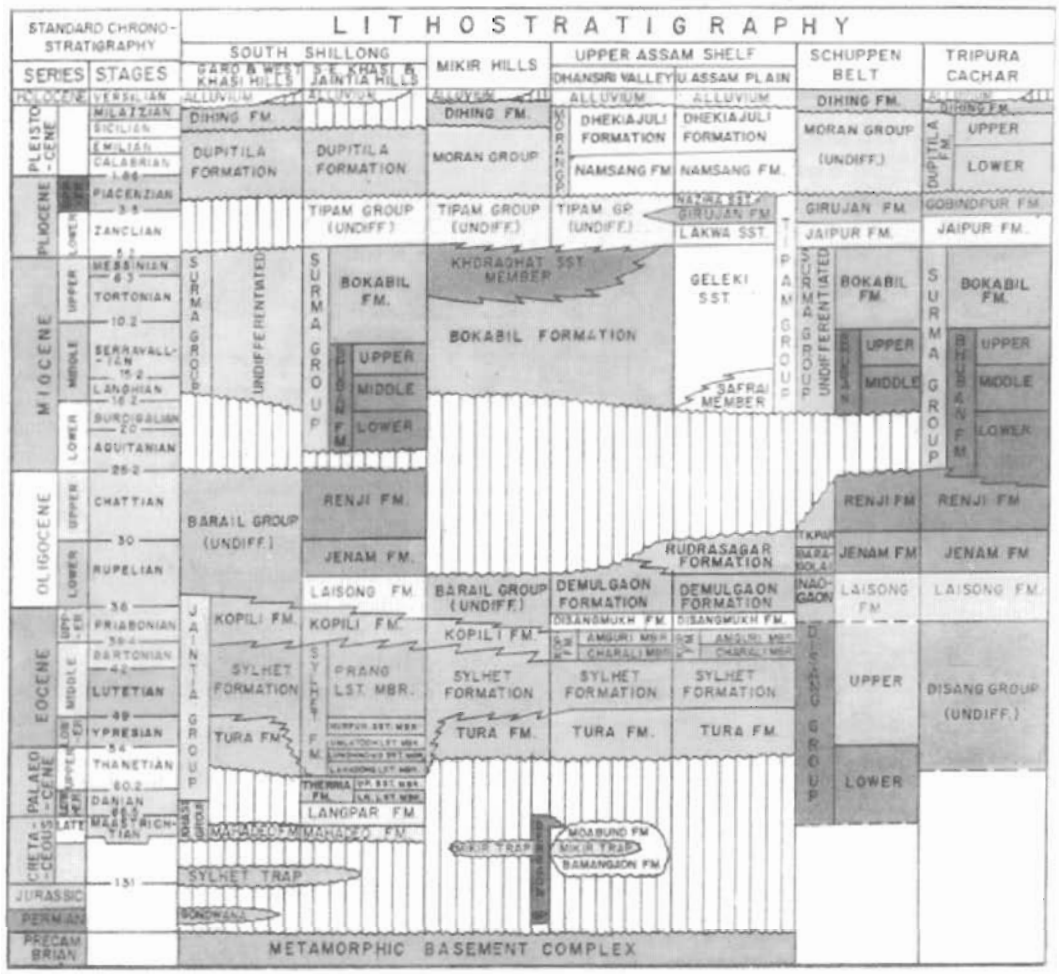


Fig. 2. Generalised Stratigraphy of Assam shelf (after Deshpande *et al.*, 1993).

on the study of outcrop areas. The gross faunal content and diversity is good for the Palaeogene or older sediments as tropical Tethyan larger foraminifera help recognize important age diagnostic zones. Planktons are generally rare and sporadic during the Palaeogene (Pre-Barail) intervals. Thirteen zones in stratigraphic order are:

Unfossiliferous Zone
Ammonia–Globigerina prebulloides occulosa Assemblage Zone
Ostrea latimarginata Assemblage Zone
Arenaceous foraminifera Zone
Cribrohantkenina - *Pellatispira* Assemblage Zone
N. beaumonti – *Discocyclina* Assemblage Zone
Nummulites acme zone
N. somalinensis D. dispansa Assemblage Zone.
N. atacicus – *A spira* Assemblage Zone
Unfossiliferous Zone
Miscellanea miscella Zone
Siderolites calcitropoides - *Orbitolites* Assemblage Zone
Inoceramus - *Rzehakina* Assemblage Zone

Southeast Khasi and Jaintia hills: This region possesses the famous outcrop of the Um-Sohryngkew river section in Meghalaya, where Cretaceous/Tertiary (K/T) boundary and Palaeogene biostratigraphy were studied by several workers (Nagappa,1959; Pandey,1972; Pandey and Ravindran,1988). The foraminiferal occurrence is significant and diversified, comprising good planktic, smaller benthic and larger foraminiferal assemblages. Eighteen biozones identified in the area range from Late Cretaceous (Early Maastrichtian) to Oligocene in age. The youngest two zones have either long ranging smaller benthic foraminifera or unfossiliferous, hence, the age determination is not possible. The biozones are described below in stratigraphic order:

Unfossiliferous Zone
Poorly fossiliferous Zone
Arenaceous foraminiferal Zone
N. fichteli Zone
N. fabianii Zone
N. discorbinus – *A spira* Partial Range Zone
Unfossiliferous Zone
Orbitolites complanata Partial Range Zone
Cuvillierina vallensis Partial Range Zone
M. miscella Partial Range Zone
Unfossiliferous Zone
Poorly fossiliferous Zone
T. pusilla –*Acarinina unicata* Partial Range Zone
T. inconstance Partial Range Zone
T. psuedobulloides Partial Range Zone
Guembellitria cretacea – *Heterohelix* Assemblage Zone
Globotruncana stuarti Partial Range Zone

Dorothia oxycana Partial Range Zone

Dhansiri Valley

The Palaeogene foraminiferal occurrences observed in the subsurface of Dhansiri valley also belong to the Tethyan tropical assemblages and have a good taxonomic similarity & diversification with the South Shillong Shelf as well as the Upper Assam Shelf. Larger benthic foraminifera, which often show certain amount of provincialism and lithofacies control is rapidly evolving and exhibiting acme during the Sylhet limestone sedimentation. At places, well sections have also shown evidences of recycling or rolling of fauna and such phenomena are taken into account while interpretating the data. During the Tertiary, eleven biozones were proposed in the DVP areas and are mentioned below in stratigraphic order:-

Unfossiliferous Zone III
Planktic foraminifera Zone II
Unfossiliferous Zone II
Arenaceous foraminifera Zone
Smaller benthic foraminifera Zone
N. pengaronensis Zone
N. discorbinus – Assilina Assemblage Zone
N. acutus - A. ellipitica Assemblage Zone
Poorly fossiliferous Zone
Planktic foraminifera Zone I
Unfossiliferous Zone I

Upper Assam

The lower Palaeogene sediments, wherever recorded in the subsurface of Upper Assam, are proliferated by larger as well as smaller benthic foraminifera. The planktons are rare and occur sparsely. In Demulgaon, Rudrasagar, Geleki and other adjoining areas, the Tura Sylhet and Kopili sediments have shown the presence of tropical Tethyan assemblages of benthic foraminifers. Nine biozones were observed and presented below in stratigraphic order:-

Unfossiliferous Zone II
Arenaceous foraminifera Zone II
Unfossiliferous Zone I
Arenaceous foraminifera Zone I
Poorly fossiliferous Zone II
N. pengaronensis Zone
N. discorbinus- Assilina Assemblage Zone
N. acutus. F. elliptica Assemblage Zone
Poorly fossiliferous Zone I

PALAEOGENE LARGER FORAMINIFERA ZONATION

The larger foraminifera belonging to Nummulitidae, Discocyclinidae, Rotaliidae and other families are the most prominent index markers for the shallow marine Palaeogene sediments. Their occurrence and biostratigraphic use in the Assam Basin is mentioned below.

Tethyan Shallow Benthic Zones

Serra-Kiel *et al.* (1998) presented the larger foraminiferal biostratigraphy of the Tethyan Palaeocene and Eocene comprising 20 Shallow Benthic Zones (SBZ) from the eastern Atlantic and Mediterranean basins to the central part of Tethys (covering areas from India and Pakistan). According to Serra-Kiel *et al.* (1998), the Shallow Benthic Zones form scheme is the outcome of a revision of classical biozonation based on alveolinids, *Assilina* and *Nummulites*, established in 1960's by earlier workers. These are typologically defined biozones or the oppel zones based on both the occurrence and concurrence of species from key localities and key levels having chronostratigraphic value. The SB Zones scheme are also linked to the standard planktic/nannofossil zonations. Each SB biozone corresponds to the total ranges of some larger foraminifera and utilizes multiple first and last appearances of taxa from all available neritic paleoenvironments. The SBZ 1-20 are described in Table I along with their key foraminifera and the proposed Indian equivalent species which are based on the first author's own experience in the larger foraminiferal biostratigraphy from the important sedimentary basins of India. The proposed scheme is of suggestive nature and may be supplemented with the new data in future.

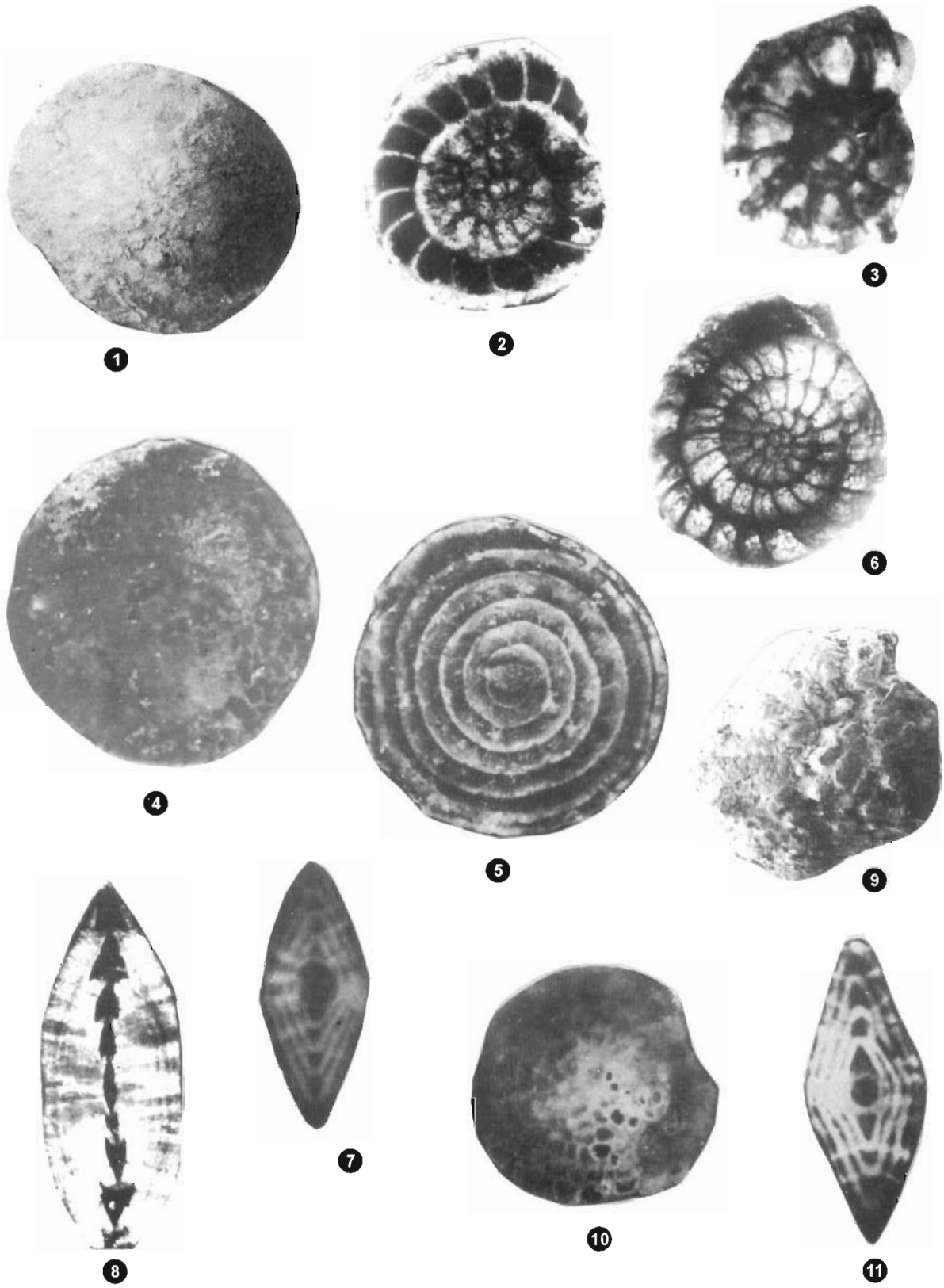
Well-Wise Shallow Benthic Zonation

In order to study Palaeogene larger foraminiferal zonation in the selected wells from Assam-Shillong shelf and correlate with the Shallow benthic zones, 23 wells spread over the entire shelf area were analyzed, by the authors. Two broadly correlatable lines (Figs. 4a, 4b and 4c) roughly along the general strike direction (NE-SW), have been prepared and the SBZ identified in each well correlated. Since the biostratigraphic data is derived from the well samples, all depths mentioned in the correlation also correspond to the driller's depth. Ideally, a biostratigraphic zonation should be based on the continuous surface record, i.e. cored section, however, these are rare and the ditch cuttings with the known limitations of caving and mixing of fauna etc. have been utilized. Published data from the outcrop sections in the south Shillong shelf conforms to the presence of finer (smaller) intervals of sediments which can be assigned to precise ages, biostratigraphically (Jauhri and Agarwal, 2001). Jauhri (1994) and Jauhri *et al.et al.* (2006), suggested that the carbonate buildups in the Lakadong Formation developed as progradational highstand deposits during the early Palaeogene. The Lakadong Formation comprises three foraminiferal associations/assemblages viz. Rotalid–Miliolid Association; *Glomaveolina primaeva – Distichoplax*

EXPLANATION OF PLATE I

1. ***Assilina dandotica*** Davies,1937. External view, x15
2. ***Assilina dandotica*** Davies, 1937. Equatorial section, x15
3. ***Daviesina langhami*** Equatorial section, x25
4,10. ***Nummulites fichteli*** Michelloti,1841.External view, 15(4); x11(10)
5. ***Nummulites fichteli*** Michelloti, 1841. Equatorial section, x13
6. ***Assilina pustulosa*** Doncieux, Equatorial section, x12
7. ***Nummulites fichteli*** Michelloti,1841. Axial section, x10
8. ***Assilina hamzehi*** Axial section, x10
9. ***Daviesina langhami*** External view
11. ***Nummulitesfichteli*** Michelloti,1841. Axial section, x12

Plate I



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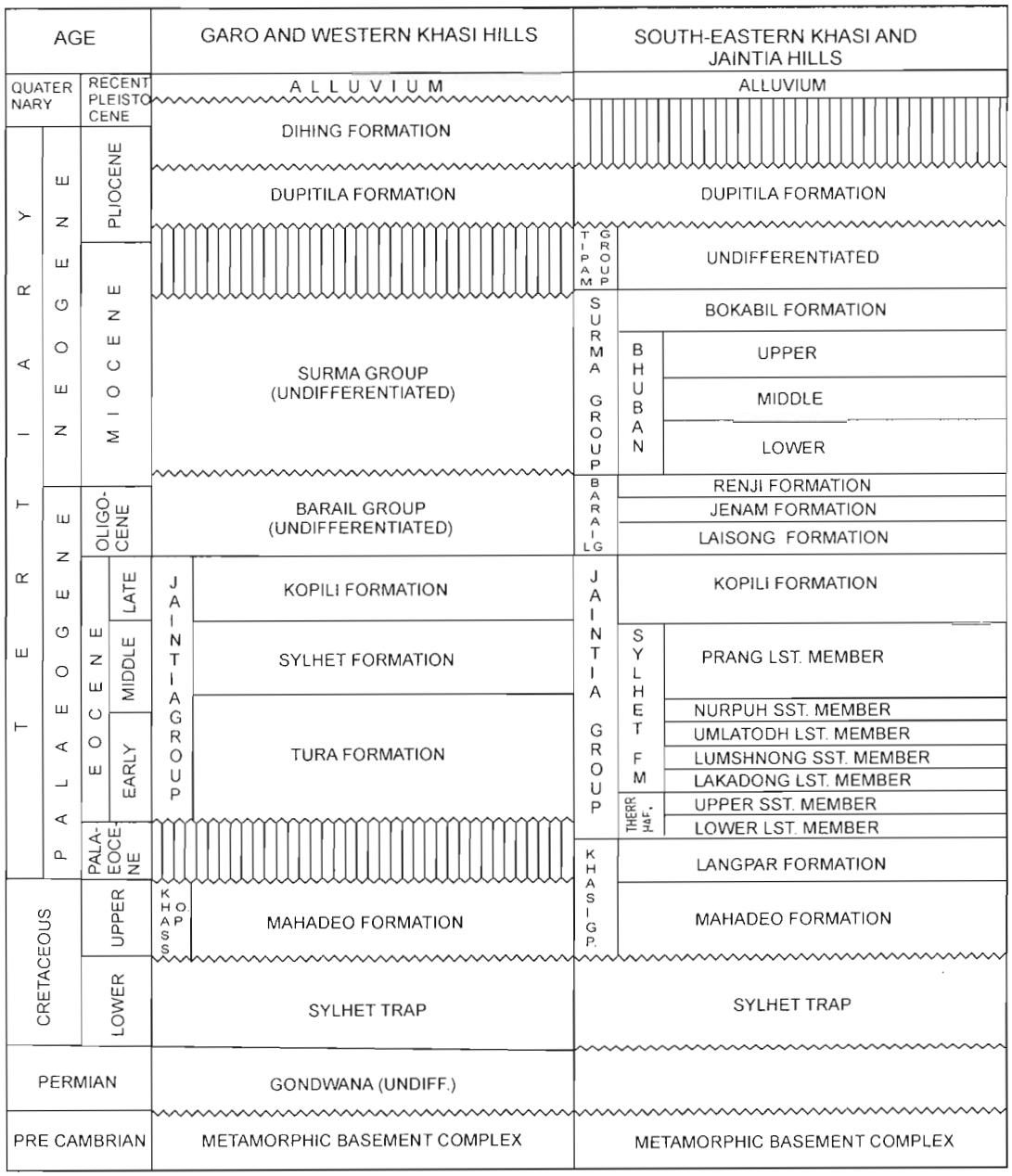

Fig. 3. Classification of Pre-Barail formations in South Shillong areas (after Deshpende *et al.*, 1993).

biserialis Association; *and Discocyclina - Ranikothalia* Association; in stratigraphic order. Based on the occurrence of *Miscellanea* species and associated taxa in the region, he (1998) proposed two species viz. *M. yvettae* & *M. juliettae* as corresponding to the *Glomalveolina primaeva* and *G. levis* zones (late P4 - P5 boundary = Thanetian). The *M. miscella* along with *Ranikothalia nuttalli, Orbitosiphon aff, O. prepunjabensis and Orbitoclypeus ramaraoi* are younger and correspond to *Alveolina vredenburgi* zone (P5= early Illerdian). As evident from these records, the Lakadong Formation may correspond to SBZ 3-6. The lower part of the formation with Rotaliid- Miliolid Association may probably correspond to SBZ 2 (upper part).

In the well sections **A1, B 1 and C1**, the oldest identifiable shallow benthic zone corresponds to SBZ 14/15 in the first two wells, whereas the **C 1** has shown only SBZ 15/17 between the depth interval 2757-2778m (D.D.). In this well, the upper part of the Sylhet formation was only penetrated and the well was drilled to a depth of 2778m only. In the well **A 1**, the basal interval between depths 570-600m did not yield foraminifera, hence no SBZ could be suggested. The SBZ 14/15 is suggested between 510-570m; SBS 15/17 between depths 477-510m and SBZ 19/20 between depths 397-417m. The intervening depths 417-477m have not yielded index larger benthic foraminifera, hence assigned to ? SBZ-18. Similarly, depths 357-397m may be assigned to ?SBZ-20. In **B 1**, depths 1445-1505m is assigned to SBZ 14/15; 1315-1445m to SBS 15/17; 1175–1295m to SBZ 19/20; and 1130-1175m to ?SBZ 20, and 1060-1130m to SBZ 20 or younger. The intervening depth 1295-1315m may be assigned to ?SBZ-18. Further east, in well **C 1**, the depth 2757-2778m is assigned to SBZ 15/17; interval 2639-2757m is assigned to ?SBZ 18, 2472-2639m to SBZ 19/20 and

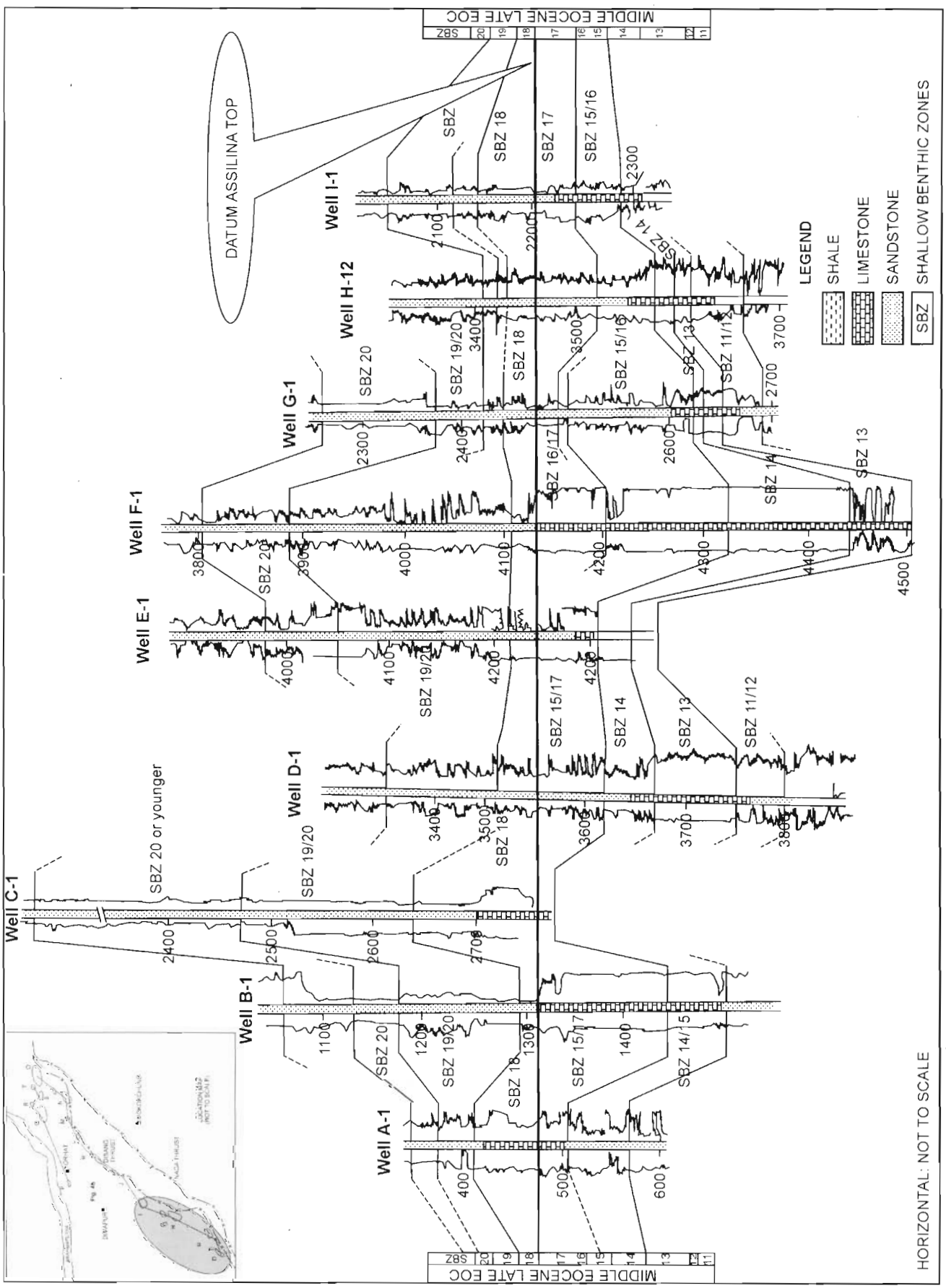

Fig. 4a. Biostratigraphic correlation of shallow benthic zones (SBZ) along wells A-1 to I-1. Assam-Arakan shelf, India

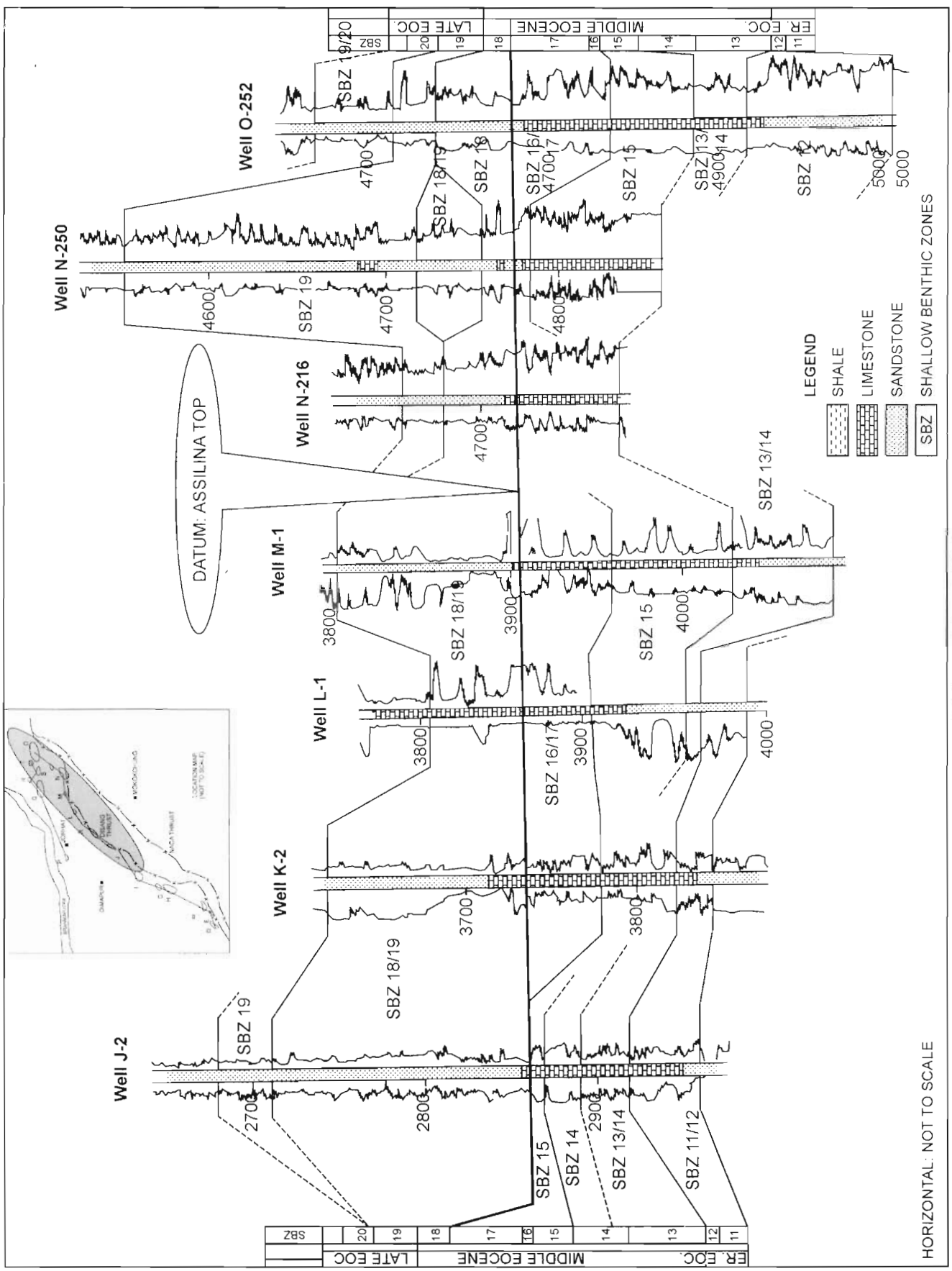

Fig. 4b. Biostratigraphic correlation of shallow benthic zones (SBZ) along wells J-2 to O-252, Assam-Arakan shelf, India.

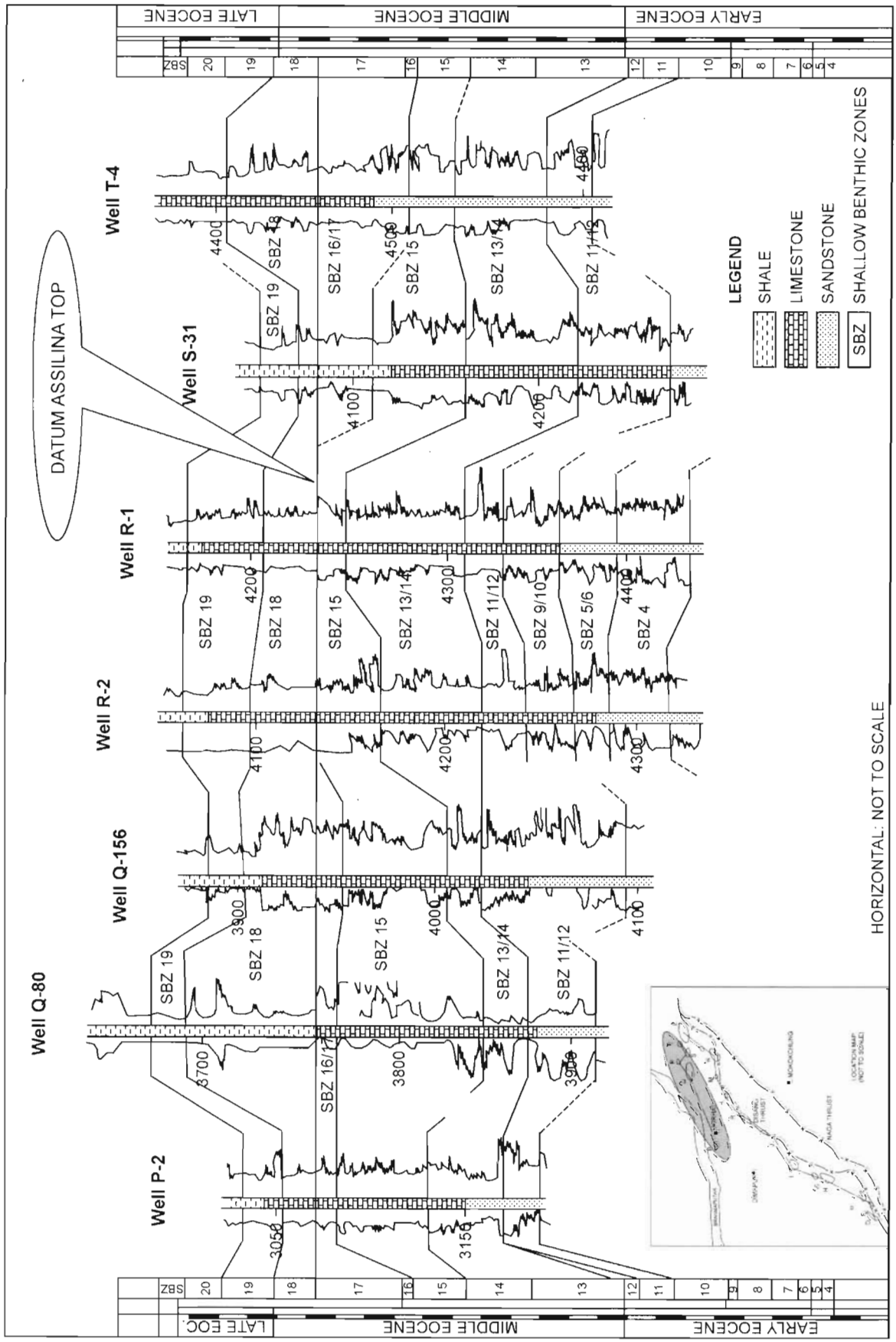

Fig. 4c. Biostratigraphic correlation of shallow benthic zones (SBZ) along wells P-2 to T-4. Assam-Arakan shelf, India.

2100-2472 m to SBZ 20 or younger zones. The interval (2639-2757) represents non diagnostic foraminifera.

In the Dhansiri valley area, SBZ 11/12 could be identified in wells **D 1, G 1, H 12, J 2 K 2** and **L 1.** In **D 1**, the depth interval 3750-3800m corresponds to SBZ 11/12; depths 3670-3750m to SBZ 13; 3620-3670m to SBZ 14 ; 3550-3620m to SBZ 15/17 ;3510-3550 to SBZ 18; and 3405-3510m to SBZ 18/19. In **E1,** the basal section between 4360-4380m could not assigned to any SBZ; depths 4336-4360m is assigned to SBZ 13; depths 4300-4336m to SBZ 14; depths 4240-4300m to SBZ 15/17; depths 4215-4240m to SBZ 18; depths 4045-4215m to SBZ 19/20 and depths 3975-4045 to ?SBZ 20. The interval 3300-3375m has arenaceous foraminifera. In the well **F1,** the basal section between interval 4440-4500m is assigned to SBZ 13; interval 4320-4440 to SBZ 14; interval 4200-4320m to SBZ 15/16; interval 4130-4200m to 16/17; interval 4105-4130m to SBZ 18; interval 3885-4105m to SBZ 19 and interval 3800-3885m to ?SBZ 20.

In the Khoraghat-Nambar area, well **G 1** has SBZ 11/12 in the interval 2650-2690m. The interval 2640-2650m may be referred to SBZ 13/14; interval 2620-2640m to SBZ 14; interval 2500-2620m to SBZ 15/16; interval 2490-2500m to SBZ 16, interval 2470-2490m to SBZ 17; interval 2440-2470m to SBZ 18; interval 2420-2440m to SBZ 19, interval 2370-2420m to SBZ 19/20 and interval 2260-2370 to ?SBZ 20. In the well **H 12**, basal interval 3215-3265m is assigned to SBZ 11/12; interval 3200-3215m to SBZ 13/14; interval 3180-3200m to SBZ 14, interval 3120-3180m to SBZ 15/16; interval 3060-3120m to SBZ 17; interval 3030-3060m to SBZ 18; interval 3020-3030 m to SBZ? 18; and interval 3005-3020m to SBZ 19.Further up, smaller benthic and arenaceous foraminifera are reported, in the remaining Paleogene section. In well **I 1**, basal interval 2240-2285m is assigned to SBZ 15/16; interval 2200-2240m to SBZ 17; interval 2140-2200m to ?SBZ 18 (because of occurrence of recycled forms); interval 2115-2140m to SBZ 18; and interval 2050-2115m to SBZ 19. Further up arenaceous foraminifera dominate the interval 2005-2050m.In the well **J 2** the oldest SBZ identified 11/12 between depth interval 2920-2960m. This is followed by interval 2890-2920m referred to SBZ 13/14; interval 2870- 2890m to SBZ 14; interval 2865-2870 to SBZ 15; interval 2710-2865m to SBZ 18/19 ; and interval 2680-2710m to SBZ ?19. In well **K 2**, the basal interval (sediments) between 3825-3845m are assigned to SBZ 11/12; followed by interval 3780- 3825m referred to SBZ 13/14; interval 3735- 3780m to SBZ 16/17; 3620-3735m to ?SBZ 18/19. The younger sediments between 3135-3620m largely comprises arenaceous foraminifera. In the well **L 1**, the oldest biozone SBZ 11/12 could be identified between depth interval 3966-3996m. Above it, the interval 3954- 3966m is referred to SBZ 13/14; interval 3900–3954m is referred to SBZ 15; interval 3864-3900m to SBZ 16/17 and interval 3804-3864m to SBZ 18/19.The well section between 3774-3804m has smaller benthic foraminifera only. In well **M 1**, interval 4030-4095m is assigned to SBZ 13/14; interval 3905-4030m to SBZ 15/17; and interval 3800-3905m to SBZ 18/19. The overlying section between depths 3300-3800m largely comprise smaller benthic and or arenaceous foraminifera.

In the Geleki area, two wells **N 216 and N 250** were taken up. In well **N 216**, the oldest SBZ identified is SBZ 15/17 between depth intervals 4720-4780m. The interval 4680-4720m is assigned to SBZ 18; interval 4655-4680m to SBZ 19. The overlying intervals 4560-4655m and 4100-4560m respectively contain smaller benthic and arenaceous foraminifera. In well **N # 250**, the basal interval 4785-4865m may be referred to SBZ 15; interval 4775-4785m to SBZ 16/17; and interval 4755-4775m to SBZ 18. The interval 4720-4755m has not yielded foraminifera, whereas interval 4550-4720m with larger foraminiferal species may be assigned to SBZ 19. In the well **O 252**, the basal section between 4920-5016m is assigned to SBZ-12 interval 4890-4920m to SBZ 13/14; interval 4840-4890m to SBZ 15; interval 4785-4840m to SBZ 17/16; interval 4740-4785m to SBZ 18; and interval 4715-4740m to SBZ 19. The overlying interval 4670-4715m largely comprises smaller benthic and arenaceous foraminifera non-suggestive of any definite shallow benthic zonation.

On another strike line (B-B) close to the present course of river Brahmaputra and starting from well **P 2**, the following inferences are drawn. In the well **P 2,** the basal sediments between depths 3170-3190m are assigned to SBZ-11.The overlying interval 3130-3170m may be assigned to SBZ 13./14; interval 3080-3130m to SBZ 15; interval 3070-3080m to SBZ 16/17; interval 3050-3070m to SBZ 18 and interval 3030-3050m to SBZ 19. The overlying sediments between interval 2860-3030m and 2800-2860m, respectively, comprise smaller benthic and arenaceous foraminifera. In the well **Q 80,** the basal section between 3875-3915m may be referred to SBZ 11/12, interval 3850-3875m to SBZ 14/15, 3769-3850m to SBZ 15; interval 3760-3769m to SBZ 16/17, interval 3690-3760m to SBZ 18, and interval 3670-3690m to SBZ 19. The overlying section between 3440-3670m largely comprises smaller benthic foraminifera and may partly belong to SBZ 20. In well **Q 156**; the basal interval between 4025-4100m may be assigned to SBZ 13 or older; interval 4005-4025m may be referred to SBZ 14/15, interval 3950-4005m to SBZ 15; interval 3935-3950m to SBZ 16/17, interval 3900-3935m to SBZ 18; and interval 3880-3900m to SBZ 19. In the well **R 2,** the basal section between depths 4322-4355m is believed to exhibit caved-in foraminifera, hence not assigned to any SBZ. The interval 4290-4322m may be assigned SBZ 4; interval 4270-4290m to SBZ 5/6; interval 4244-4270m to SBZ 10; interval 4220-4244m to SBZ 11/12; interval 4165-4220m to SBZ 14/15; interval 4130-4165m to SBZ 15; interval 4095-4130m to SBZ 18; and interval 4060-4095m to SBZ 19. The overlying section successively depicts smaller benthic and arenaceous assemblages. In the well **R 1**, eight biozones could be identified in stratigraphic order. The basal section between interval 4390-4430m may be assigned to SBZ 4. The interval 4430-4445m is believed to comprise foraminiferal caving. Interval 4360-4390m may be assigned to SBZ 5/6; interval 4330-4360m to SBZ 9/10; interval 4310-4330m to SBZ 11/12; interval 4245-4310m to SBZ 14/15; overlying interval 4230-4245m to SBZ 15; interval 4200-4230m to SBZ 18; and interval 4160-4200m to SBZ 19. The overlying section contains smaller benthic and arenaceous foraminifera, successively. In the well **S 31**, the basal interval between 4220-4270m may be assigned to SBZ 12; interval 4160-4220m to SBZ 13/14; interval 4110-4160m to SBZ 15; interval 4080-4110m to SBZ 16/17; interval 4070-4080m to SBZ 18; and interval 4050-4070m to SBZ 19. The overlying interval 3820-4050m comprises sporadic occurrence of smaller benthic foraminifera and globular bodies, which could not be assigned to SBZ scheme. In the well **T 4**, only few foraminiferal slides could be examined in the basal part of the lower Palaeogene section, as most of the assemblage slides were affected by flood water. The basal section between interval 4575-4600m may be assigned to SBZ 11/12; interval 4525-4575m to SBZ 13/14; interval 4500-4525m to ? SBZ 15, interval 4450-4500m to SBZ 16/17; and interval 4400-

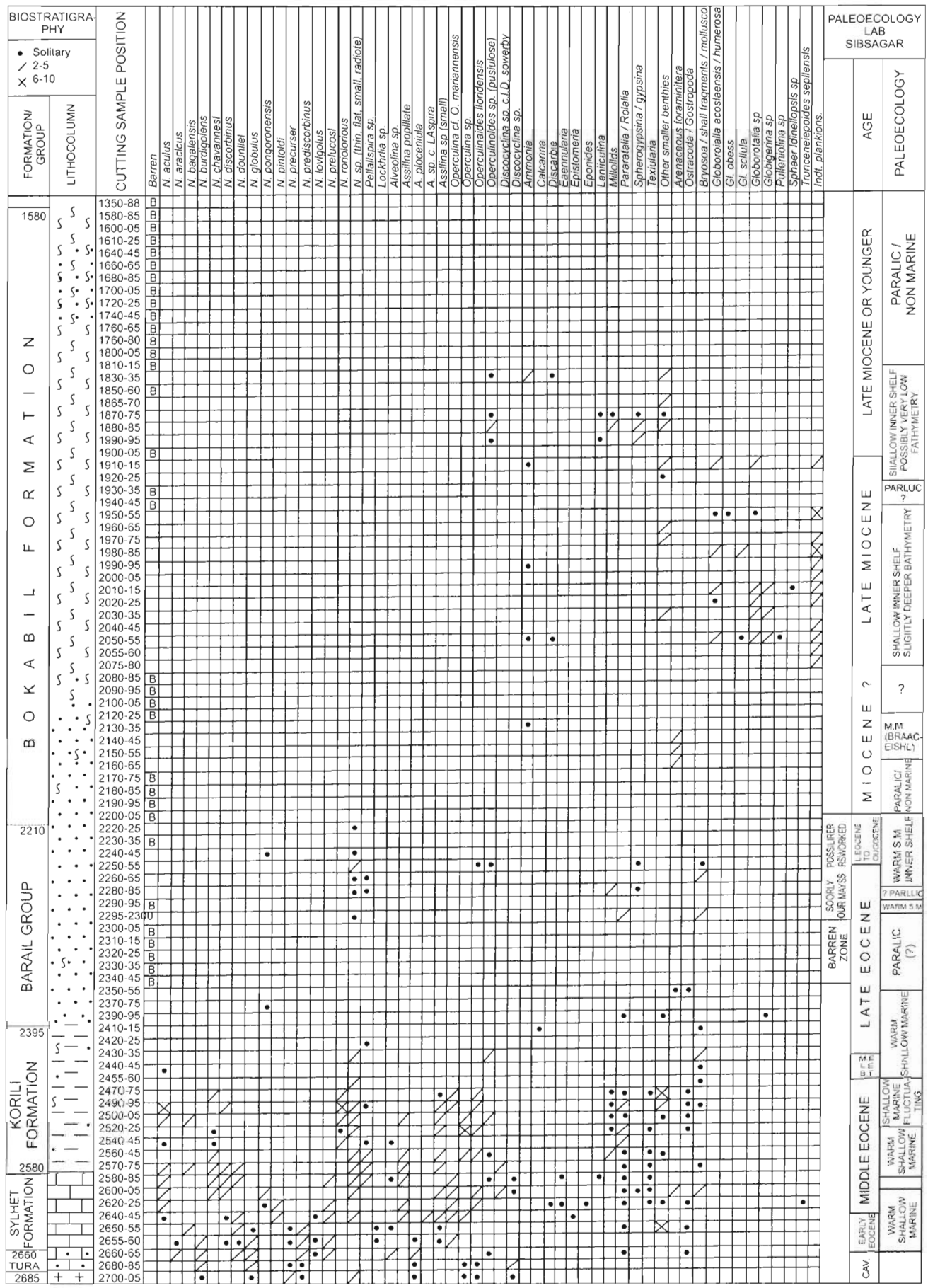

Fig. 5. Foraminiferal distribution, age and palaeoecology well G-1.

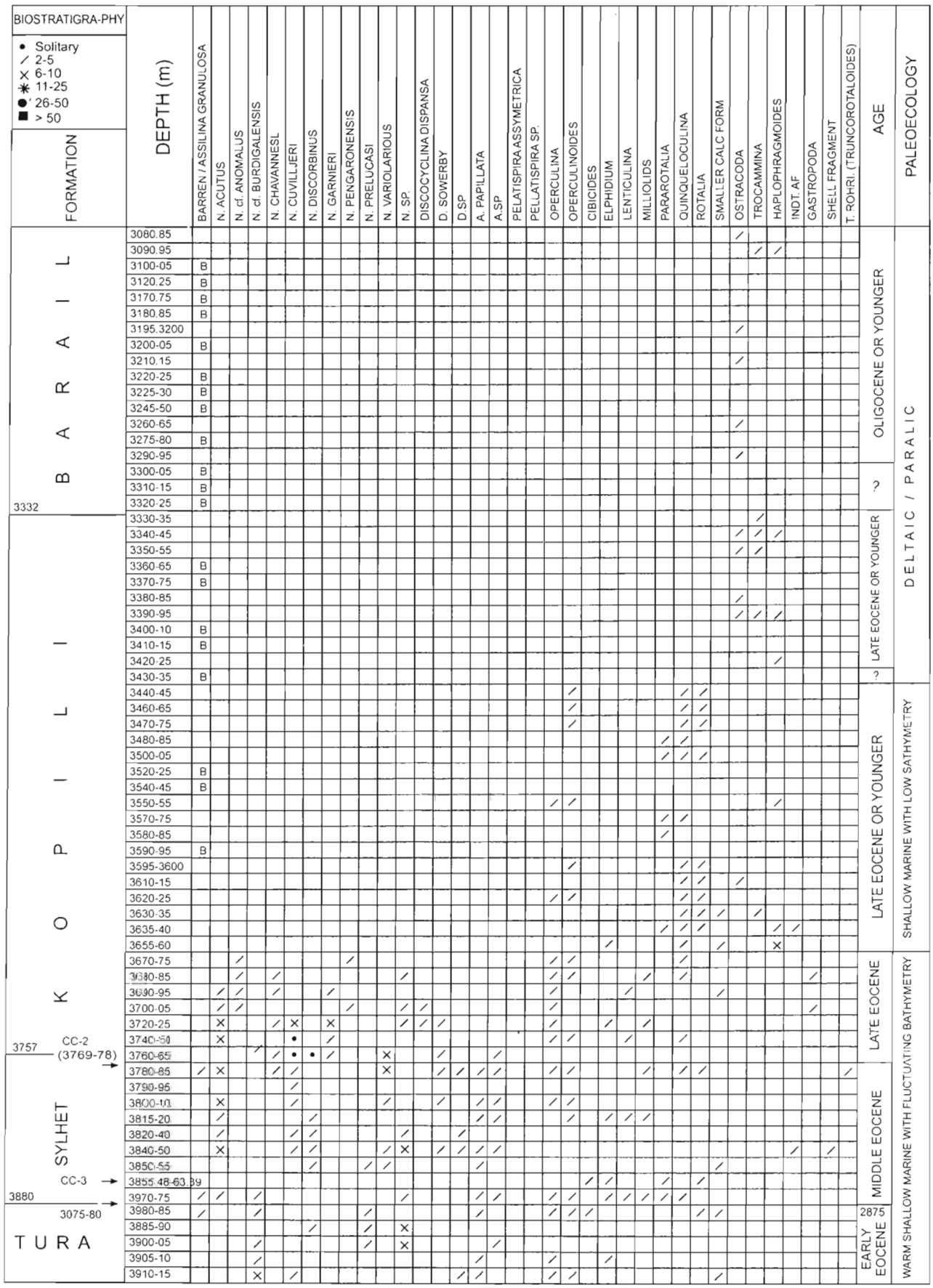

Fig. 6. Foraminiferal distribution, age and palaeoecology well # Q.

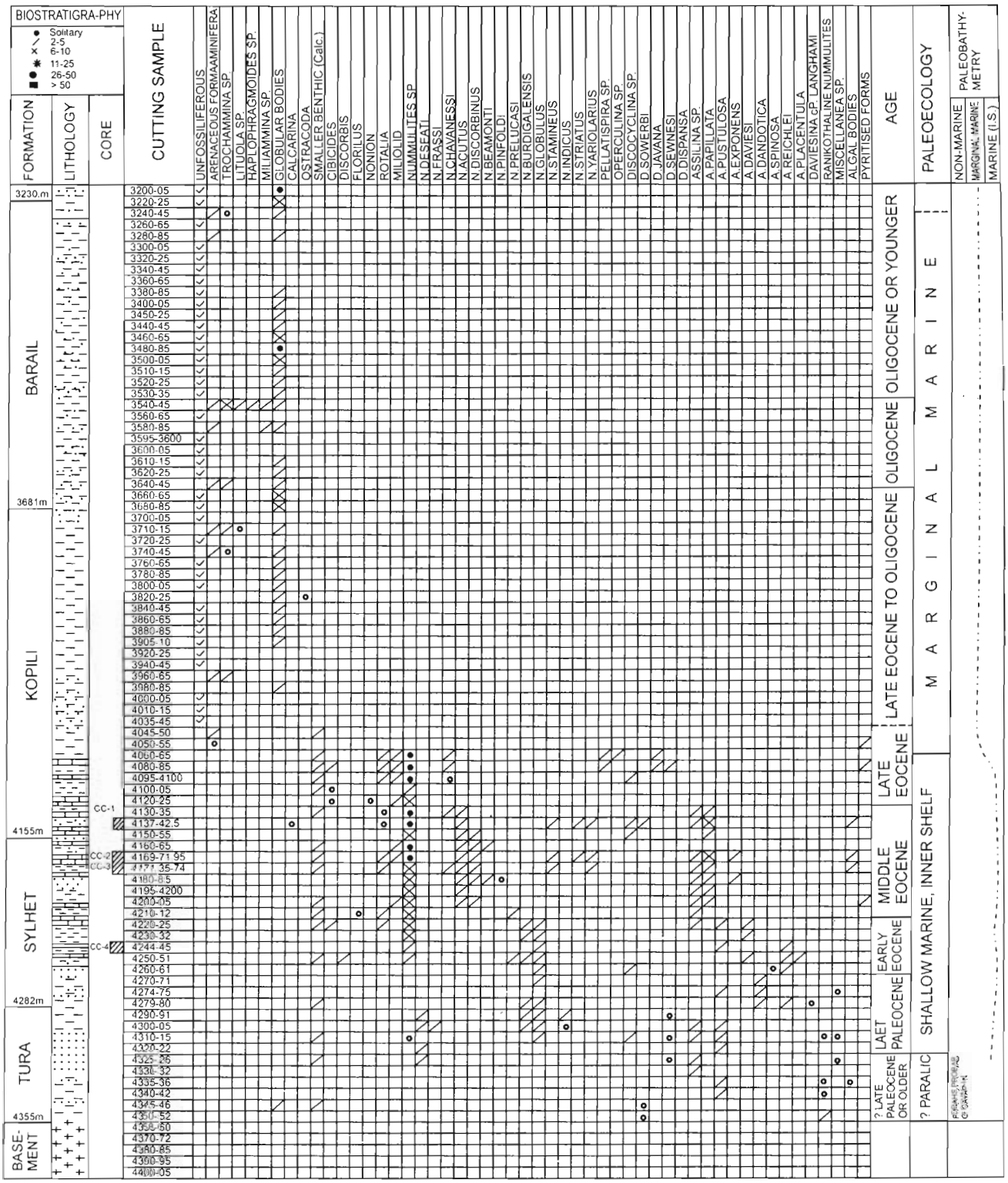

Fig. 7. Foraminiferal distribution, age and palaeoecology well # R.

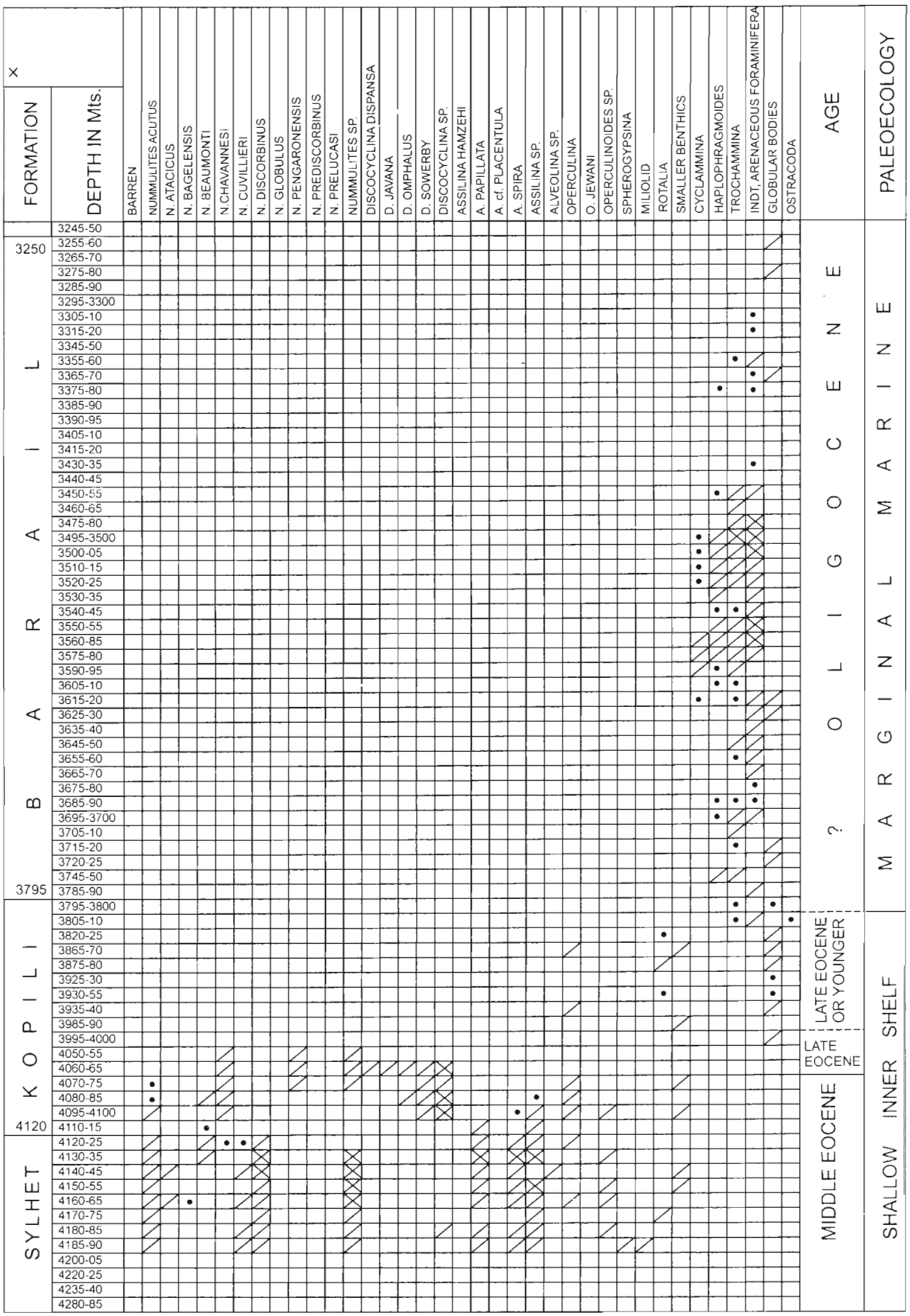

Fig. 8. Foraminiferal distribution, age and palaeoecology well # S.

4450m to SBZ 18. The overlying interval 4100-4400m largely comprises smaller benthic and arenaceous foraminifera, successively.

All the identifiable shallow benthic zones are correlated across the studied wells. The SBZs are superimposed on the litho- and electrologs to observe possible similarities/dissimilarities across the correlation profile. However, generally it has been observed that the bio-zones may not follow the litho-boundaries or the electrolog-based divisions.

DISCUSSION

The marine palaeoenvironmental conditions are known to transgress through the Cretaceous/Tertiary boundary [K/T boundary] in the South–Shillong plrteau especially during the deposition of the Langpar sediments, which also depict a change from clastic to carbonate sedimentation in the Khasi Hills. It is generally believed that the middle Eocene marine transgression was most widespread over the Assam-Arakan shelf. The late Eocene regressive facies are dominantly clastic with gradually decreasing frequency as well as diversity of calcareous foraminifera, Further up, it grades into the deltaic-paralic facies with few calcareous and dominantly arenaceous foraminifera. However, the pre-Barail section provides good larger benthic foraminiferal indices to determine the ages, biozonations and paleoenvironments in the entire area.

While studying the well sections (with cutting samples) for faunal analysis, it is a matter of common constraint to eliminate the caved-in forms and know the true contents of the assemblage along with LADs, etc. In the absence of continuous cored intervals or the outcrop sections, the possibility of non-demarcation of one or more shallow benthic zones increases. In such situation, clear demarcation of top and bottom of individual shallow benthic zones may be difficult and often more than one shallow benthic zone could be inseparable in a given interval. However, we have tried to overcome this constraint to the extent possible and have correlated different wells utilizing a common datum plane. In addition, we proposed record of an Indian equivalent species and zonation for SBZ of Serra-Kiel *et al.* (1998), for the first time in an Indian Basin.

Serra-Kiel *et al.* (1998) suggested that the abundance, diversity and high evolutionary rates make larger foraminifera useful biostratigraphic indices for dating the shallow marine sediments. Each SBZ has one or more key elements, multiple FAs (First appearance) and LAs (Last appearance) and concurrence of several taxa. Presently, SBZ 1 to 20 ranging in age from Palaeocene (Danian) to Eocene (late Priabonian) were studied and occurrence of one or more zones in the respective well sections, attempted. In the well cuttings, many times a single SBZ is not traceable, however, the total or concurrent range of few index species suggest an interval belonging to more than one SBZ, i.e. SBZ 15/17. For the purpose of correlation, the top of *Assilina* sp. has been taken as the correlation datum and all the wells have been correlated along this plane. The *Assilina* top in most of the Assam shelf wells, roughly corresponds to the top of middle Eocene and barring a few early ecological eliminations, the same could be traced all through the basin. While dealing with the *Assilina* top, the problem of respective *Assilina* species tops i.e. *Assilina papillata* top; *A hamzehi* top or *A. spira* top vis a vis the generic top which is slightly higher to the mentioned species, was observed. Therefore, following the SBZ scheme, *A papillata* top in all the wells are referred to SBZ 15 and *Assilina* sp. top to SBZ 17. For the purpose of correlation, the zonal tops are joined together with the nearby wells, after deciding and interpreting the faunal assemblages present in each well.

CONCLUSIONS

Tethyan shallow benthic zones [SBZ] for 23 wells, spread across the shelf, covering areas from South Shillong, Dhansiri valley and upper Assam, have been proposed to provide basic framework for high impact biostratigraphic / sequence stratigraphic studies.

Use of local bio-events and their mapping under different paleoenvironmental set ups during Paleocene–Eocene times has provided finer biostratigraphic divisions for stratigraphic modeling. Integration of such data with other geological information would be immensely useful in the stratigraphic traps exploration.

Recognition of marine early Eocene sediments referable to SBZ 11/12 in the Dhansiri Valley, particularly Rajaphe, Nambar, Khoraghat, Mekrang, Mariani and Naginijan areas suggests onset of marine transgression during upper Ypressian [Cuisian, upper part] times. The oldest marine sediments referable to SBZ 4, SBZ 5 / 6 and so on are from Panidihing area and belong to late Palaeocene and basal early Eocene ages. The marine transgression appears to have started earlier in this area.

Preservation of older sediments in different areas over the shelf indicates the palaeogeographical conditions. A number of small unconformities or hiatus may also be observed in individual wells / areas.

Indian equivalent species for each SBZ have been worked out (Table 1) and include both the Tethyan key foraminifera and concurrent shallow larger benthic species to act as the local reference for future studies.

Top of *Assilina* sp has been taken as the correlation datum for all the wells. This level almost corresponds to the top of middle Eocene in the area. The SBZ 18 is transitional and corresponds to the middle Eocene/late Eocene boundary span.

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