Elemental Analysis on Marine Sediments Related to Depositional Environment of Bangka Strait

Analisis Unsur-unsur dalam Sedimen Laut Kaitannya dengan Lingkungan Pengendapan di Selat Bangka

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ABSTRACT: Study of elemental composition in sediment has been proven useful in interpreting the depositional environmental changes. Multi Sensor Core Logger (MSCL) is a non-destructive analysis that measures several parameters in sediment core including magnetic susceptibility and elemental composition. Magnetic susceptibility and elemental analysis were measured in four selected marine sediment cores from western part of Bangka Strait (MBB-67. MBB-119, MBB-120 and MBB-173) by using magnetic susceptibility and X-ray Fluorescence (XRF) sensors attached to the MSCL. The data was collected within 2 cm interval. Scatter plots of Y/Zr and Zr/Ti show singular trend demonstrated by sediments from MBB-173 and two groups that composed of MBB-67 (Group 1) and MBB-119 + MBB-120 (Group 2). MBB-67 that is located adjacent to Klabat Granite shows upward changes in mineralogy, slight increase of grain size and negligible change in Y concentration. Cores MBB-119 and MBB-120 are inferred to be deposited during regression that resulted in the accummulation of Y-bearing zircon in MBB-119 before the mineral could reach MBB-120. Core MBB-173 is interpreted to be the product of plagioclase weathering that is submerged by rising sea level. This core contains a horizon of rich Y-bearing zircon at 60 cm.

Keywords: Multi Sensor Core Logger, X-Ray Fluorescence, magnetic susceptibility, depositional environment, Bangka Island

ABSTRAK: *Studi tentang komposisi unsur kimia dalam sedimen telah terbukti bermanfaat dalam interpretasi perubahan lingkungan pengendapan.* Multi Sensor Core Logger *(MSCL) adalah sebuah analisis yang* non-destructive, *untuk mengukur beberapa parameter dalam bor sedimen termasuk suseptibilitas magnetik dan kandungan unsur. Suseptibilitas magnetik dan kandungan unsur diukur dari 4 bor sedimen laut yang terpilih di bagian barat Selat Bangka (MBB-67. MBB-119, MBB-120 and MBB-173) dengan menggunakan sensor suseptibilitas magnetik (MS) dan* X-ray Fluorescence *(XRF) yang terpasang pada MSCL. Pengukuran dilaksanakan dengan interval 2 cm. Plot Y/Zr dan Zr/Ti menunjukkan satu trend yang diperlihatkan oleh sedimen bor MBB-173 dan dua grup yang terdiri atas MBB-67 (Grup 1) dan MBB-119 + MBB-120 (Grup 2). Bor MBB-173 ditafsirkan sebagai hasil pelapukan plagioklas yang kemudian terendam air laut. Bor ini memperlihatkan horizon yang kaya akan zirkon pembawa yttrium pada kedalaman 60 cm.*

Kata kunci : Multi Sensor Core Logger, X-Ray Fluorescence, *suseptibilitas magnetik, lingkungan pengendapan, Pulau Bangka*

INTRODUCTION

Elemental composition of marine sediment has been used to understand sedimentological processes and paleoenvironment including sediment diagenesis, provenance studies, and identifying terrigenous sediment (e.g. Croudace *et al.*, 2006; Jones *et al.,* 2011; Govin *et al.*, 2012; Hendrizan *et al.,* 2016). Croudace *et al.* (2006) revealed that calcium/iron (Ca/Fe) may show strong correlation with sedimentary units, and is a good proxy for sediment grading and for assessing source relationships. Furthermore, the ratio of zircon/rubidium (Zr/Rb) and titanium/rubidium (Ti/Rb) are useful as sediment-source or provenance indicators. Govin *et al.* (2012) indicated several element ratios such as iron/calcium (Fe/Ca), titanium/calcium (Ti/Ca), titanium/aluminum (Ti/Al), iron/potassium (Fe/K) and aluminium/silicon (Al/Si) are the most commonly used for paleoclimate reconstructions. They concluded that Fe and Ti are related to the siliciclastic components of the sediment and vary with the terrigenous fraction of the sediment. While K can be derived from potassium feldspar or illite, which both characterize drier region with low chemical weathering rate.

Bangka Islands is part of the Southeast Asia Granite Tin Belt (Cobbing *et al.,* 1986) and situated in the Sunda Shelf that was exposed during Late Quaternary low sea level periods (Voris, 2000). Numerous studies on marine sediments from this area have been conducted to understand the distribution of tin placer deposits that are related to paleochannels. Recent findings from Bangka Islands revealed high accumulation of magnetite, ilmenite, zircon and apatite in fine sand fractions (Rohendi and Aryanto, 2012) that contain rare earth elements (REE). To date, elemental analysis in this area is only conducted on discrete samples and no continous measurement has been conducted on core samples collected from this area. Continous elemental measurement on core samples could provide valuable information on REE contents and their distribution. This information could be used to interpret depositional environment to improve our understanding of the placer deposits.

This paper employ continuous elemental analysis to establish the depositional environment of marine sediments from West Bangka waters. Considering the preference of REE-bearing heavy minerals in fine sand fractions, this paper will discuss the relationship between REE-bearing minerals and grain size. The study area is located on the western part of Bangka Strait (2 03'S to 2 10'S and 105 10'E to 105 40'E) within the Bangka Regency, Bangka Belitung Province (Figure 1).

Geological Setting

Bangka Island is formed by Paleozoic and Mesozoic rocks that are covered Quaternary Alluvium (Figure 2). The oldest rocks found in Bangka Island is Paleozoic to Permian Pemali Complex that comprises of phyllite, schist intercalated with quartzite and calcareous lenses that was undergone deformation in Late Paleozoic that resulted in Permo-Triassic Diabase Penyabung intrusion (Mangga and Djamal, 1994). The Tanjunggenting Formation that is composed of interlayering of metasandstone, sandstone, clayey sandstone with lenses of limestone was deposited during Triassic and found covering most of the island (Mangga and Djamal, 1994). Magma activity during Upper Triassic – Jurassic formed Klabat Granite intrusion that cut into all the older rocks (Mangga and Djamal, 1994). The youngest rocks found in the island is Ranggam Formation that consists of interlayering of sandstone, claystone and conglomerate that was deposited in Middle Miocene – Pleistocene (Mangga and Djamal, 1994).

Klabat Granite is part of the main granite belt of Malay Peninsula (Cobbing et al., 1986) that serves as source for tin placer deposit. Field observation of Klabat Granite that is outcropped in Toboali exhibit grayish white in color, coarse phaneric, holocrystalline, equigranular granite that is composed of plagioclase, quartz, biotite and some opaque minerals (Aryanto and Kamiludin, 2016). Rohendi and Aryanto (2012) reported that seafloor sediments off Betumpak Cape

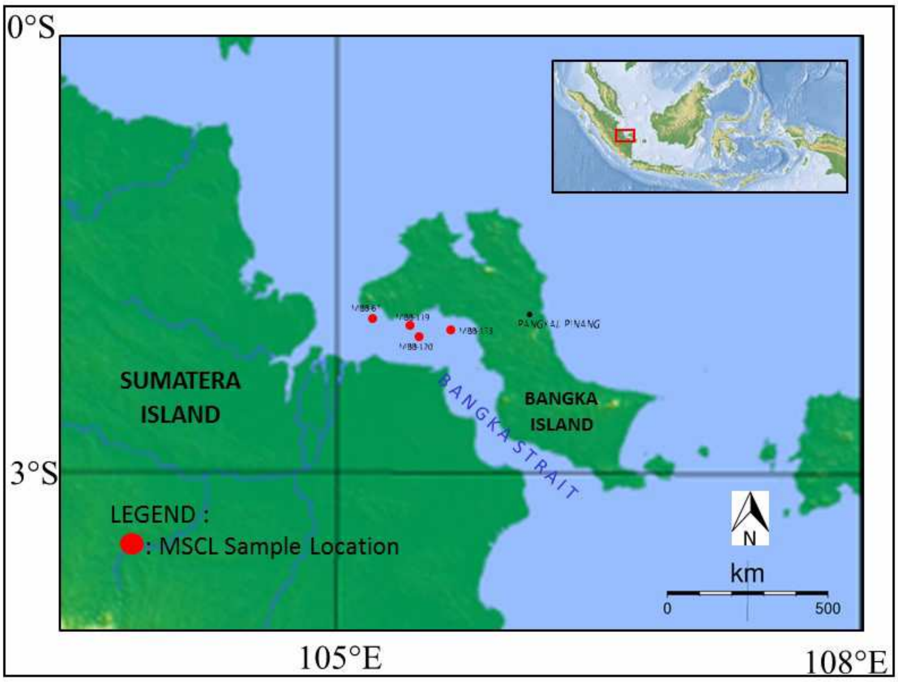


Figure 1. Map of study area and sampling sites.

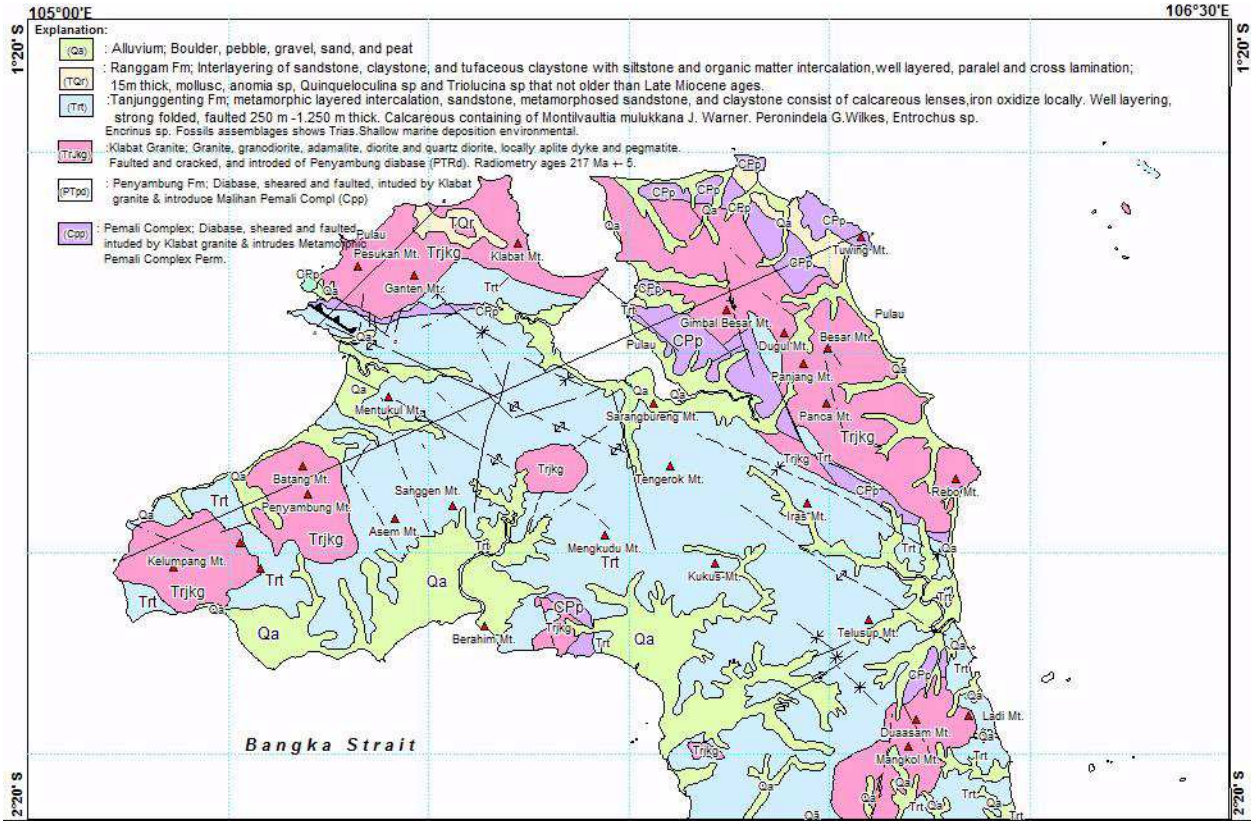


Figure 2. Geological map of Bangka Island (Mangga and Djamal,1994).

(west Bangka) comprise of quartz, clay, and mafic minerals that include apatite and zircon.

The formation of tin placer deposits is suggested to be controlled by Cenozoic eustatic sea level (Batchelor, 1979) that occurred in three phases: (1) extremely low sea level during Late Miocene to Early Pliocene resulted in Sundaland exposure under semi arid condition that led to deep lateritisation and red-bed sedimentation; (2) Late Pliocene to Early Pleistocene discontinously rising sea level with regular rainfall resulted in increase denudation that formed piedmont and fan and alluvial plain; (3) Middle Pleistocene to Holocene sea level rise that changed the climate in the region and resulted in braided river system and paralic sedimentation and river incision. The Quaternary stratigraphy of Sundaland of Batchelor (1979) can be summarised into Figure 3.

METHODS

This study was conducted on four selected gravity core samples (MBB-67, MBB-119, MBB-120 and MBB-173) that have been collected in 1996 from western part of Bangka Strait, between 9 – 30 m water depths. These samples were analyzed by a non-destructive scanning method in order to determine magnetic susceptibility and X-Ray Fluorescence in 2 cm intervals. The scanning was conducted using MSCL-S Geotek, at the Core Laboratory of the Marine Geological Institute in Cirebon.

Magnetic susceptibility (MS) measurement was performed using Bartington MS2E point sensor, while the elemental composition of sediment was measured by XRF handheld Olympus Innov-X. Both sensors are installed to the MSCL equipment. As has been described, elemental composition of sediment can be used as an indicator of terrigenous material, while magnetic susceptibility is sensitive to mineralogy and weathering process (Li *et al.*, 2007; Stoner and St-Onge, 2007; Zheng *et al.*, 2010; Zhou et al, 2014).

The elements that are used in this study is determined by their correlation coefficients following Hendrizan et al (2016) and their relation to REE and grain size. Previous studies used various grain size proxies, such as Zr/Ti (Oldfield et al., 2003) and Zr/Rb (Dypvik and Harris, 2001). Calculations of correlation coefficient on Zr, Ti and Rb (Table 1) yield highest value on Zr/Ti (0.7) that is used as grain-size proxy in this paper.

Rare earth minerals in Indonesia are present as accessory minerals in tin placer deposit (Rohendi and Aryanto, 2012). Aryanto and Kamiludin (2016) found that yttrium (Y) is predominant REE in coastal sediments of Toboali, south Bangka. Yttrium concentration in study area is presented as natural log ratio (ln) to avoid variation related to sedimentary

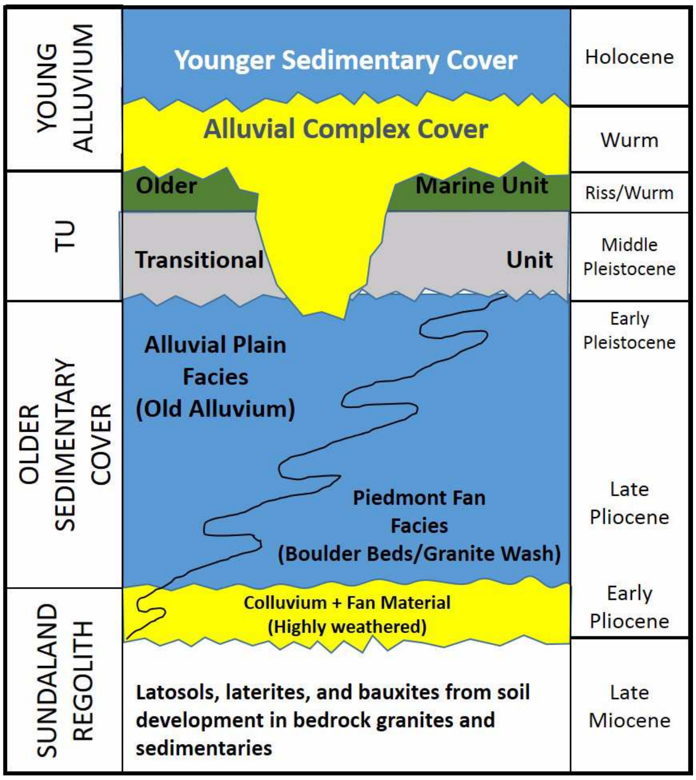


Figure 3. Regional stratigraphic column of Late Cainozoic sediments of Sundaland (Batchelor, 1979).

dilution effect (Dypvik and Harris (2001). Considering the concentration of Y in sedimentary rocks is influenced by heavy minerals, such as zircon, xenotime and garnet (De Vos and Tarvainen, 2006), this study uses log ratio of Y/Zr as proxy of REE content. This selection is supported by its high correlation coefficient (0.61) as is presented in Table 1.

Table 1. Correlation coefficient of MBB-67, MBB-119, MBB-120 and MBB-173.

Ratio	MBB-67	MBB-119	MBB-120	MBB-173	Average
Y:Zr	0.27	0.71	0.58	0.88	0.61
Zr:Rb	0.30	0.68	0.52	-0.13	0.34
Zr:Ti	0.63	0.71	0.80	0.58	0.68

RESULT

The elemental data is evaluated by comparing Y to Zr and Ti to Zr in scatter plot. Figure 4a shows singular trend composed of MBB-173 samples while MBB-119, MBB-120 and MBB-67 samples exhibit large variation that form two distinct group (Figure 4a): MBB-67 and MBB-119 + MBB-120. Both groups show relatively independent nature of Y to Zr and is speculated to be caused by different Y source that containes different concentration of Y. The close relationship of Y to Zr in MBB-173 suggests zircon as the main source of Y in this site.

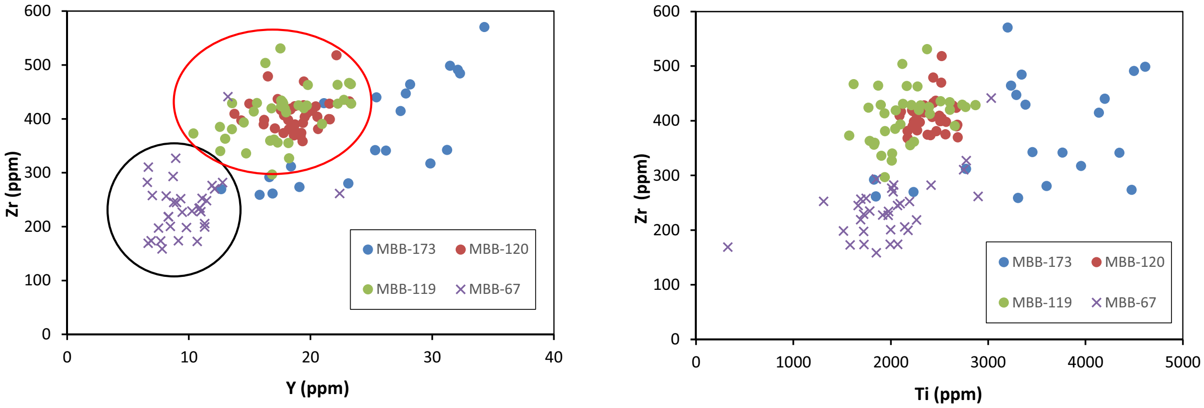
A large variation is revealed in Ti/Zr plot (Figure 4b) with MBB-173 shows positive trend with large scatter, whereas MBB-67, MBB-119 and MBB-120 exhibit clustering of data. Those trends suggest the possibility of mixed grain size in MBB-173 and relatively similar grain size in the three cores.

Vertical variation of magnetic susceptibility, ln Y/Zr and ln Zr/Ti for each core is illustrated in Figure 5. Magnetic susceptibility in MBB-67 shows higher value in the bottom part of the core and reaches its peak (105.9 x 10^{-5}) at 60 cm before decreases upward. The lowest value observed is 2.3 x 10^{-5} at 0 cm. In this sediment core, ln Y/Zr shows slight increase to the top with maximum value of -2.46 is also observed at 60 cm and minimum value of 3.84 at 66 cm. A slight increasing upward trend is also demonstrated by ln Zr/Ti with maximum value of -0.65 observed at 0 cm and minimum value of -2.48 at 36 cm.

In contrast to the previous core, MS in core MBB-119 exhibits increasing upward trend with two peaks (14.2 x 10^{-5} and 14.9 x 10^{-5} SI) observed at 7.7 and 21.7 cm. The minimum value of 0.1 x 10^{-5} SI is found at 13.7 cm. Similar trend is also observed in ln Y/Zr with maximum value of -2.87 at 35.7 cm and minimum value of -3.58 at 9.7 cm. An increasing trend is demonstrated by ln Zr/Ti with maximum value of -1.24 at 57.7 cm and minimum walue of -1.92 at 51.7 cm.

Core MBB-120 reveals different trends for the three components: increasing upward on MS and ln Zr/Ti whereas ln Y/Zr decreases to the top. The maximum value of MS (20.5 x 10^{-5}SI) is detected at 8.7 cm and minimum value of 2.1 x 10^{-5} at 66.7 cm. Ln Y/Zr shows maximum value of -2.92 at 64.7 cm and minimum value of 3.39 at 24.7 cm. The maximum value of ln Zr/Ti (-1.58) is observed at 36.7 cm while the minimum value (-1.98) at 44.7 cm.

The last sediment core, MBB-173, reveals increasing upward trends on all three components. The maximum value of MS (5.3 x 10^{-5}SI) is detected at 19.5 cm and minimum value (0.8) at 35.5 cm. Ln Y/Zr shows maximum value (-2.36) at 25.5 cm and minimum (-3.06) at 7.5 cm. The maximum value of ln Zr/Ti (-1.72) is found at 35.5 cm, coincidentally at the same depth of MS minima, whereas the minimum valur of ln Zr/Ti (-2.79) is at 19.5 cm which is concurrent with MS maxima.



a) b)

Figure 4. Plot of XRF data from MBB-67, MBB-119,MBB-120 and MBB-173: a) Y/Zr and b) Ti/Zr. Black and red circles in a) indicate the two group that can be recognized.

DISCUSSION

Mineralogy and grain size

The mineralogy of marine sediment from Bangka Strait is inferred from the assumed relationship between Y and Zr (Figure 4a). Among the four cores, only MBB-173 shows strong correlation between Y and Zr that points to zircon as the source of Y. Coastal and marine sediments in Toboali that was collected near Klabat Granite outcrop has been detected to contain between 3.32 and 106 ppm of yttrium (Aryanto and Kamiludin, 2016). Figure 4b displays the mixed nature of grain size in this core with clay fraction as predominant component. Examination of core MBB-173 reveals white to reddish fine-grained sediments (Figure 6) that points to kaolinite with iron oxide impurities as predominant clay minerals. This interpretation is supported by Rohendi and Aryanto (2012) who found kaolinite in marine sediment off Batumpak Cape. They explain the kaolinite as the result of plagioclas weathering from adjacent Klabat Granite.

The independent nature of Y from Zr in sediments of cores MBB-67, MBB-119 and MBB-120 (Figure 4a) might be related to the geology of surrounding land. Cores MBB-119 and MBB-120 were acquired in the central part of the study area where the coastal area is covered by alluvium, while MBB-67 was collected southwest of Muntok that is situated on Klabat Granite (Figure 2). Those difference is manifested in Y/Zr as two distinct groups: Group 1 consists MBB-67, while Group 2 comprises MBB-119 and MBB-120. Yttrium content of MBB-67 sediment is narrowly ranged with relatively lower value in comparison to the three other cores (Figure 4a) that might indicate enrichment of Y-bearing minerals in MBB-119, MBB-120 and MBB-173. Group 1 and Group 2 are also discernible in Figure 4b: Group 1 is dominated by relatively coarser-grain sediments; and Group 2 is mostly composed of finer-grained sediments. The sediment color of the three cores is dominated by gray to brown (Figure 6) that is interpreted as deposited in nearshore to marine environment.

Changes in Depositional Environment

The highest magnetic susceptibility values are found at the bottom part of core MBB-67 at ~100 x10^{-5}SI (Figure 5). Constrastingly, the other three cores (MBB-119, MBB-120, and MBB-173) indicate maxima values in the upper part of the cores. Even though the MS of MBB-119, MBB-120, and MBB-173 demonstrate similar increasing upward trend, the variability patterns are relatively different. These variations might be related to different depositional age, and/or different magnetic mineralogy of each core in view of sensitivity of MS to mineralogy (Stoner and St Onge, 2007).

Zr is found concentrated in silt-fine sand fraction (Veldkamp and Kroonenberg, 1993), whereas Ti is commonly found in clay fractions (Oldfield *et al.*, 2003). The log ratio of Zr/Ti might be useful for grain size proxy, indicating depositional environmental changes. The decrease of ln Zr/Ti value reflects increasing clay fraction in sediment while increase of ln Zr/Ti ratio might indicate coarser sediment grain. This variation is interpreted to reflect environmental changes related to sea level: from shore/nearshore to open sea, or vice versa. This interpretation is supported by core MBB-173 that is considered as product of subaerial weathering (Figure 6), as was described before.

Comparison of MS plot to ln Y/Zr and ln Zr/Ti of core MBB-67 reveals additional source of Y in this site which is detected by high MS and ln Y/Zr values at the bottom part of the core that coincides with low ln Zr/Ti (Figure 5). The decreasing upward of MS values might be related to the change of mineralogy that followed the deposition of high concentration of Y-bearing zircon.

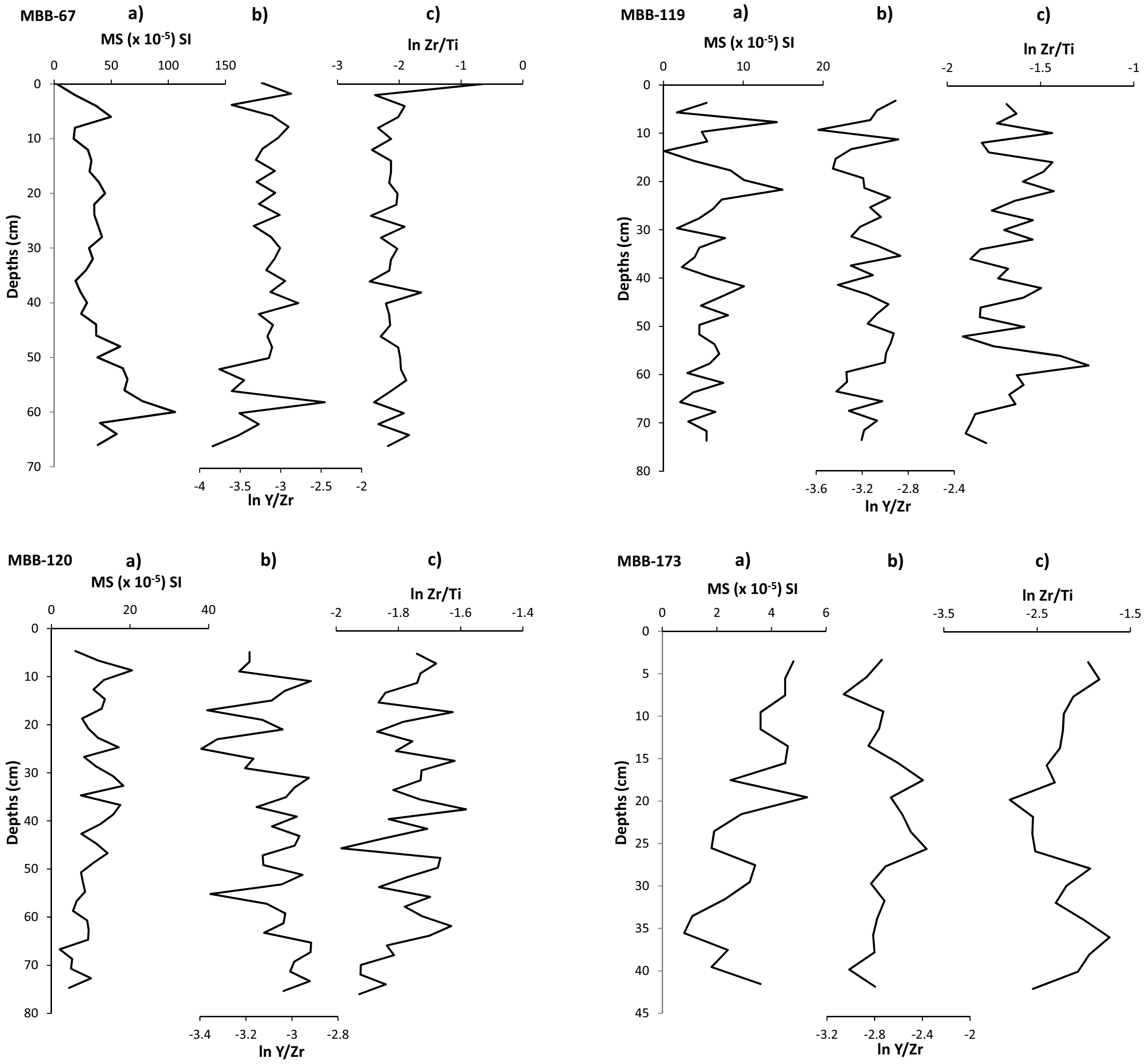


Figure 5. Vertical variations of magnetic susceptibility, ln Y/Zr, ln Zr/Ti of cores MBB-67 (top left), MBB-119 (top right), MBB-120 (bottom left) and MBB-173 (bottom right).

Slight change in grain size implies the absence of extreme environmental changes at the site such as sea level change. This interpretation is supported by sediment color that point to marine environment.

Even though cores MBB-119 and MBB-120 belong to the same group, each core show different vertical variations. Core MBB-119 exhibits increasing upward trend of the three components that reflects changes in the mineralogy of the sediment with increasing grain size (Figure 5). The trend suggests increasing influx of coarser grain, more magnetic minerals with higher Y content to the top.

Core MBB-120 shows increasing upward trend of MS and ln Zr/To as opposed to ln Y/Zr. This pattern is interpreted as increasing concentration of magnetic minerals that are coarser grained and contain less Y (Figure 5). The coarsening upward trends in MBB-119 and MBB-120 might be deposited during regression that resulted in accummulation of Y-bearing zircon in MBB-119 before the mineral could reach MBB-120.

Core MBB-173 is an interesting short core that all three components show increasing upward trend. The peak of MS is observed at 15-30 cm depth and coincides with low ln Y/Zr and Zr/Ti (Figure 4b). This observation points to a horizon of coarser grain magnetic mineral that contains less yttrium, that is not clearly visible (Figure 6). The core is interpreted as the product of subaerial weathering of plagioclase that is submerged by increase of sea level.

CONCLUSIONS

Continous measurements of magnetic susceptibility and elements on four marine sediment cores (MBB-67, MBB-119, MBB-120 and MBB-173)

Figure 6. Line-scan image of MBB-67, MBB-119, MBB-120 and MBB-173 showing distinct color of MBB-173 compared to the rest. Core images are from Sampurno et al. (2017).

from Bangka Strait reveal the relationship between yttrium content to mineralogical composition (ln Y/Zr) and grain size (ln Zr/Ti). Scatter plots of Y/Zr and Zr/Ti demonstrate the importance of local geology to marine sediments. Two distinct groups can be recognized: Group 1 (MBB-67) and Group 2 (MBB-119 and MBB-120) and core MBB-173. Core MBB-67 that is located adjacent to Klabat Granite shows upward changes in mineralogy, slight increase of grain size and negligible change in Y concentration. Cores MBB-119 and MBB-120 are interpreted to be deposited during regression that resulted in the accummulation of Y-bearing zircon in MBB-119 before the mineral could reach MBB-120. Core MBB-173 is inferred to be the product of plagioclase weathering that is submerged by rising sea level. The core contains a horizon of rich Y-bearing zircon at 60 cm.

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