Benthic Foraminifera in Marine Sediment Related to Environmental Changes off Bangka Island, Indonesia

K. T. Dewi, N. Nurdin, Y. A. Priohandono and A. Sinaga
Marine Geological Institute, Bandung

Corresponding author: ktdewi2004@yahoo.com

ABSTRACT

Bangka Island is a famous tin island that lies offshore southeast of Sumatra. Tin mining has taken place both on land and from paleo-valleys under the sea by dredging or hydraulic method. Nearshore tin mining activities may have indirectly affected the environment, including marine organisms such as benthic foraminifera. The purpose of this study is to understand foraminifera in the sediment from offshore Sungailiat, Bangka Island as marine stress environment.A total of 25sea floor sediment samples were acquired by using a grab sampler at water depth between 6 and 26 meters.. About 300 foraminiferal shells were picked from each sample and then they were identified, calculated and documented. Some abnormal specimens were then analyzed by using EDX-SEM.

The results show that there are more than 60 species which belong to 39 genera of benthic foraminifera in the study area and Rotaliida is the leading order. More than 50% of the foraminiferal shells have poor preservation or abnormal tests such as abraded, blackish, yellowish and brownish tests. Based on EDX analysis, these abnormal specimens are composed of Al_2O_3 (4-18%), Fe_2O_3 (8.87%), SiO_2 (5-27%), K_2O (1%), FeO (4-7%) and TiO_2 (9.29%).The occurrence of abundant abnormal shells may be related to physical characteristics in the study area that are likely to affect the turbidity, nutrients and pollutants of the marine environment.

Keywords: *benthic foraminifera, abnormal tests, EDX analysis, Bangka Island.*

INTRODUCTION

Foraminifera have been used widely as bio-indicator of environmental changes especially in polluted marine areas. Parameters used include foraminiferal diversity, population density/abundance, assemblage structure, biological responses, test ultra-structure, test pyritization, test chemistry and test morphology (Yanko et al., 1999). Foraminifera's response to "unusual" living environment varies depending on the source of the pollutant. Banerji (1992, in Yanko et al., 1999) studied a correlation between heavy metals in sediment and foraminiferal tests. He found that species diversity tends to be high when Fe, Mn and Zn concentration increases in the sediment. *Ammonia* prefers environments with high concentration of Fe, Mn, and Zn but its abundance decreases by increasing the concentrations of Cd, Co, and Pb. Yasuhara and Yamazaki (2005) recorded the decreasing population of foraminifera and ostracods up to 90% due to high industrial activities in Osaka between 1960-1970. Another response is shown by deformed foraminifera tests. Rositasari (2011) found abundant abnormal foraminiferal tests of *Ammonia beccarii* in Jakarta Bay, which might be related to both natural and anthropogenic causes. Furthermore, Dewi et al. (2011) collected abnormal shells of foraminifera, ostracods and other organic particles from offshore Berau Delta, east Kalimantan. The specimens appear as darkish shells (black, dark green and dark brown) that are composed of various chemical compositions from different sources.

The purpose of this study is to recognize foraminiferal community affected by environmental stress in the offshore Sungailiat, Bangka Island. Bangka is a famous tin island (30% of the world's tin) that lies in the southeastern part of Sumatera. Tin has been mined both on land and from paleo-valleys under the sea since the 1700s. Offshore mining is done by dredging or hydraulic method from makeshift (wooden) pontoons (unconventional floating mines). This method uses machines to suck up sands from the seafloor, which destroys the seabed, coral reefs and marine organisms, such as foraminifera. This mining process also uses toxicchemicals that have indirect consequences to environmental condition and are damaging marine ecosystem.

METHODOLOGY

The study area is located offshore in the eastern part of Bangka Island, between Tanjung Tuing in the north and Rebo beach in the south of

Sungailiat (the second largest city in Bangka after Pangkal Pinang). A total number of 44 surface sediment samples have been collected by a grab sampler and scuba divers from an area within longitude 106°00'-106°32" E and latitude 1°60' - 1°92'S (Figure 1). The sediment samples were taken from water depth between 4.5 m and 23.8 m. Twenty five samples were selected for foraminiferal study with volume of about 25 cm^3 of wet sediment. These sediment sampleswere then washed through a sieve of 0.063 mm and dried in an oven. About 300 specimens of foraminifera were picked out from other sediment particles and placed onto assemblage plates. Then, they were identified and calculated based on normal and abnormal specimens. The abnormal specimens were classified as abraded and covered or filled by black or non-black particles (Figure 2). The selected abnormal specimens were then analyzed by using SEM-EDX (Scanning Electron Microscope-Energy Dispersive X-ray spectroscopy) in the Laboratory of Quaternary Geology, Centre of Geological Survey, Bandung (Figure 3).

RESULT AND DISCUSSION

Benthic foraminifera

We found abundant benthic foraminifera in all sediment samples, usually between 200 and 300 specimens except in one sample (Station 3). This station is located very close to the coastal area and river mouth,with sediment composed of gravelly sand. There are more than 60 identified species of benthic foraminifera, belonging to 39 genera (Table 1). Selected species of benthic foraminifera are documented as shown on Plate 1.

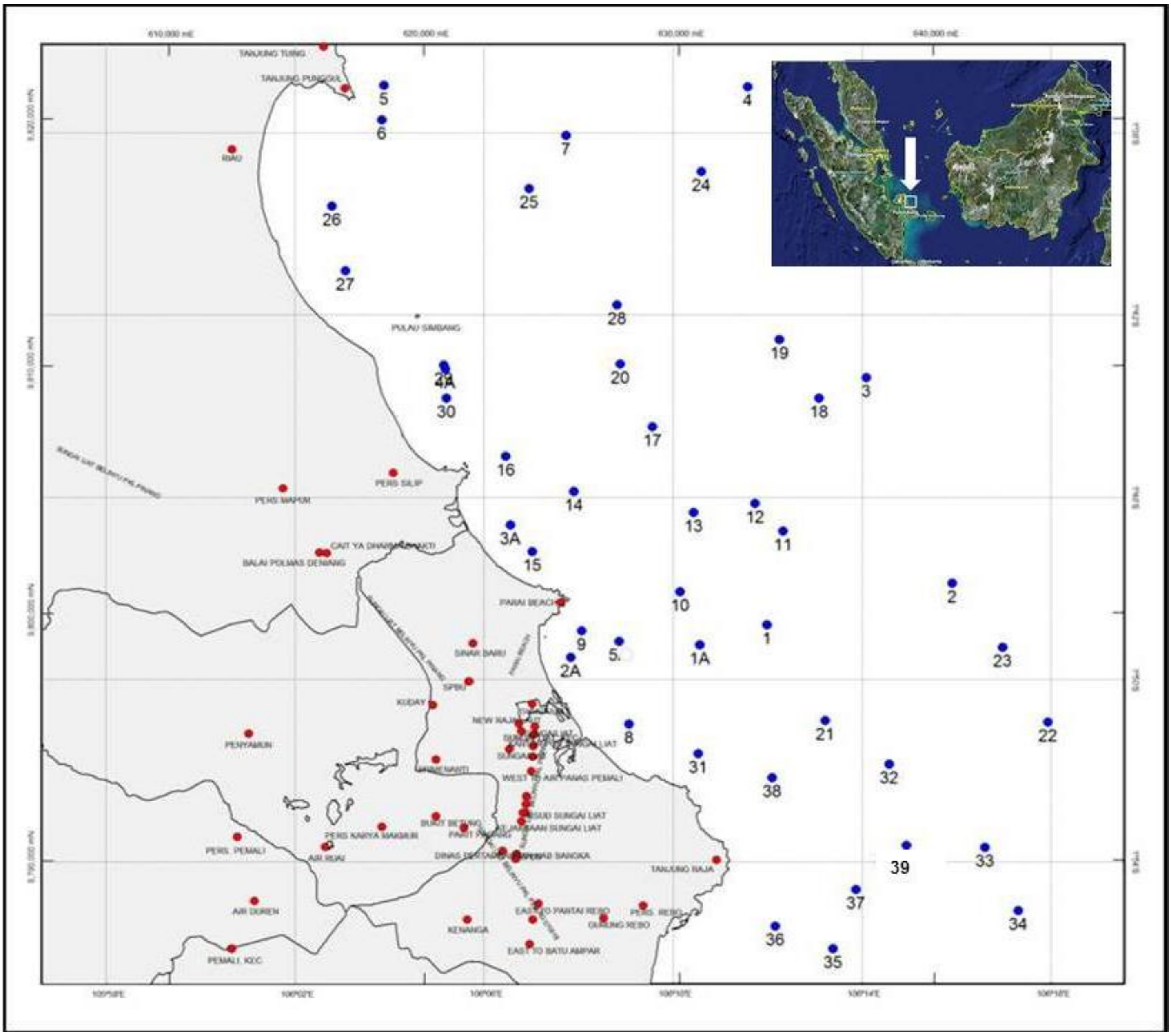


Figure 1. *Sediment sampling location of the study area. Inset map is from Google Earth.*

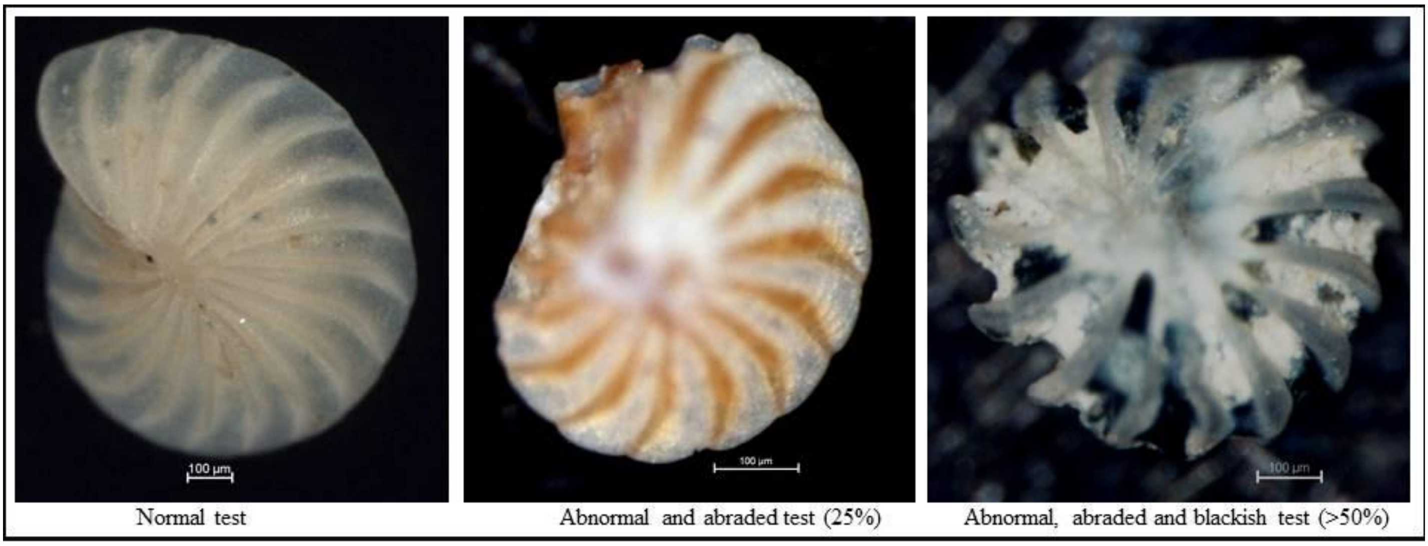


Figure 2. *Appearances of foraminiferal tests of Dendritina striata.*

Station 39 was considered as the healthiest station. This dive spot is in reef environment,which is characterized by abundant to very abundant *Cymbaloporetta, Eponides, Amphistegina* and *Dendritina.* This composition is unusual because it is does not contain typical 'reefal' symbiotic bearing benthic foraminifera, but it is composed of opportunistic genera such as *Elphidium, Ammonia, Bolivina* and heterotrophic small benthic foraminifera such as genera Miliolida and Textulariida. It seems that this site belongs to marginal environment for reef growth as classified by Hallock et al. (2003) based on foraminiferal index.

The occurrence of abundant and widely distributed *Amphistegina radiata* can be an indicator of shallow water environment associated with reef complex. This species is found predominantly on the reef slope of Spermonde shelf, south Sulawesi (Renema et al, 2001; Renema and Troelstra, 2003). Two species of the genera *Amphistegina* are also found in the reef slope on the coral rubble or fragments and sand in the Seribu Islands, Java Sea (Renema, 2008). Natsir et al. (2012) recognized that *Amphistegina lessonii* is common in the Waigeo island of Raja Ampat, Papua, where they were collected from water depth of less than 11 m.

Certain stations contain more than 25 specimens (very abundant) of *Amphistegina, Operculina, Elphidum, Quinqueloculina, Rosalina, Rotalinoides* or *Eponides..* The first four genera are widely distributed throughout the study area and are typical genera for shallow marine environments. The widest distribution belongs to *Elphidium*, which appears at almost at every station. According to Hallock et al. (2003), *Elphidium* is classified as certain stations opportunistic group that will appear in the reef and other environments. This genus consists of several species including *E. advenum, E. crispum, E. depressulum* and *E. striatapunctatum* sp. In the nearshore to offshore areas(Stations 4, 5, 9, 11, 15, 18, 21, and 28), the collected samples include abundant *Quinqueloculina*, *Amphistegina* and *Operculina*. They were found in sediment types of slightly gravelly sand and silty sand at water depth between 6 and 26 meters.

The occurrences of benthic foraminifera were then grouped into several of the 16 orders proposed by Sen Gupta (1999). This classification is not only based on texture and composition of the test wall but is also completed by data on chemistry and mineralogy. In the study area, it has only six orders:

1. Order TROCHAMMINIDA (genus *Trochammina*), agglutinated wall with proteinaceous or mineralized matrix;
2. Order TEXTULARIIDA, characterized by agglutinated wall, with particles cemented by low-Mg calcite. In the study area, it is represented by *Textularia, Agglutinella* and *Martinottiella*;
3. Order MILIOLIDA with test of high-Mg calcite, surface texture porcellaneous (*Spiroloculina, Parahauerina, Massilina, Miliolinella, Quinqueloculina, Triloculina, Dendritina, Peneroplis, Marginophora*);
4. Order LAGENIDA, test of low-Mg calcite, wall monolamellar, represented by *Nodosaria*;
5. Order BULIMINIDA, test of low-Mg calcite, wall bilamellar (*Bolivina* and *Rectobolivina);* and
6. Order ROTALIIDA, test of low-Mg calcite, wall bilamellar, chamber arrangement mostly low (*Cancris, Eponides, Rsalina, Discorbinella, Planulina, Planorbulina, Amphistegina, Florilus, Asterorotalia, Ammonia, Operculina, Rotalia, Elphidium, Calcarina,* and *Cibicides*). This study shows that the study area is characterized by Order Rotaliida and is dominated by *Amphistegina, Elphidium* and *Operculina.*

Deformed foraminifera specimens

Recent benthic foraminiferal assemblages have been used as proxies to monitor the effects of pollution in marginal marine water. One response of benthic foraminifera to degradation of environmental condition is by occurrences of deformed specimens. Morphological abnormalities of foraminifera are characterized by abraded and/or loss of part of test, suture and chambers.

No	Station number	1	2	3	4	5	6	7	9	11	13	14	15	17	18	21	22	25	27	28	29	31	34	35	36	39
	Water depth (m)	13.7	22.5	23.6	26.5	11.4	10.4	23.8	6.0	18.9	16.2	12.2	7.8	17.8	22.8	17.9	22.6	21.9	6.9	21.1	10.5	10.0	19.4	11.2	8.9	4.5
	Sediment types	Sg	S(g)	S(g)	S(g)	S(g)	Sm(g)	Sg	Sg	S(g)	Sg	Gs	Smg	Sg	S(g)	S(g)	S(g)	S(g)	Sm(g)	S(g)	Ms(g)	Smg	S(g)	S(g)	Sg	Zs
	Genera of benthic foraminifera																									
1	*Amphistegina*	C			VA	A	VA	C	F	VA	A	C	C	A	VA	VA	VA			A	A	C	A			A
2	*Elphidium*	C	A		A	A	A	C	A	C	C	C	A	A	A	C	A	A	C	A	A	A	A	C	A	F
3	*Quinqueloculina*	C	F		VA	VA	C	C	VA	C		C	VA	A	VA	A	VA	A		VA	VA	C		C	C	C
4	*Operculina*	A			VA	VA	A	C	F	C	C		R		VA	A	VA	A		VA	C					F
5	*Spiroloculina*	C	F		C	F	C	C	A	C			F	F	R	F	R	A	C		A	C	C		C	F
6	*Dendritina*	F			A	C	C	F	C			C	C	A	C	C	C	C		C	A		F			A
7	*Triloculina*	F	F					F	F	F			F		R		F	C		F	R	F	C	C	C	F
8	*Peneroplis*	F			C	A			A	F	F		F		A	F	A	C	F	C	A		C			F
9	*Textularia*	F			F			F	R	C	C		R		F		F				F		C	C	C	F
10	*Rotalia*	F			R			C		F			R	R	F		R		C	R	F	C		R		F
11	*Pseudorotalia*	R			C	R	C		F			C	F		R		R			F	F	C		F		
12	*Rosalina*	F						C							R					C		VA	C	C	A	
13	*Ammonia*		VA					F		F			VA						A			C	F		C	
14	*Asterorotalia*					F		F	A					F							C					F
15	*Brizalina*	R	F							F			R						F			F	F			
16	*Calcarina*				R																C					
17	*Cancris*							F						F	F		R			R						
18	*Rotalinoides*					VA			A			F			F		R				C					
19	*Cibicides*				F										F	F							C	C		C
20	*Martinotiella*				C			C		F	F												F		F	C
21	*Cymbaloporetta*																									VA
22	*Sprirolina*																									C
23	*Heterolepa*																									
24	*Discorbinella*								R						R						F					
25	*Planorbulina*				R				F				A								F			F	F	F
26	*Massilina*	F				R			C					R							F		F	F		F
27	*Adelosina*								F						R						F	F	C	C	C	
28	*Agglutinella*								F				F				R				F	F	F	F		
29	*Trochamina*								F				R								R				C	
30	*Eponides*															C				F						VA
31	*Florilus*												R						F							
32	*Planulina*															R	R									
33	*Shlumbergerina*								F																	
34	*Bolivina*				R															F						F
35	*Pararotalia*																									F
36	*Parahauerinoides*																				R					C
37	*Rectobolivina*																				R					
38	*Nodosaria*				R																					F
39	*Alliatinella*				R																					F

Legend

R : Rare (1 specimen)
F : Few (2-5 specimens)
C : Common (6-10 specimens)
A : Abundant (11-25 specimens)
VA : Very abundant (>25 specimens)

Classification of sediment (Folk, 1980)

Sg : Gravelly sand
S(g) : Slightly gravelly sand
Sm(g : Slightly gravelly muddy sand
Smg : Gravelly muddy sand
Gs : Sandy gravel
Ms(g) : Slighltly gravelly sandy mud
Zs : Sandy clay

Table 1. *Distribution of benthic foraminifera in the study area.*

Some of them have unusual color such as covered or filled by grey, yellow, brown or black particles (Plate 2).

In the study area, the number of normal tests is mostly lower (<50%) than abnormal specimens, except at Stations 2, 14, 15, 27, 31, 35 and 36 (Figure 3). Abnormal shells with non black colors (grey, brown, yellow) can reach more than 50% of the total specimens and they are characterized by broken tests. The black particles are usually filling the chambers rather than covering the test. It seems that the chambers were broken first due to physical factors and then were filled by black sediment particles. The highest number of abraded with black color occurs at Station 5, which is located close to the river mouth. The genus *Dendritina* was found mostly with heavy damages that can reach 80%. This genus is associated with reef environments and indirectly it can be an indicator of environmental changes on coral reef in the study area. It appears that this genus is the most sensitive genus to environmental changes in the study area. The interesting point is that their abraded specimens are not only covered by blackish color but also loss of their chambers. This may be related to physical activities of offshore tin mining in the study area that are likely to affect turbidity, nutrients and pollutants of its marine environments. This physical influence can also be seen on other genera such as *Operculina, Elphidium, Amphistegina, Quinqueloculina*, etc (Figure 3). The heavy damages (60-80%) are usually found on larger foraminiferal specimens with flat and rounded morphological tests, such as *Operculina* and *Dendritina.*

Result from SEM-EDX shows that eight selected and abnormal specimens are composed of Al_2O_3 (4-18%), Fe_2O_3 (8.87%), SiO_2 (5-27%), K_2O (1%), FeO (4-7%), TiO_2 (9.29%), as seen on Figure 4. The Carbon value is between 9.25 and 15.27%, which is lower than the result from offshore Berau Delta that reaches 74.19% (Dewi and Illahude, 2005; Dewi et al., 2011). The low values may indicate that the black color is not derived from coal but other sources. It may be from sediment components that contain Al_2O_3 ,SiO_2 , FeO, and

TiO_2. Most of these chemical components are also found in the abnormal specimens from off Berau Delta with exception of TiO_2. The last element is only detected in the Bangka study area and occurs in one specimen of *Textularia*. This genus has specific wall structure that is built by materials from surrounding area. Therefore, it can be related to quartz sand that are commonly found in the study area. We also tested the normal specimen of *Amphistegina* with opaque test (Figure 4, number 8) and it is composed of C (9.25%) and CaO (90.75%) only. Another study by Sharifi et al. (1991) shows that deformed testscontain high proportions of metal such as Cn and Zn.

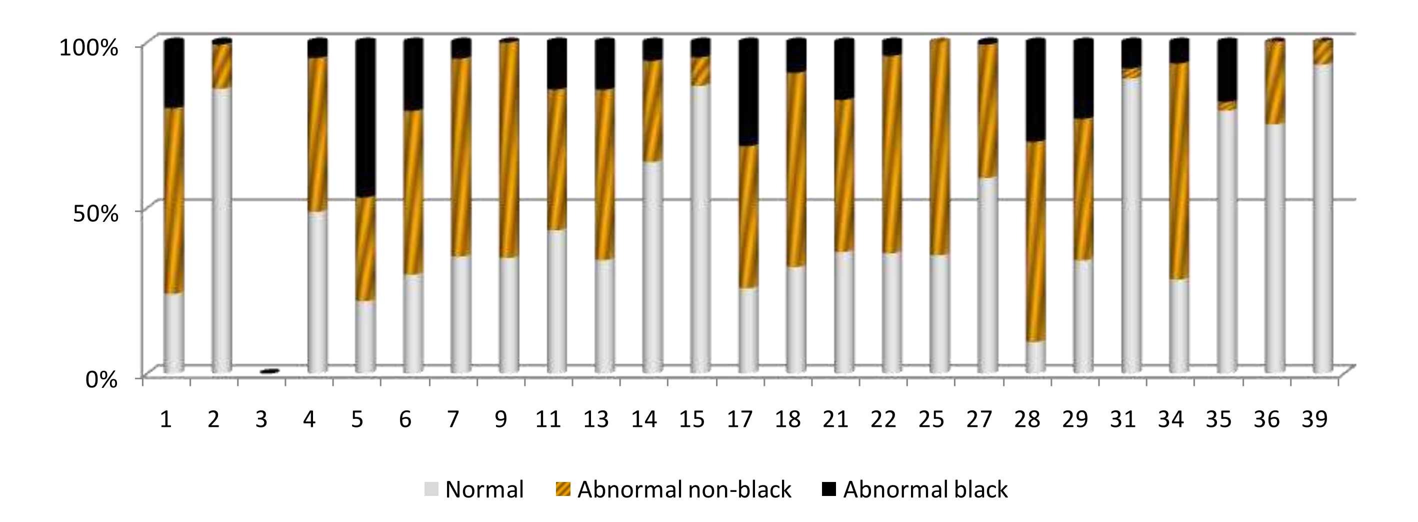


Figure 3. *Comparison number of normal and abnormal tests of foraminifera.*

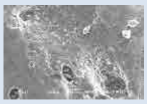
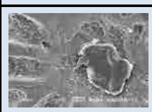
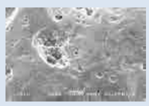
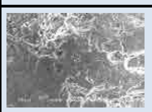
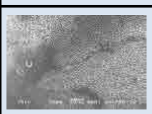
No.	SEM-EDX analysis		Chemical composition								
	Specimen	SEM	C	CaO	Al_2O3	Fe_2O_3	SiO_2	MgO	K_2O	FeO	TiO_2
1			10.54	57.25	9.01		18.66	3.52	1.02		
2			12.47	47.87	9.12		17.15	6.85		6.53	
3			15.27	44.54		8.87	18.47		1.12	7.08	
4			12.44	63.44	4.03		5.88	7.85		6.36	
5			10.09	25.11	21.7		35.69	2.32		4.09	
6			12.89	55.88	5.34		14.17	7.5		4.21	
7			11.21	27.83	18.47		27.14			6.07	9.29
8			9.25	90.75							

Figure 4. *Chemical composition of selected foraminiferal tests.*

CONCLUSION

There are more than 60 species of benthic foraminifera from offshore Bangka Island, southeast Sumatera. They belong to 39 genera and mostly belong to Order Rotaliida. These species and their diversity appear to represent normal (non-deltaic and non-reefal) shallow tropical marine assemblages.

More than 50% specimens are deformed shells, such as abraded, blackish, yellowish, brownish tests. Based on EDX analysis, these abnormal specimens are composed of Al_2O_3 (4-18%), Fe_2O_3 (8.9%), SiO_2 (5-27%), K_2O (1%), FeO (4-7%) and TiO_2 (9.29%). The occurrence of abnormal shells may be related to marine tin mining in the study area, which likely would have affected the turbidity or light intensity, hydrodynamics, food availability and pollutants to the environment. On the other hand, many of the poorly preserved specimens may be the result of post-mortem degradation processes, like transport by currents or waves, burial and reworking, scavenging by sediment-feeding organisms, etc. It is not known whether the sediments sampled were actually disturbed by dredging and tin removal processing.

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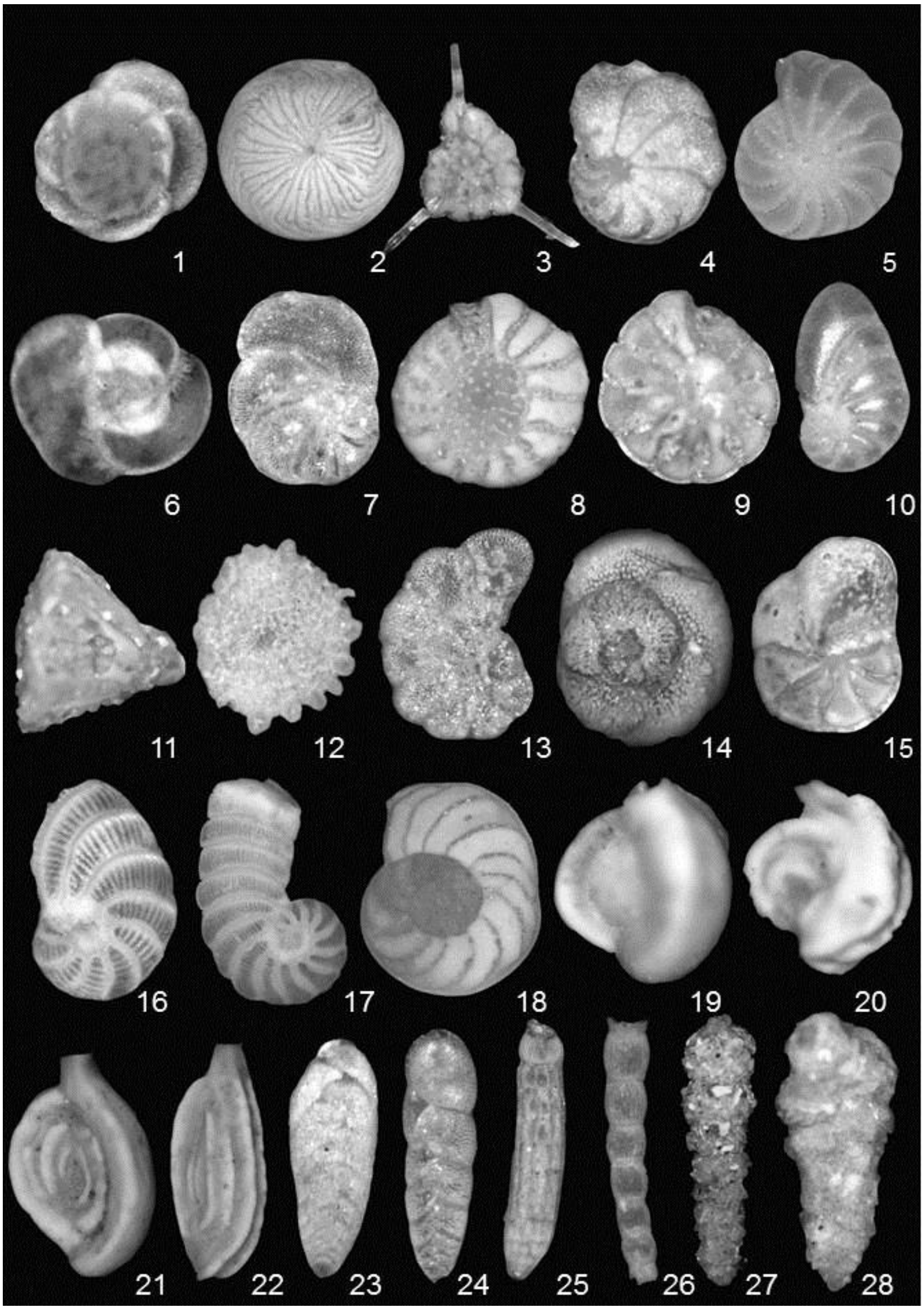

Plate 1. *Selected normal shells of benthic foraminifera from off Bangka Island.*

Plate 1:
1. *Ammonia beccarii*(Linnaeus), L = 0.35 mm
2. *Amphistegina radiata* (Fichtel and Moll),L = 1.24 mm
3. *Asterorotalia trispinosa* (Thalmann), L = 0.6-1.1 mm
4. *Discorbinella bertherloti* (d'Orbigny),L =0.24 mm
5. *Elphidium striata punctatum* (Fichtel and Moll), L =0.22 mm
6. *Parahauerinoides* sp., L=0. 68 mm
7. *Cancrisauriculus* (Fichtel and Moll), L = 0.44 mm
8. *Pseudorotalia schroeteriana* (Parker and Jones), L=0.88 mm
9. *Rotalinoides gaimardii* (d'Orbigny), L=1.3 mm
10. *Florilus elongatus* (d'Orbigny), L = 0.25 mm
11.*Pseudorotalia schroeteriana* (Parker and Jones), H = 0.62 mm
12.*Planorbulinella larvata* (Parker and Jones), L = 1.35 mm
13.*Alliatinella* sp. L = 0.30 mm
14. *Rosalinaglobularis* d'Orbigny, L = 0.32 mm
15. *Eponides cribroepandus* (Asano and Uchio), L=0.83 mm
16. *Peneroplis pertusus* (Forskal), L = 1.75 mm
17. *Spirolina arietina* (Batsch), L= 1.85 mm)
18. *Operculina ammonoides* (Gronovius), L = 1.57 mm
19. *Triloculina trigonula*(Lamarck), L= 0.55 mm
20. *Adelosina* cf. *A. litoralis* Martinotti, L= 0.2mm
21. *Spiroloculina subimpressa* Parr, L = 0.85 mm
22. *Quinqueloculina quiquecarinata* Collins, L = 0.45 mm
23. *Brizalinaantegressa* (Subbotina), L = 0.32 mm
24. *Bolivinaabbreviata* Cushman, L = 0.38 mm
25. *Rectobolivina brifrons* (Brady), L = 0.52 mm
26.*Nodosaria ovalis* (Koch), L=0.4 mm
27. *Martinottiella communis* (d'Orbigny), L = 1.30 mm
28. *Textularia agglutinans* d'Orbigny, L = 0.70 mm

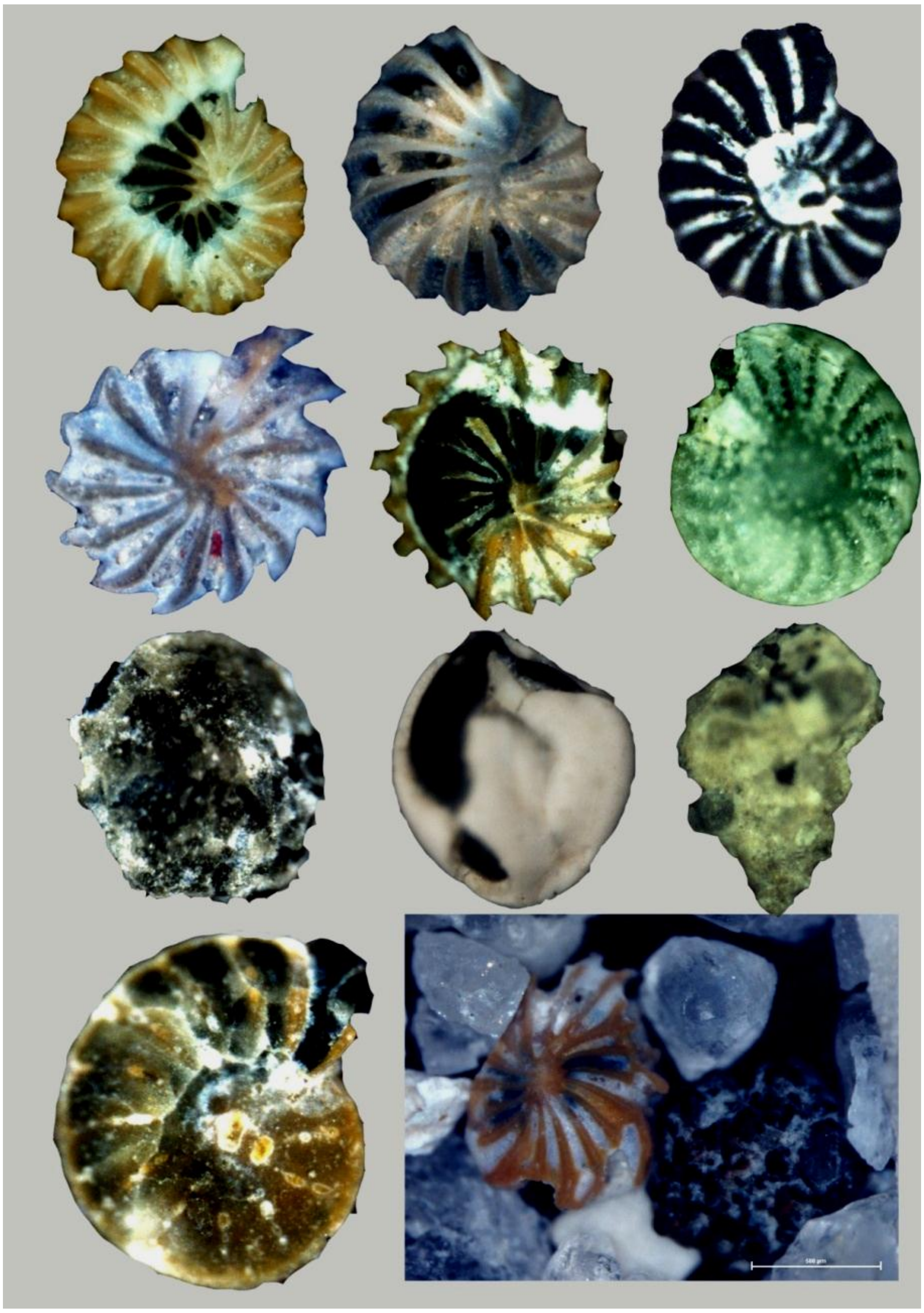

Plate 2. *Abnormal tests from various species of benthic foraminifera.*