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Contribution to the Foraminiferal Biostratigraphy and Paleoecology of the Pyawbwe Formation, Sakangyi – Thayet Area, Myanmar

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Authors' contributions

This work was carried out in collaboration between all authors. Author SML designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors RMEG and NPO managed the analyses of the study. Author OH managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Litho- and foraminiferal biostratigraphic studies were carried out on the Lower Miocene siliciclastic Pyawbwe Formation exposed at Sakangyi area, Myanmar. The investigated planktonic and benthonic foraminiferal species showed great similarities and close affinities to those of the Mediterranean Region. The studied planktonic foraminifera were grouped into three globally foraminiferal biozones compared with standard biozones N4, N5, N6 and N7. The benthonic foraminifera revealed two locally biozones arranged from base to top as follows; 1- *Ammonia beccarii* and 2- *Bolivina vaceki* Zones. Three abundant foraminiferal assemblages are defined, characterised and documenting three environmental factors, energy levels, oxygen levels and water productivity. Near the base and top of the section both foraminiferal taxa abundance and diversity are very extremely low, corresponding to the increased sand content indicating high

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energy levels and turbidity. The Pyawbwe Formation may be deposited under shallow marine. The middle part of the section was deposited in relatively deeper marine conditions (> 30 m. to 150 m. depth) and regressed in upper most parts to lagoon depth less than 30 m.

Keywords: Pyawbwe formation; Myanmar; biostratigraphy; biozone; Mediterranean Region.

1. INTRODUCTION

Myanmar is made up of a mosaic of tectonostratigraphic terranes. More data and detailed tectonic-stratigraphy are greatly explained by works of [1,2,3,4,5] and others of these, tectonostratigraphic belts, the Central Myanmar (Burman) Basin (Fig. 1). It is divided into several Tertiary sub-basins along its nearly 1100 km. length. The sub-basins have been almost filled since the Indo-Asian collision [1,2,3,4,5]. These sub-basins may have formed as a series of *en echelon* pull-apart basins trending approximately NW-SE with about 50 km. wide in the Early Eocene as the Burma Plate moved northward relative to the Asia Plate [6,7]. A 15 km majorly succession of Cenozoic deposits was found in Central Myanmar Belt [7]. Recently, Central Myanmar Basin attracted the geological attentions of several workers as [8,9,10] and others because of discoveries of hydrocarbons in Miocene and post Miocene sediments. The faunal and lithological variations across the Lower Miocene siliciclastic Pyawbwe Formation succession in the Sakangyi-Thayet area, Myanmar, have not been studied in detail before. However, few and general studies have been done on the foraminiferal micropaleontology of the Pyawbwe Formation of the Central Myanmar Basin as [11,12,13] outside the present study area. The present study presents detailed information on the conditions that have prevailed during the sedimentation of the Pyawbwe Formation across the Sakangyi-Thayet area, and evaluate the climatic and paleoceanographic history of the low-latitude Tethys continental shelf of Lower Miocene siliciclastic Pyawbwe Formation. The study area is currently situated in the Thayet Suddle and northern margin of the Pyay Sub-Basin (Fig. 1A). It is structurally complex trending NNW –SSE with many folds and fault systems (Fig. 1B & 1D). It is majorly fallen in the Sakangyi anticline to the north of the Thayet, bounded by Tokkaing syncline in the west and Thayet thrust fault to the east. This structure is cored by the Pyawbwe Formation and surrounded by middle Miocene to Pliocene sediments (Fig. 2). Stratigraphically, the Pyawbwe Formation lies between the Okhmintaung Formation (Upper Oligocene) at lower and the Kyaukkok Formation (Middle Miocene) at the upper level (Fig. 1C). In general, all the rocks belonging to the Oligocene – Miocene ages are mainly built up conglomerate, sandstone, mud, siltstone, shale and claystones. Lithologically, the Pyawbwe Formation consists of blue grey shales and clays.

2. LITHOSTRATIGRAPHY

The early Miocene Pyawbwe Formations is well exposed at Sakangyi-Thayet area near Thayet Saddle and near the northern margin of the Pyay embayment. This basin is mainly composed of siliciclastic deposits. Lithologically, Pyawbwe Formation (820 m. majorly, Fig. 3) is essentially represented by grayish – blue argillaceous sandy and silty clays and thick fairly soft clays interbedded with four sandstone members with minor disseminated gypsum veinlets (Plate 1). The interbedded sandstones are calcareous, fairly indurated bedded to fine to medium grained and with some trace fossils in the middle members. In the middle parts of the formation, the clays and shales are soft, light to bluish grey and thin bedded to massive with nodular shale. The shales and clays are structured with sandstone geodes (10 cm. in diameter) and calcite crystals in the middle and upper part. The Pyawbwe Formation is highly rich in foraminiferal content by means of which the formation can be differentiated from the overlying Kyaukkok Formation. It is well distributed in the study area and noted along the western bank of Ayeyawaddy River (Fig. 1B) and the northern part of the Thayet town. The Pyawbwe Formation is stratigraphically overlain conformably by the Kyaukkok Formation (early to middle Miocene) and underlain unconformable by Okhmintaung Formation (late Oligocene). The Pyawbwe is bounded by upper and lower beds of sandstones.

3. MATERIALS AND METHODS

The investigated materials come mainly from the exposed Pyawbwe Formation at the Sakangyi-Thayet area (Fig. 3). About hundreds of samples were collected, only 16 interval samples (from P1 to P16) represent the whole formation sequence covering the stratigraphic intervals of the Early Miocene were studied and investigated for their foraminiferal assemblage. For the study of the planktonic and benthonic foraminifera, samples were disaggregated in water and washed through a 100 µm sieve. Each sample was cleaned using ultrasonic agitation, with washing repeated until a clean foraminiferal residue was recovered. The final residue was dried in an oven at a temperature below 50°C. About 30 gm of the washed residue from every sample was checked under the stereomicroscope to pick up the index planktonic and benthonic foraminiferal groups.

All the studied materials are stored with the present third author in the Geology Department, Yangon University, Myanmar.

4. FORAMINIFERAL BIOSTRATIGRAPHY

4.1 Planktonic Foraminiferal Biostratigraphy

The planktonic foraminiferal analysis was carried out on a total of 16 Interval-samples (from P1 to P16) (Fig. 3). Distribution patterns have been constructed counting about 1161 specimens of all planktonic species from splits of the total sample. There are recorded 19 planktonic foraminiferal species of 7 genera covering the studied Pyawbwe Formation (Table 1a & 1b), Plate (2) [19,20,21,22].

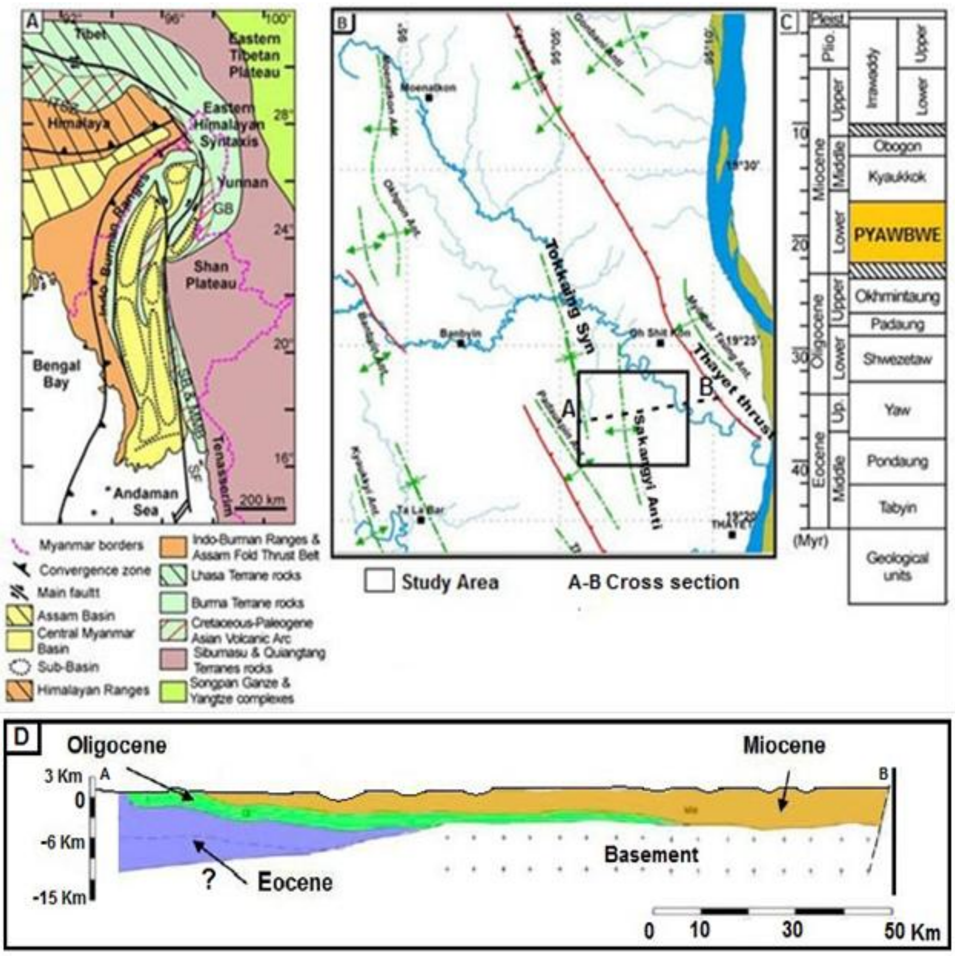


Fig. 1. (A) Simplified geological map of central Myanmar Basin after [14].
(B) Detailed structural map of the study area in Central Myanmar (partially Pyay sub-basin, [15]).
(C) Schematic stratigraphic log of the Central Myanmar Basin [16] showing the stratigraphic position of the Pyawbwe Formation.
(D) Schematic cross section across through the study are (Generally modified from [2])

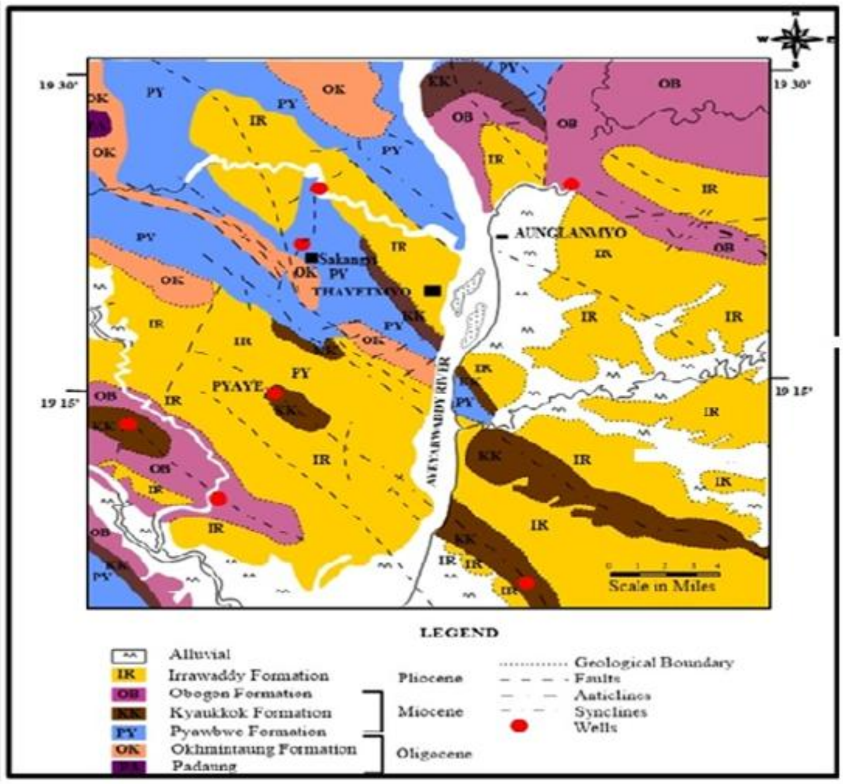


Fig. 2. General geological map showing distribution of the Pyawbwe Formation around the Central Myanmar Basin, Pyay Sub-Basin, Sakangyi- Thayet area (after [17])

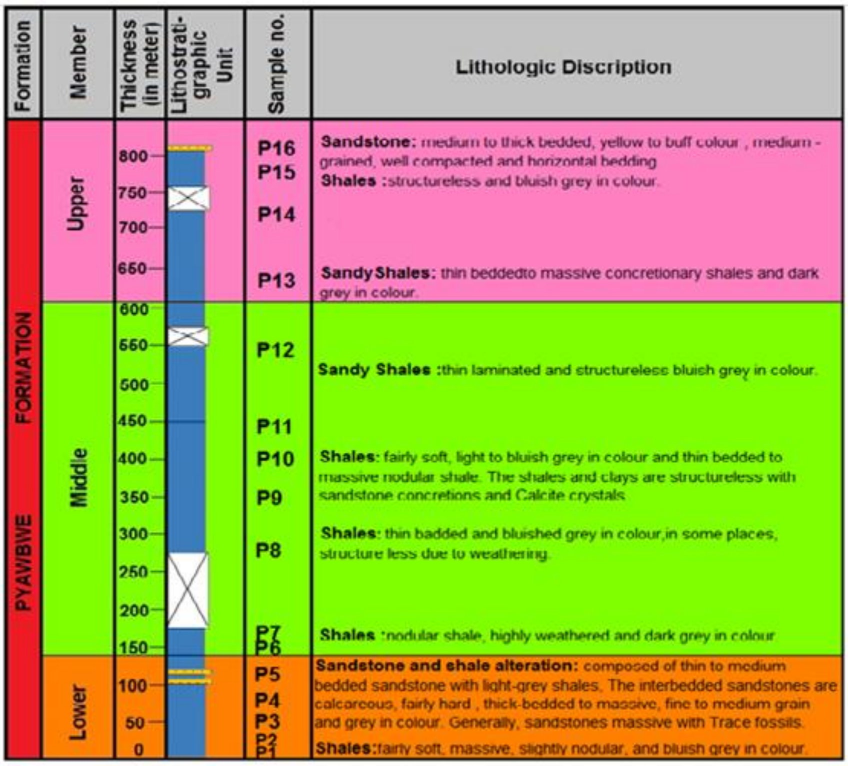


Fig. 3. Columnar section of the Pyawbwe Formation, Sakangyi area, Myanmar

Plate 1. (1): Light grey,thin-bedded to massive concretionary shales, (2): Bluish –grey, thin-bedded to massive concretionary shales exposed in the Upper part of the Pyawbwe Fm., (3): Thin-to medium bedded dark bluish grey shales, (4): Light-grey, majorly bedded to massive sandstone with trace fossils (*Dendrophyllia* sp.) exposed in the middle part of the formation, (5): Thin-to medium bedded,dark bluish grey shales, (6): Bluish-grey, majorly-bedded to massive, silty shales and siltstones with fine –grained, thin-bedded sandstones, (7): Light-grey ,majorly -bedded to massive, silty shales and siltstones, (8): Massive, light grey, slightly mottled clay exposed in the lower part of the formation, (9): Massive, Light grey, slightly mottled clay exposed in the lower part of the formation, (10): Light grey, slightly mottled clay exposed in the lower parts of the Pyawbwe Formation

The distribution of the taxa is listed in Fig. 4. The highest population was in sample P8 –Interval while the lowest population was in samples P5 and P12. The abundance arrangements of the planktonic foraminiferal taxa are as follows in descending order: *Globorotaloides variabilis* Bolli, *Globigerina praebulloides* Blow, *Globigerinoides triloba* (Reuss) and *Globigerina trilocularis* Orbigny (Fig. 4). The planktonic foraminifera are abundant only in middle part of the studied section showing moderate preservation. In spite of a minor resolution, planktonic foraminiferal bioevents of the Pyawbwe Formation (Fig. 5) are recorded as in the time equivalent index fossils and composition as with those of the Mediterranean sequences [28].

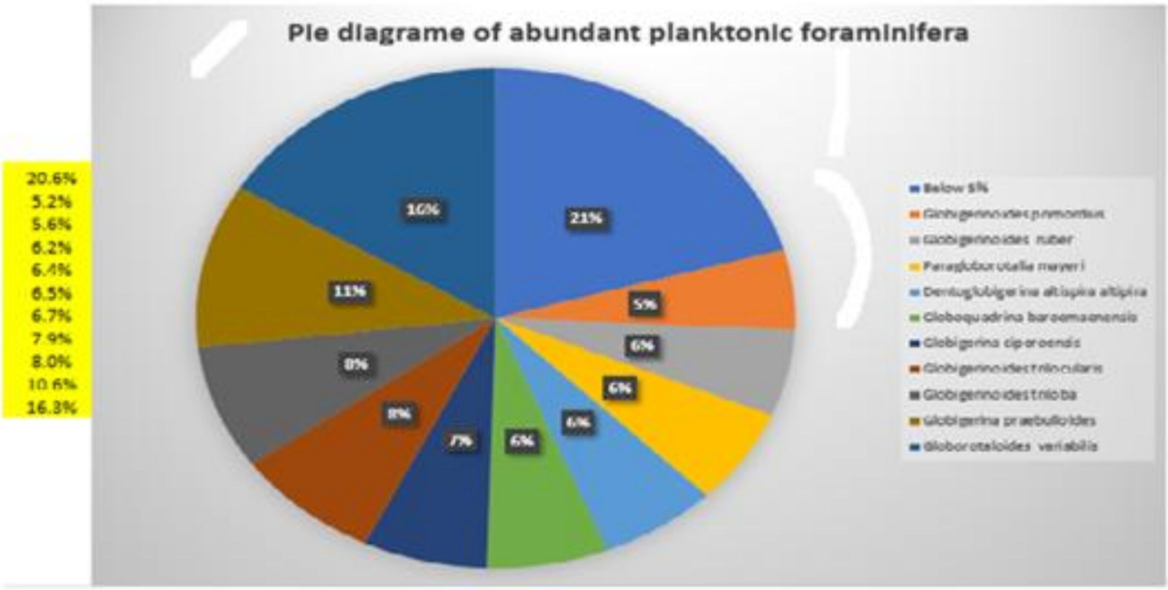
The quantitative distribution patterns of 19 planktonic foraminiferal taxa (Table 1a & 1b) show some categories represent different taxa linked by morphological or phyletic affinities. *Globigerina praebulloides* Blow has been a characteristic species for the Mediterranean Middle Miocene [28], while it shows limited distribution through Early Miocene Pyawbwe Formation and represents the most popular taxon in the middle part (especially P8). This observation emphasises that this taxon flourished in certain ecological conditions.

Globigerinoides quadrilobatus (Orbigny) group contains *Globigerinoides quadrilobatus* (Orbigny) and *Globigerinoides triloba* (Reuss). *Dentoglobigerina altispira altispira* (Cushman and Jarvis) is referred to *Globoquadrina baroemoensis* (Le Roy). Most of the recorded taxa having discontinuous distribution may due to ecological sedimentation factors. We consider the appearance / disappearance of marker species which are used here as biohorizones. The results, as well as, adopted biozonal scheme are represented in Fig. 5.

Table 1a. Total abundance of the identified planktonic foraminiferal species, Pyawbwe Fm., Sakangyi area, Myanmar

No.	SUMPLE NUMBERS / FORMANIFORI SPECIES	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	Total Number
1	*Globigerina ciperoensis*				2				76									78
2	*Globigerina praebulloides*		1		1	1			116		1	1	2					123
3	*Globigerina praeturritilina*								4									4
4	*Globigerina rohri*								44									44
5	*Globoquadrina baroemaenensis*								76									76
6	*Globigerinoides altiaperturus*		1						8									9
7	*Globigerinoides primordius*		3		1			2	54									60
8	*Globigerinoides bispherica*								4		3	2				2		11
9	*Globigerinoides trilocularis*		2		2				88									92
10	*Globigerinoides triloba*								84		2	3				4		93
11	*Globigerinoides quadrilobatus*								16									16
12	*Globigerinoide ruber*								64			1						65
13	*Paragloborotalia mayeri*					1		2	66			3						72
14	*Globorotaloides suteri*		2						48							1		51
15	*Globorotaloides variabilis*								189									189
16	*Globoquedrina dehiscens*				1				52		1	2						56
17	*Dentoglobigerina altispira altispira*		3						70							1		74
18	*Catapsydrax dissimilis*		2															2
19	*Globigerinella praesiphonifera*								44							2		46
	Total numbers of population	0	18	0	7	2	0	4	1099	0	7	12	2	0	0	10	0	1161

Table 1b. Pie diagrame of abundant planktonic foraminifera



The zonal marker used here are the same those used in several Mediterranean Miocene sections [23,24], with the improving biochronological calibrations [25,26]. The stratigraphic distribution of the identified taxa is shown in Fig. 4.

Three planktonic foraminiferal zones are recognised in the Pyawbwe Formation of the Sakangyi-Thayet area. The recognised zones are discussed in an ascending order (Figs. 5 & 6).

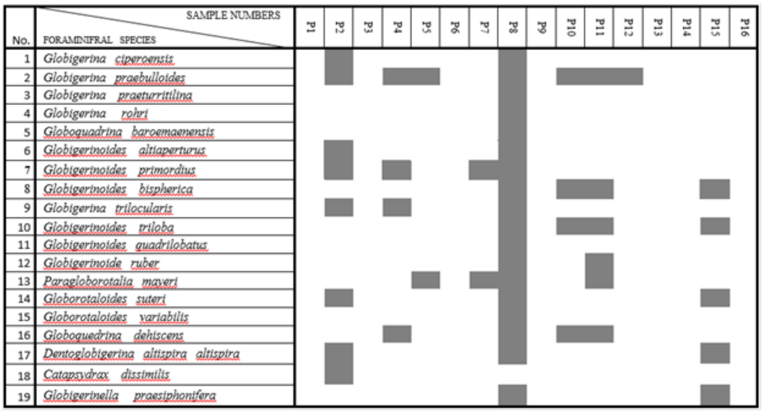


Fig. 4. Range chart of the identified planktonic foraminiferal species, Pyawbwe Formation, Sakangyi area, Myanmar

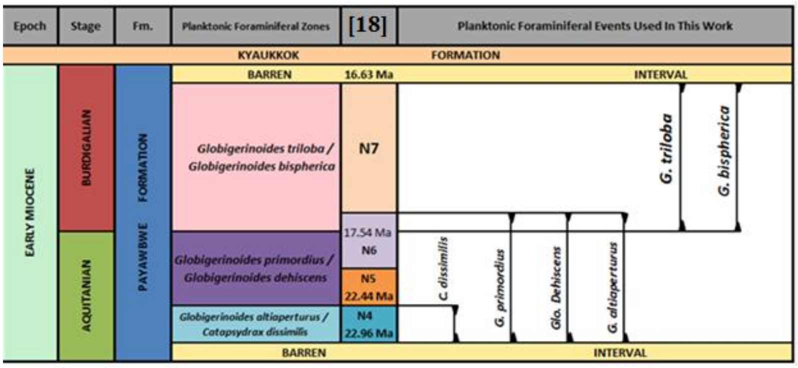


Fig. 5. Range chart and bioevents of the zonal marker planktonic species used in this work against the time scale of [25], the Pyawbwe Formation, Sakangyi area, Myanmar

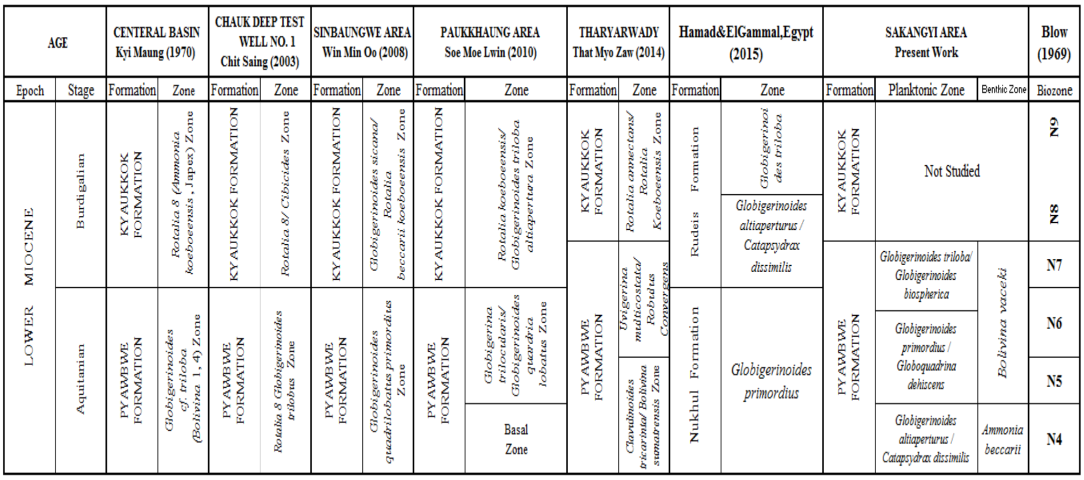


Fig. 6. Comparison between the results of the present work and the previous related planktonic foraminiferal zonal schemes of the Early Miocene in Myanmar and general world wide

Plate 2. Selected important and marked foraminiferal taxa
1. Catapsydrax dissimilis **(Cushman and Bermudez,1937).** ***2. Globorotaloides variabilis*** **Bolli, 1957.** ***3. Globigerina trilocularis*** **Orbigny, 1826.** ***4. Globigerina praebulloides*** **Blow, 1959.** ***5. Globigerinoides altiaperturus*** **Bolli, 1957.** ***6. Globigerinoides bispherica*** **Todd, 1954.** ***7. Globigerinoides primordius*** **Blow and Banner, 1962.** ***8. Globigerinoides triloba*** **(Reuss, 1850).** ***9. Globoquadrina dehiscens*** **(Cushman, Parr and Collins, 1934).** ***10. Globigerina praeturrtilina*** **Blow and Banner, 1962.** ***11. Bathysiphone abuillotoensis*** **Bermudez, 1949.** ***12. Haplophragmoides carinatus*** **Cushman and Renz, 1941.** ***13. Haplophragmoides reticulatus*** **Boomgaart, 1949.** ***14. Bolivina caudriae*** **Cushman and Renz, 1941.** ***15. Bolivina vaceki*** **Schubert, 1901.** ***16. Bulimina aculeate*** **Orbigny, 1826.** ***17. Bulimina striata*** **Orbigny, 1832.** ***18. Uvigerina mediterranean*** **Hofker, 1932.** ***19. Cibicides bantamensis*** **Le Roy, 1939.** ***20 & 21. Ammonia beccarii*** **(Linnaeus, 1758).** ***22. Uvigerina carapitana*** **Hedberg, 1937.** ***23. Uvigerina costata*** **Beida, 1936.** ***24. Cibicides dorsoputulosus*** **Le Roy, 1939.** ***25. Lenticulina americana*** **(Cushman, 1918)**

4.1.1 *Globigerinoides primordius / Globoquadrina dehiscens* Zone (Interval Zone)

Author: [18]

Age: Early Miocene (Aquitanian)

Definition: as the interval of last occurrence of both *Globigerinoides primordius* Blow and Banner and *Globoquadrina dehiscens* (Chapman, Parr and Collins) and still *Globigerinoides triloba* (Reuss) does not appear at this level interval.

Remarks: It may correlate with N5 and partly lower N6 of [18]. It includes an assemblage of *Paragloborotalia mayeri* (Cushman and Ellisor), *Globigerina trilocularis* Orbigny, *Globigerina praebulloides* Blow, *Globigerina ciperoensis* Bolli, *Globigerinoides primordius* Blow and Banner and *Globoquadrina dehinscens* (Chapman, Parr and Collins).

Thickness: It covers the lower parts to partially lower of the middle part of the Pyawbwe section (Interval samples from P1 to P3).

4.1.2 *Globigerinoides altiaperturus/ Catapsydrax dissimilis* (Concurrent Range Zone)

Author: [27]

Age: Early Miocene (Burdigalian)

Definition: interval from the last occurrence of *Globigerinoides altiaperturus* Bolli to the last occurrence of *Catapsydrax dissimilis* (Cushman and Bermudez) together with the occurrence of *Globorotaloides variabilis* (Blow and Banner) at the middle of the Pyawbwe The last occurrence of *Catapsydrax dissimilis* delineated the upper boundary of this zone.

Remarks: The results of many studies show that the Oligocene / Miocene boundary is marked by the first appearance of *Globigerinoides primordius / trilobus s.l.* [28] in tropical regions and by the first occurrence of *Globoquadrina dehiscens* in temperate regions [29,30,31].

The species *Globigerinoides primordius* may be reworked here from the underlying siliciclastic Oligocene beds. This zone is characterised by a low frequency of planktonic foraminiferal species as *Dentoglobigerina altispira altispira* (Cushman and Jarvis), *Globrotaloides suteri* Bolli, *Globigerina trilocularis* Orbigny, *Globigerina praebulloides* Blow, and the reworked Oligocene *Globigerina ciperoensis* Bolli.

Thickness: This zone is recorded in the lowest part of the Pyawbwe Formation covering the interval samples from P4 to P7.

4.1.3 *Globigerinoides trilob / Globigerinoides bispherica* Zone (Interval Zone)

Author: [27]

Age: Early Miocene (Burdigalian).

Definition: originally it is defined from the last appearance datum of *Catabsydrax dissimilis* (Cushman and Bermudez) to the first appearance datum of *Praeorbulina glomerosa* (Blow).

It is redefined here as the first appearance of *Globigerinoides triloba* (Reuss) and the upper boundary is not defined exactly here due to the stratigraphic end limit of the studied Pyawbwe Formation and the *Praeorbulina glomerosa* (Blow) as zonal maker species of the Middle Miocene is not present in our material.

Remarks: Therefore, the upper boundary of our *Globigerinoides triloba / Globigerinoides biospherica* Zone is not precisely defined.

The most common species recorded are *Globigerinoides triloba* (Reuss), *Globigerinoides quadrilobatus* (Orbigny), *Globigerina praeturritilina* Blow and Banner, *Globigerina rohri* Bolli, *Globigerinella praesiphonifera* (Blow), *Globigerinoides rubra* (Orbigny), *Globoquadrina baroemoensis* (Le Roy).

This zone is equivalent to the upper part of N6 and all N7 interval of [18] and could be equated with the *Globigerinoides trilobus* Zone of [27, 29,32,31] in the Mediterranean region.

Thickness: It covers the interval from middle to upper parts of the Pyawbwe Formation of Sakangyi –Thayet area.

4.2 Benthonic Foraminiferal Biostrati-aphy

The examination of present material yielded 8 agglutinated genera, 12 species and total 44 agglutinating population. The calcareous benthonic genera are 26, 59 species and more than 1200 calcareous population. The encountered benthonic taxa and their distribution are listed in Fig. (7).

The agglutinated taxa are of low diversity and limited abundance while the calcareous taxa show highest abundances in the middle and lower stratigraphic levels of the whole section. The agglutinated taxa are dominant in middle parts of the section. *Haplophragmoides reticularis* Boomgaart is the most dominant agglutinated taxon (Table 2b). The abundance of the benthic taxa increases from the base upward to the middle levels of the formation. *Ammonia beccarii* (Linnaeus), *Bolivina caudria* Cushman and Renz, *Bolivina vaceki* Schbert, *Bolivina goesii* Cushman are the most popular species throughout the Pyawbwe Formation (Plate 2). The reworked forms are restricted to the lowest levels of the section.

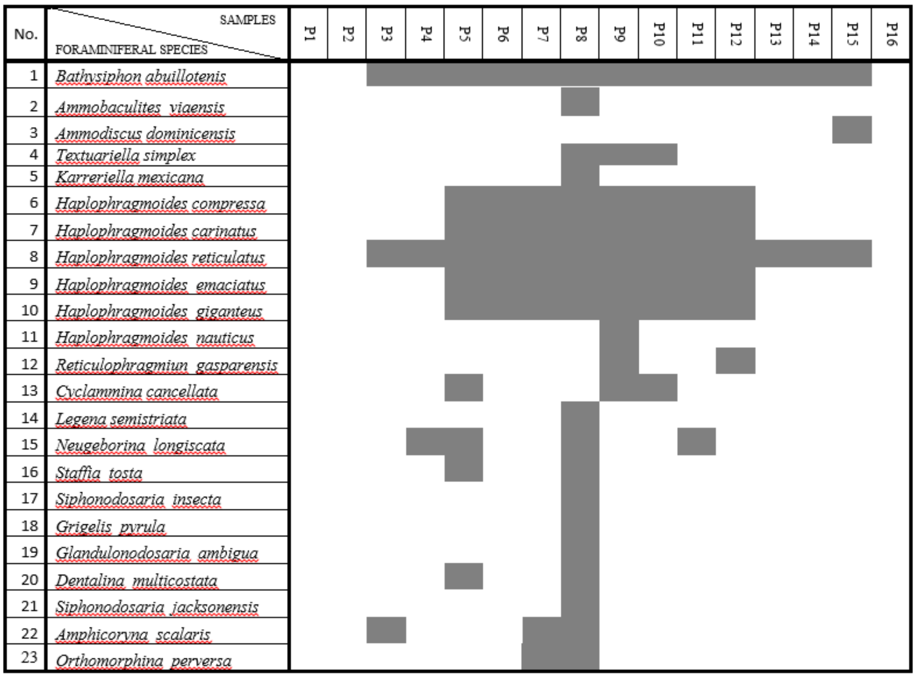


Fig. 7. Range chart of the identified benthonic foraminiferal species, Pyawbw Formation, Sakangyi area, Myanmar

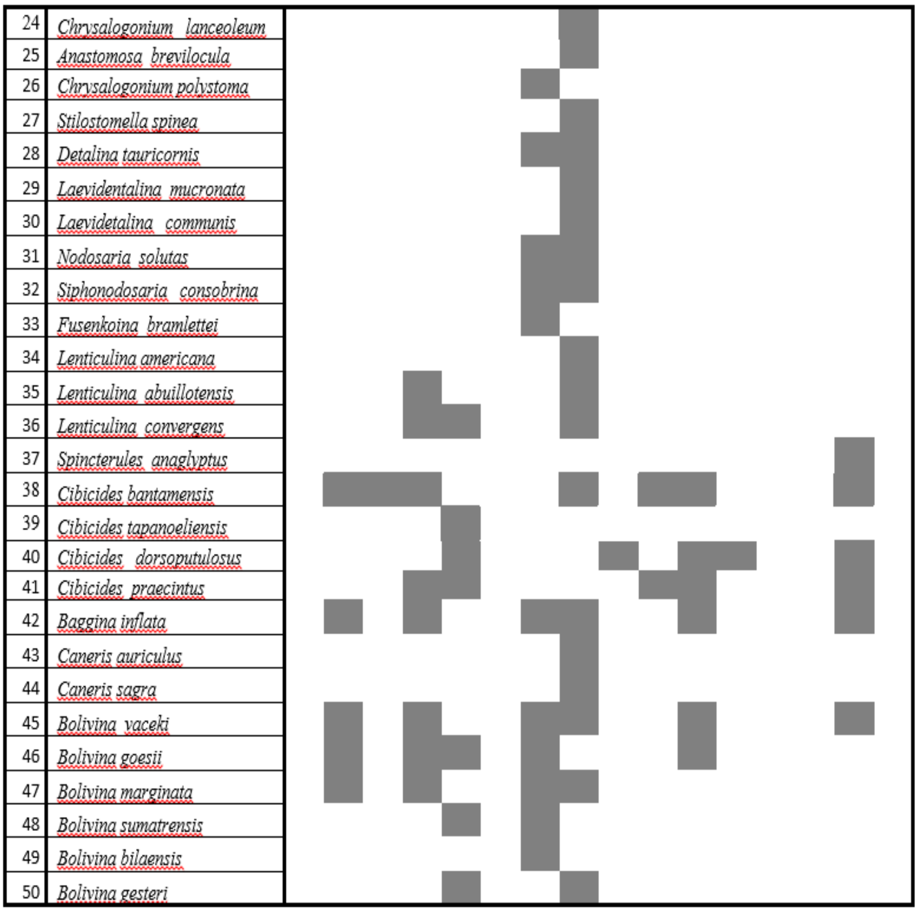


Fig. 7 (Con.)

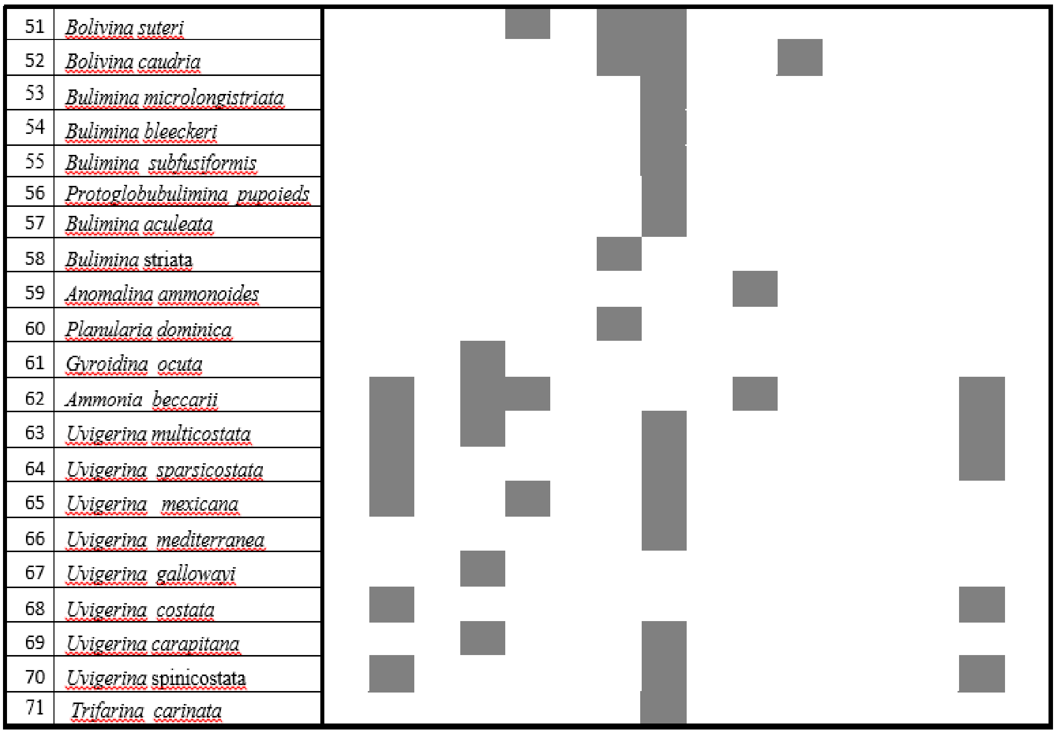


Fig. 7 (Con.)

Table 2a. Total abundance of the identified benthonic foraminiferal species, Pyawbwe Formation, Sakangyi area, Myanmar

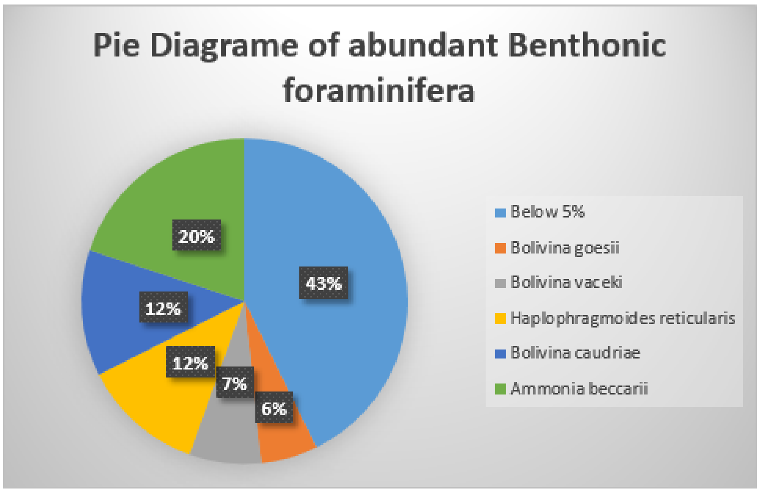
No.	FORAMINIFERAL SPECIES \ SAMPLE NUMBERS	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	Total Number
1	*Bathysiphon abuillotenis*			3	1				1		8					5		18
2	*Ammobaculites viaensis*								6									6
3	*Ammodiscus dominicensis*															3		3
4	*Textuariella simplex*								1		1							2
5	*Karreriella mexicana*								1									1
6	*Haplophragmoides compressa*					3				1	14		15					39
7	*Haplophragmoides carinatus*					14				14	9		9					36
8	*Haplophragmoides reticularis*			10		2			7	18	11	1	48			51		148
9	*Haplophragmoides emaciatus*					4				4			4					12
10	*Haplophragmoides giganteus*					2			1				16					19
11	*Haplophragmoides nauticus*									9								9
12	*Reticulophragmiun gasparensis*									4			1					5
13	*Cyclammina cancellata*					3				2	2							7
14	*Legena semistriata*								1									1
15	*Neugeborina longiscata*				13	1			4			3						2
16	*Staffia tosta*					1			1									2
17	*Siphonodosaria insecta*								2									2
18	*Grigelis pyrula*								1									1
19	*Glandulonodosaria ambigua*								3									3
20	*Dentalina multicostata*					1			1									2
21	*Siphonodosaria jacksonensis*								2									2
22	*Amphicoryna scalaris*			1				1	2									4

Table 2a. (Cont.)

23	*Orthomorphina perversa*							1	6									7
24	*Anastomosa brevilocula*								4									4
25	*Chrysalogonium lanceoleum*								3									3
26	*Chrysalogonium polystomum*							1										1
27	*Stilostomella spinea*								2									2
28	*Detalina tauricornis*							2	6									8
29	*Laevidentalina mucronata*								1									1
30	*Laevidetalina communis*								2									2
31	*Nodosaria solutas*							1	1									2
32	*Siphonodosaria consobrina*							1	24									25
33	*Fusenkoina bramlettei*							3										3
34	*Lenticulina americana*								2									2
35	*Lenticulina abuillotensis*				1				2									3
36	*Lenticulina convergens*				3	1			14									18
37	*Spincterules anaglyptus*															2		2
38	*Cibicides bantamensis*		1	1	7				9		1	5				6		30
39	*Cibicides tapanoeliensis*					2												2
40	*Cibicides dorsopustulosus*					6				8		2	4			1		21
41	*Cibicides praecintus*				1	5					1	1						8
42	*Baggina inflata*		1		1			1	18			4				1		26
43	*Caneris auriculus*								3									3
44	*Caneris sagra*								9									9
45	*Bolivina vaceki*		1		2			26	4			51				3		87
46	*Bolivina goesii*		7					1				26						69
47	*Bolivina marginata*		1		6			15	2									24
48	*Bolivina sumatrensis*					3		24										27
49	*Bolivina bilaensis*							32										32
50	*Bolivina gesteri*					1			2									3
51	*Bolivina suteri*					1		1	7									9
52	*Bolivina caudria*							35	6			112						153
53	*Bulimina microlongistriata*								1									1
54	*Bulimina bleeckeri*								1									1
55	*Bulimina subfusiformis*								2									2
56	*Protoglobobulimina pupoieds*								1									1
57	*Bulimina aculeata*								2									2
58	*Bulimina* striata							1										1
59	*Anomalina ammonoides*										1							1
60	*Gyroidina ocuta*				1													1
61	*Planularia dominica*							20										20
62	*Ammonia beccarii*		38		188	12					3					3		244
63	*Uvigerina multicostata*		2		1				6							1		10
64	*Uvigerina sparsicostata*		3						4							2		9
65	*Uvigerina mexicana*		1			3			3									7
66	*Uvigerina mediterranea*								2									2
67	*Uvigerina gallowayi*				1													1
68	*Uvigerina costata*		2													1		3
69	*Uvigerina carapitana*				1				2									3
70	*Uvigerina* spinicostata		1						2							1		4
71	*Trifarina carinata*								1									1
	Total numbers of population	**0**	**68**	**15**	**230**	**67**	**0**	**186**	**188**	**56**	**51**	**205**	**97**	**0**	**0**	**81**	**0**	**1244**

Table 2b. Pie Diagrame of abundant benthonic foraminifera

Below 5%	42.7%
Bolivina goesii	5.6%
Bolivina vaceki	7.1%
Haplophragmoides reticularis	12.1%
Bolivina caudriae	12.5%
Ammonia beccarii	19.9%



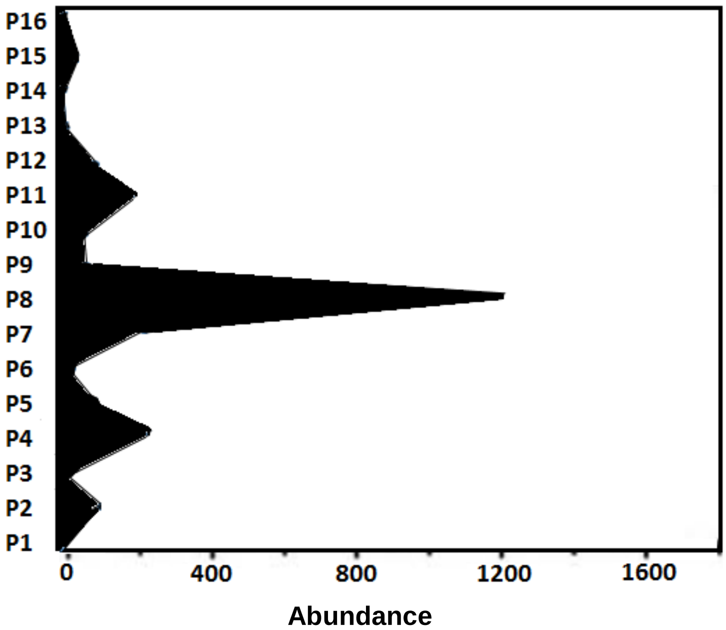


Fig. 8. Foraminiferal abundance curve of the Pyawbwe Formation at Sakangyi area

Based on a detailed qualitative and quantitative analysis and stratigraphic distribution of the benthic foraminiferal taxa, two locally benthic foraminiferal biozones are recognised, where these zones are established on the geographic distribution of the benthonic foraminiferal species with facies – controlled and most of these benthic foraminiferal assemblages are mixed association of different water levels.

4.2.1 The lowe: *Ammonia beccarii* Assemblage Zone

It is defined as Aquitanian marker species where *Ammonia beccarii* (Linnaeus) is present as the first appearance in the most beds of the Early Miocene Pyawbwe Formation (Fig. 6). It correlates with N4 [18] and equated with the *Globigerinoides altiaperturus / Catapsydrax dissimilis* Zone. It is characterised by *Bolivina vaceki* Schubert, *Bolivina goesii* Cushman, *Bolivina marginata* Cushman, *Uvigerina multicostata* Le Roy, *Uvigerina costata* Beida and *Haplophragmoides reticularis* Boomgaart. Also, this zone is characterised by the absence of deep marine benthic and very rare planktonic foraminiferal populations suggesting an inner shelf marine environment.

4.2.2 The Upper: *Bolivina vaceki* Assemblage Zone

It is defined as Aquitanian – Burdigalian zonal marker species where *Bolivina vaceki* Schubert flourished and populated in the middle and upper beds of the Pyawbwe Formation. It is correlated with N5 and N6 of [18] and may equate to the following planktonic zones *Globigerinoides primordius/ Globoquadrina dehiscens* Zone and *Globigerinoides triloba / Globigerinoides biospherica* Zone.

This zone includes assemblage as *Lenticulina convergens* (Bornemann), *Siphonodosaria consborina* (Orbigny), *Baggina inflate* Le Roy, *Cancaris auriculus* (Fichtel and Moll), *Cancaris sagra* (Orbigny), *Bolivina bilaensis* Le Roy, *Planularia dominica* Bermudez, *Uvigerina carapitana* Hedberg, *Haplophragmoides* spp. *Protoglobobulimina pupoides* (Orbigny), *Bulimina bleekeri* Hedberg and *Bulimina aculeata* Orbigny.

5. PALEOECOLOGY

5.1 Planktonic Foraminiferal Pattern and Paleoecologic Significance

Planktonic foraminiferal recovery (Table 1a) was extremely poor as only 19 species, while planktonic abundance 1161 specimens. The planktonic /benthonic ratio is only ~0.5 reflecting the abundance, diversity and planktonic foraminiferal composition are strongly controlled by temperature. According to [33,34,35] and others, the *Globigerinoides primordius, Globigerinoides quadrilobatus* and *Globigerinoides triloba* are commonly indicative of warming waters. Also, Spezzaferri [33] indicated that *Globigerina praebulloides* is an indicator of high productivity. The maximum foraminiferal abundance of sample interval P8 of the present studied Pyawbwe Formation (Fig. 8) indicated both temperature and feeding nutrient rich water were highly productive interval often used as good proxy for upwelling [36,37]. The planktonic foraminiferal distribution is controlled primarily by variations in a primary productivity rather than water temperature [38]. The coexistence of the above group together with the surface dwellers as *Globigerinoides altiaperturus, Globoquadrina dehiscens* and G*loborotaloides suteri*, which are characteristic for warm oligotrophic conditions and stratified waters at the lower intervals of the Pyawbwe section (P2-P5), suggests high seasonal contrasts and high primary productivity and its presence declines significantly till the top of the section (P9-P15) interval. Significant peaks in abundance of *Globigerina praebulloides* and *Globorotaloides variabilis* indicate warm oligotrophic waters in the middle parts of the section (P8 interval). However, the presence of low trophic levels, normal salinities and warm waters are indicated by the elevated abundance of *Globigerinoides triloba* in some middle parts of the section.

The high abundance of *Globigerina praebulloides* may reflect paleodepth ranging between outer neritic and upper bathyal [39]. There is a trend towards higher values of planktonic percentage from lower levels to middle levels through the Pyawbwe section indicating a deepening upward trend. This is followed by a regression phase to the upward of the upper levels of the section as indicated by a very extremely poor foraminiferal abundance (Fig. 8, Table 1a & 1b).

5.2 Benthic Foraminiferal Paleoenvironmental Significance

About 1244 distributed benthic foraminiferal specimens (Table 2a), belonging to 71 species, were picked and identified from the Early Miocene Pyawbwe Formation, Sakangyi area. Within this sequence, agglutinated foraminifera are extremely rare, while the calcareous benthic are represented by 75% of the total identified forms (Fig. 9).

Benthic foraminiferal results reveal a taxonomically diverse fauna. Abundance and diversity vary up the section (Figs. 10 and 11). The most frequent species are *Ammonia beccarii, Bolivina caudria, Haplophragmoides reticulatus, Bolivina vaceki, and Bolivina goesii* (Table 2b). The most frequent benthonic genera are *Bolivina* spp, *Haplophragmoides* spp, *Ammonia sp., Cibicides* spp. and *Uvigerina* spp. (Fig. 10). Additional significant groups as *Bulimina, Lenticulina, Laevidentalina, Chrysalogonium, Siphonodosaria* and others. As a consequence, we discuss the distributional patterns of the identified benthonic foraminifers under different titles as follows:

5.3 Benthic Foraminiferal Assemblages

The ranges of some dominant species are shown in Table (3). The encountered taxa may group into three assemblages which have been identified based on species abundant fluctuations.

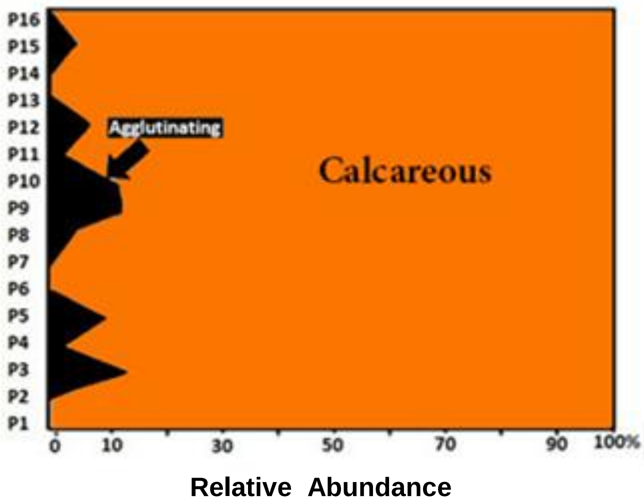


Fig. 9. Relative abundance of agglutinating to calcareous taxa of the Pyawbwe Fm. ,Sakangyi area

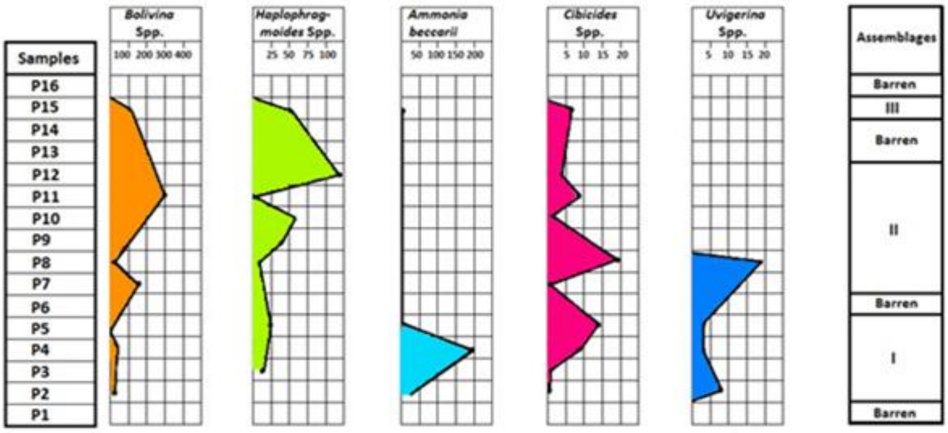


Fig. 10. Relative abundances of selected recorded highly abundan benthic species record of Pyawbwe Fm. and comparable benthic assemblages. The barren intervals are sandstone facies

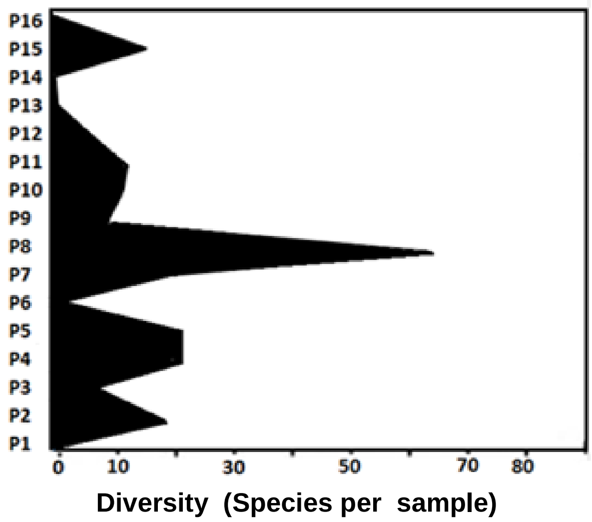


Fig. 11. Foraminiferal Diversity of the Pyawbwe Fm. at the Sakangyi area

Table 3. Paleoenvironmental interpretation of the identified Foraminiferal Assemblages, Pyawbwe Fm., Myanmar

Assemblage	Domain species	Interval	Paleoenvironment
III	*Haplophragmoides reticulatus* *Bathysiphon abillotensis* *Globigerina praebulloides*	P13 - P16	Regression phase,high sand content, low abundance,and very low diversity indicates high energy levels, upwelling, moderate to high energy levels in deposition. Relatively shallow marine condition, less than 30 m. paleobathymetry.
II	*Bolivina caudria* *Bolivina vaceki* *Bolivina goesii* *Haplophragmoides reticulatus* *Globorotaloides variabilis* *Globigerina praebulloides* *Globigerina triloculris*	P6 - P12	Highly diversity of both planktons and benthos with more calacreous shales , stable marine shelf, well oxygenated,low energy environment ,good supply of organic carbon . Increased calcareous content may be associated with regional increase in bottom water calcite saturation (Kender *et.al* .,2009). Relatively deeper marine condition (30 - 150 m).
I	*Ammonia beccarii* *Haplophragmoides carinatus* *Bolivina goesii* *Globigerinoides primordius*	P2 - P5	High to moderate sand content,low abundance, low diversity suggesting high energy upwelling levels , shallow marine to brackish environment (less than 30 m. depth).

Table 4. Sand and mud % of the sediments in each position Pyawbwe Fm

Foraminiferal Assemblage	Interval Sample no.	Sand % in 100g of Sample		Mud % 100g of Sample		Sand / Mud Ratio	
			Mean		Mean		Mean
III	P16	86	52%	14	48%	6.2 : 1	1 : 0.9
	P15	0.6		99.4		1 : 160	
	P14	58.6		41.4		1.4 : 1	
	P13	62.9		37.1		1.7 : 1	
II	P12	1.1	25%	99	75%	1 : 88	1 : 3
	P11	28		97.2		1 : 35	
	P10	65.7		34.3		1.9 : 1	
	P9	0.4		99.7		1 : 260	
	P8	1		98.1		1 : 51	
	P7	0.3		99.7		1 : 361	
	P6	77.4		22.6		3 : 1	
I	P5	0.8	28%	99.2	72%	1 : 121	1 : 2.3
	P4	64.7		35.3		1.8 : 1	
	P3	0.6		99.4		1 : 162	
	P2	0.4		99.6		1 : 279	
	P1	72.7		27.3		1 : 2.7	

5.3.1 Assemblage I

It is characterised by almost exclusively calcareous taxa specially *Ammonia beccarii*. The lower part and the lower beds of the middle part (P2-P5 interval) are composed of numerous infaunal suboxic indicators [41] including *Uvigerina* spp. of which many are reworked Chattian and Aquitanian taxa. The lower parts are primarily composed of *Ammonia beccarii* and abundance of the epifaunal oxic but the infaunal suboxic indicators are low. This trend shows an up warding from infaunal suboxic toward epifaunal oxic indicators. Also, this stratigraphic interval is composed of high to moderate sand content, generally low foraminiferal abundance, low diversity suggesting high energy upwelling levels and shallow marine to brackish environment with bathymetry less than 30 m. depth. The sand- shale deposits of this interval are primarily shelf derived based on the very abundance of *Ammonia beccarii* indicating a well- oxygenated inner shelf or coastal marine hypoxic warm environment or intertidal marine zone [42,43,44,45,46] as a source and low reworking.

5.3.2 Assemblage II

The domain taxa are *Bolivina caudria, Bolivina vaceki, Bolivina goesii, Haplophragmoides reticulatus,* and planktonic *Globorotaloides variabilis, Globigerina praebulloides* and *Globigerina trilocularis.* This assemblage is represented by interval samples from P6 to P12 of more calcareous shale and low content of intercalated sands (Table 4).

The assemblage is considered the principal assemblage of the Pyawbwe Formation. This assemblage represents the flourishing and high diversity of both planktonic and benthonic taxa (Table 3). The environment may more stable marine shelf with deepening bathymetry condition (30 – 150 m.) of relatively deep marine. The majority taxa are of well oxygenated levels with low energy and a good supply of organic carbon [40]. The presence of a deeper dwelling species as *Bulimina aculeata* is indication to high organic flux [47,48]. In the Mediterranean Sea, this species requires relatively eutrophic bottom conditions [49]. The highly shifting of *Bulimina aculeata* observed in this assemblage may reflect cyclic changes in sediment input and/ or circulation (Fig. 12).

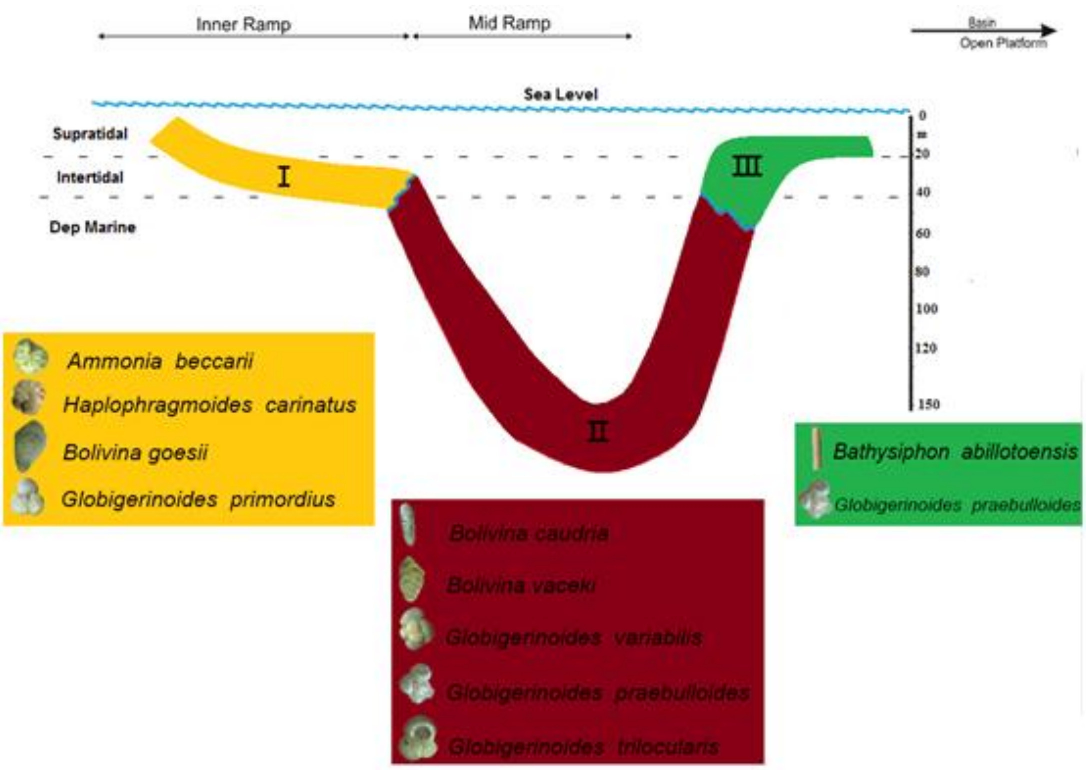


Fig. 12. Model of the depositional environments and comparative foraminiferal assemblages of Lower Miocene Pyawbwe Fm., Sakangyi area, Myanmar

Cibicides spp. are strongly present in the middle part of the section and shows fluctuating and diminishing pattern upward to the above assemblage. It is widespread in well- ventilated and oligo-mesotrophic conditions [50,51] reported that *Cibicides* (*Cibicidoides*) spp. are not tolerating environmental stress; especially Oxygen deficiency at the bottom *Uvigerina* spp. and *Anomalinoides* spps. are reported in this assemblage but in low frequency and fluctuating pattern. *Uvigerina* spp. is shallow infaunal species and characteristic to the continental slopes (i.e. In-between assemblages I & II) as recorded by [52]. *Anomalinoides* spp. thrive in mesotrophic conditions at outer shelf –upper bathyal depths [53].

5.3.3 Assemblage III

The domain species are *Haplophragmoides reticulatus, Bathysiphon abillotoensis and Globigerina praebulloides.*This assemblage covers the interval of the section from sample P13 to sample P16. This interval is presented by highly content of sands (Table 4) and characterises by very low faunal content and poor diversity. It is considered of highly levels of energy and upwelling conditions of moderate to high energy in deposition. Its paleoenvironment is relatively shallow marine conditions less than 30 m. depth. Presence of *Bathysiphon* spp. has been reported from turbiditic environments and submarine canyons and terraces close to the continental passive margin during episodes of reduced turbidity currents and minor mass flow deposition [54,55,56,57]. Foraminiferal morphogroup is common in deep marine environments with low organic matter flux [58, 59]. The irregular morphotype distribution, combined with fluctuating diversity values along the sections suggest changes in the amount of oxygen, organic matter and energy at the sea floor, probably caused by the palaeoenvironmental instability typical for the turbiditic systems [59-61].

Its low abundance – as in our case – suggests an outer neritic to lagoon environment (Fig. 13).

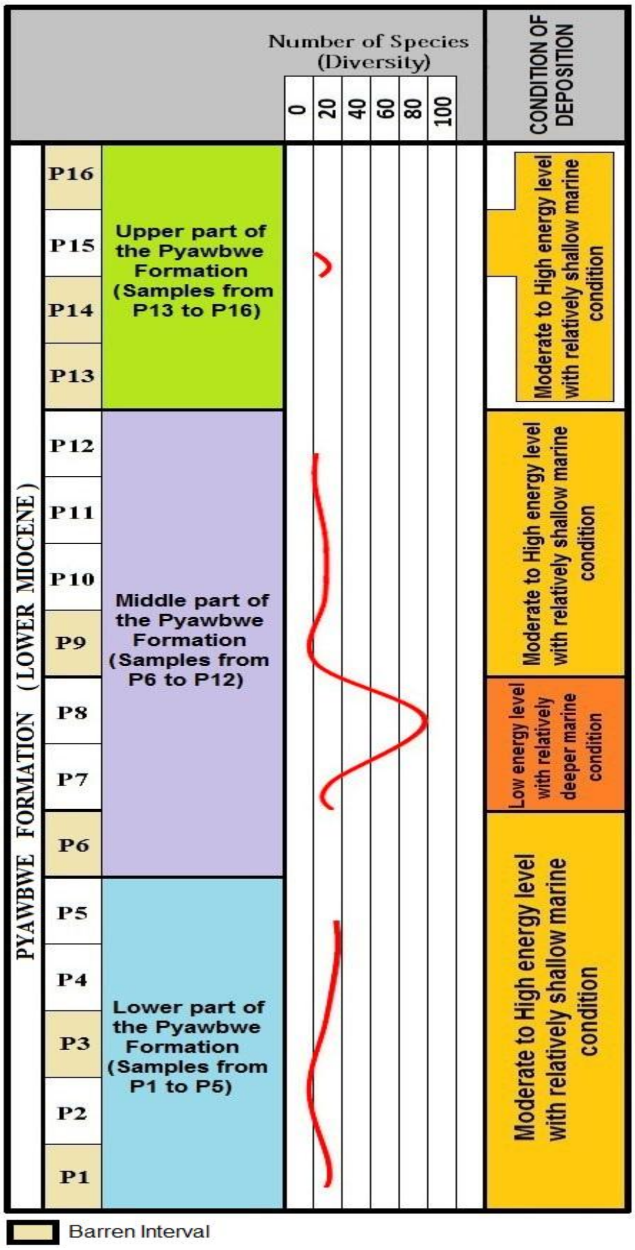


Fig. 13. Foraminiferal assemblages and foraminiferal diversity compared with the interpreted depositional conditions, Pyawbwe Fm., Sakangyi area

6. CONCLUSIONS

The 820 m. majorly section of the Pyawbwe Formation, Sakangyi area, Myanmar analysed in this study has been of Early Miocene (Aquitanian-lower part of Burdigalian) of planktonic foraminiferal biozones N4, N5, N6 and lower parts of N7 of [18] The benthonic foraminifera reveal taxonomically diverse and abundant covering two locally benthic biozones; the lower is *Ammonia beccarii* and upper the *Bolivina vaceki*. Lithologically, Pyawbwe Formation is shale-sand clastic section deposited on continental shelf of marine passive margin from less than 30 m. depth in lower parts to 150 m. depth of middle parts and regressed in upper most parts to lagoon depth less than 30 m. The majority of the section contains shales representing a relatively stable environment with low energy levels, in upper stratigraphic parts, the environment became of high energy levels indicating swallowing and regressive phase. Changes and fluctuating diversity of the benthonic tax may cause due to relatively to the type of sediments and the depth of the environment rather than supply of the organic nutrient.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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