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Sedimentary Environments of the Dumai Coastal Waters on the East Coast of Central Sumatera Island, Indonesia

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The purpose of this study is to reveal the sedimentary environments based on sediment characteristics and relative sedimentation rates of the Dumai coastal waters. The coastal waters is subdivided into three areas based on the general trend of sediment characteristics and relative sedimentation rates as following: (1) The area near the coast and central area of the waters is characterised by coarse-grained sediments, high relative sedimentation rates and dominantly terrigenous sediments influenced by rather strong tidal currents; (2) The area off the coast (central part) is characterised by the finest-grained sediments with the highest relative sedimentation rates. The area corresponds to the boundary between the water masses derived from Rupat Strait and the Dumai Waters and is under the influence of weak tidal currents; and (3) the areas relatively close to the coast of the waters (the eastern and western parts) are characterised by fine-grained sediments, rather high relative sedimentation rates and relatively high biogeneous sediments which are influenced by longshore currents. The distribution of crude oil content in sediments indicated that the study area was under the influence of tidal and longshore currents.

Key words: Bottom sediments; relative sedimentation rates; grained sediment; tidal currents; crude oil content

The Dumai coastal waters, a semi-closed inland sea, is located on the east coast of central Sumatera Island, Riau Province, Indonesia. The waters are separated from Malacca Strait by Rupat Island and connected to the strait by the Rupat Strait (Figure 1). It is elongated from the south to the northwestward with a depth of 1 to 30 meters. The waters have a rather flat bottom topography and is influenced by water masses from the river and Malacca Strait by tidal currents and anthropogenic activities.

Mangroves have thrived in the coastal area until some decades ago but are greatly diminished at present due to the land development of its hinterland. Rather strong tidal currents flow through the waters. The velocity of tidal currents ranges from 0.11–0.67 m/s.

The coastal area of the waters has been rapidly developed and became the centre of industries and of a harbour. Water from the Malacca Strait flows through the area from the south to the northwest during ebb tide and reversed during high tide. All of the anthropogenic and natural activities discharge solid wastes and fluid into the area and affect the sedimentary environment. Marine sediments can provide a record of depositional history of an area because of the much longer lifespan of the sediment (Tomiyasu *et al*. 2000).

Since the establishment of the Marine Science Department, Fisheries and Marine Sciences Faculty at Riau University, the waters have become one of the areas most intensively studied in relation to water quality, marine biology, and marine sediments. Significant studies in ecological and oceanographical aspects of the waters have been carried out by Amin and Zulkifli (1997); Brahmawanto *et al*. (2000); Amin (2001); Rifardi (2002); Amin (2004); Amin *et al*. (2006); Amin *et al.* (2007); Badrun (2008); Amin *et al*. (2009); Purba

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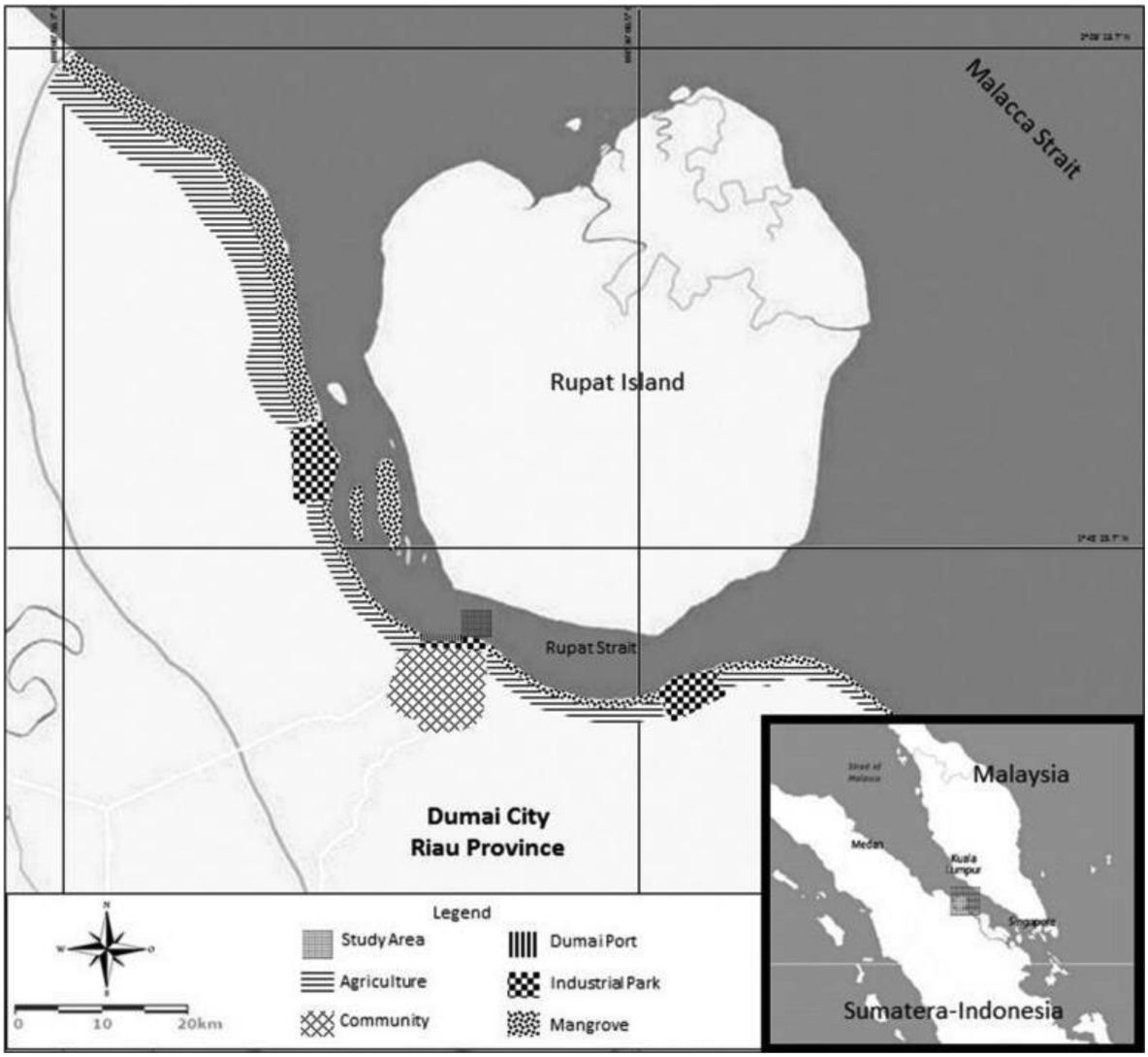

Figure 1. Index map of the study area

and Khan (2010); Nedi *et al*. (2010) and Musrifin (2011). However, only a few studies have been conducted in the bottom sediments from the sedimentological point of view.

The main purpose of this study is to clarify the relationship between the characteristics of sediments and environmental conditions, based on the analyses of bottom surface sediments from the Dumai Coastal Waters.

MATERIALS AND METHODS

The bottom surface sediment samples used for this study were collected from seven stations in the Dumai coastal waters at depths from 5.4 to 21.8 m in March 2011. The positions of the sampling stations were determined based on current system patterns and by using the Global Positioning System (Figure 2). All the sediment samples were collected with a gravity corer made by Hisanaga Co. Ltd, Kagoshima, Japan. The samples were used for analysis of mechanical grain size and crude oil content. The top one centimetre (0–1 cm) of core samples were utilised for a foraminiferal study to estimate sedimentation rates.

The gravel and sand proportions were determined by sieving and were weighed oven dried (Oki 1989; Rifardi *et al*.1998). The settling tube method was utilised to determine the mud proportion. The graphical method of Folk and Ward (1957) was used to calculate the median diameter (MdØ), sorting coefficient (Ó1) and skewness (Sk1) of the sediments. The textural proportions of gravel, sand and mud were plotted on Shepard's triangle (Shepard 1954). Crude oil contents (hydrocarbon total) of core samples were measured

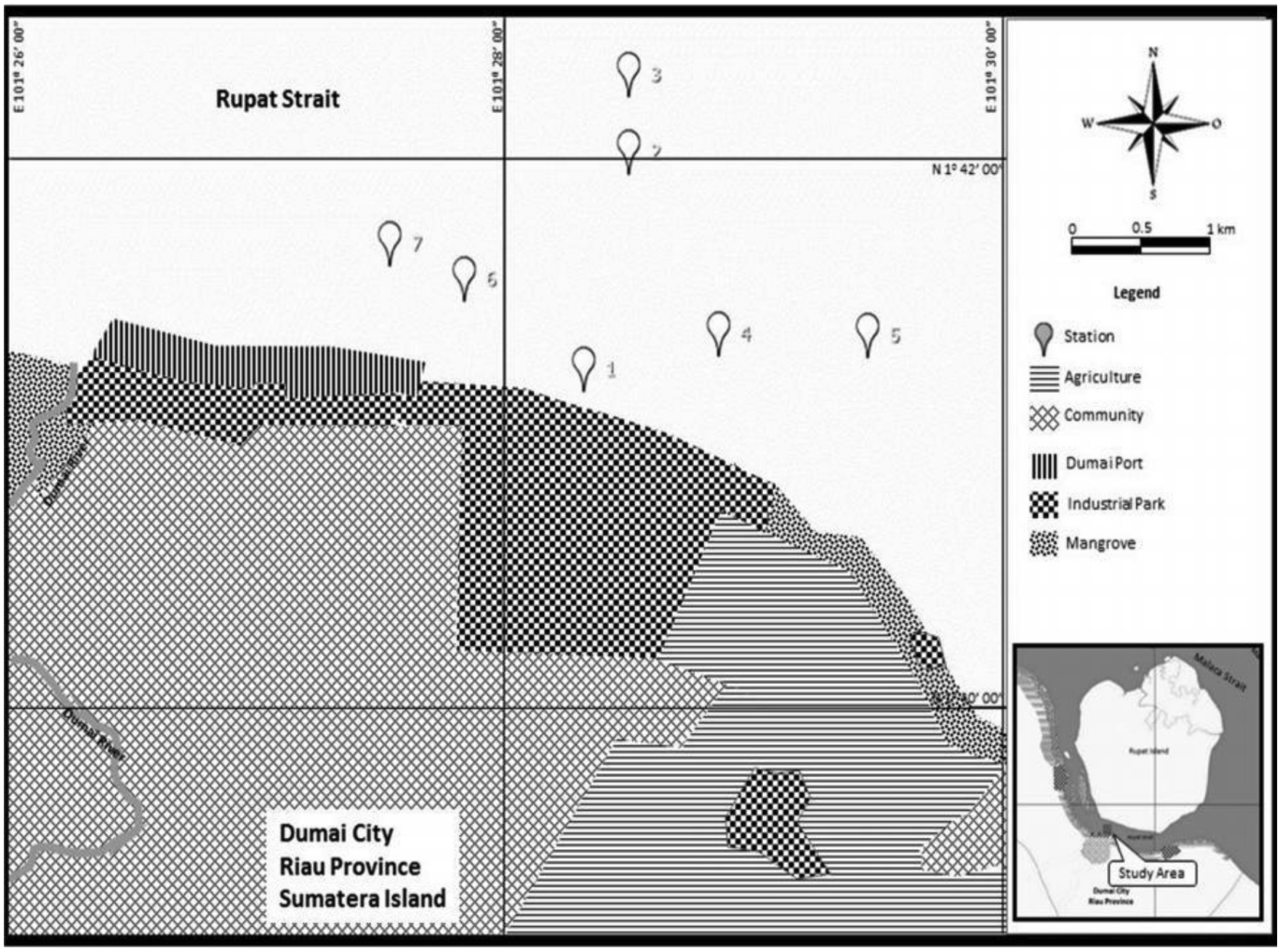

Figure 2. Map showing the sampling stations

in the laboratory using the Soxhlet Woodman Method of Sudarmadji *et al.* (1997). Organic matter content in the sediment was analysed by procedures proposed by Tech (1986).

The top most one centimetre of core samples which is approximately 10 cc of wet sediments, was preserved in alcohol and stained with Rose Bengal for discriminating living foraminiferal. Each sample was washed through a 200-mesh (0.0074 mm opening) sieve, and oven dried after removal of the dye (Rose Bengal). All the specimens were then picked from the aliquot. The aliquots containing less than 200 individuals of benthic foraminifera were supplemented by additional splits (Rifardi *et al*. 1998). All of the benthic foraminifera were indentified and counted. Living and empty (dead) tests of benthic foraminifera were used to calculate the L/TI value (the ratio of the number of living specimens to total living and empty tests) to infer the relative sedimentation rates as proposed by Oki (1989).

RESULTS

Bottom Sediment

The results of mechanical analysis of the seven samples are shown in Table 1. In general, the bottom sediment of the Dumai coastal waters are characterised by coarse sand to medium silt (MdØ: 0.61–5.5Ø) and are dominated by more than 50% sand. The areas with low median diameters (MdØ: <2 Ø) are located in central part of the waters (Station 1 and 2), namely, the area near the coast. In contrast, the areas with high median diameters (MdØ: >2 Ø except Station 3) are seen in the eastern and western parts of the waters (closer to the coast). The area off the coast (Station 3) is characterised by the finest sediments.

Based on the distribution of median diameters (MdØ), the study area can be divided into: (1) The area near the coast and central area of the waters, both of

Table 1. Results of mechanical analysis of the bottom surface sediments

Station	Latitude	Longitude	Gravel (%)	Sand (%)	Mud (%)	Md (Ø)	Sk1	Ó1 (Ø)	Bottom character
1	1°41'8.7"	102°28'19.2"	39.8	51.40	8.80	0.61	0.61	1.28	GS
2	1°41'56.4"	101°28'30"	23.84	72.67	3.49	0.73	–0.07	1.64	GS
3	1°42'13.3"	101°28'30"	0	94.29	5.71	5.50	–0.01	1.10	S
4	1°41'16.5"	101°28'51.6"	5.98	73.78	20.24	2.23	0.03	2.08	MS
5	1°41'16.1"	101°29'27.6"	11.21	70.48	25.21	2.63	0.06	1.80	MS
6	1°41'28.7"	101°27'50.4"	0.53	94.18	5.21	2.53	–0.11	0.83	S
7	1°41'36.2"	101°27'32.4"	4.66	93.94	1.40	2.00	0.12	1.02	S

Note: GS = gravely sand; S= sand; MS= medium sand

which are characterised by coarse sediments (St. 1 and 2); (2) The area off the coast characterised by the finest sediments (St. 3); and (3) The area relatively close to the coast characterised by fine sediments (St. 4–7).

Contents of Crude Oil and Organic Matter

The results of analyses of the contents of crude oil and organic matter in surface sediment are shown in Table 2. The bottom sediments in the Dumai coastal waters were characterised by high contents of crude oil (>100 ppm) and by low organic matter contents (<20%) except for Station 4 and 6 which are located relatively close to the coast.

High contents of crude oil were recognised at stations (Station 1 and 3) located close to anthropogenic activities such as industries, waste water discharged and ship transportation. The contents of crude oil were assumed to be derived from the activities that discharge them into the waters. Contrastingly, the station with low content of cruide oil was Station 5 located relatively close to the coast.

The distribution of organic matter (%) in the study area showed the same trend to that of median diameter (MdØ). The area relatively close to the coast characterised by fine sediments had high organic matter content. The area near the coast and central area of the waters characterised by coarse sediments was characterised by low organic matter content. This meant that organic matter tended to be absorbed in or adhesive to mud fraction (fine grain sediments) so that grain size showed low median diameter (coarse sediments) and the organic matter content was low. This relationship is also found in the Oura River Estuary on the east coast of northern Okinawa Island, Japan by Rifardi and Ujiie (1993).

Relative Sedimentation Rates

The values of L/Tl (relative sedimentation rates) of the seven stations are shown in Table 3. The L/Tl values in Dumai coastal waters ranged from 2.4 to 10.5%. The high L/Tl values could be recognised in the areas near to the coastal at Station 1 and 6. Contrastingly, The low L/Tl values could be recognised in the areas further from the

Table 2. Results of analysis of the contents of crude oil and organic matter

Station	Crude oil content (ppm)	Organic matter (%)
1	7773.11	5.08
2	5958.55	1.35
3	10953.61	4.49
4	5887.16	23.53
5	961.91	16.37
6	1304.80	28.57
7	3501.54	9.88

Table 3. Data on the number of total and living specimens and the L/Tl Value

Station	Number of individuals		L/Tl value
	Total (Tl)	Living (L)	(%)
1	167	12	7.1
2	229	8	3.4
3	352	37	10.5
4	79	n.a.	n.a.
5	92	3	3.2
6	246	17	6.9
7	281	7	2.4

n.a. = not available

coastal (Station 2, 5 and 7). Living benthic foraminifers were not found in Station 4 which was characterised by strong tidal currents and located near to the mangrove area. Empty (dead) tests of benthic foraminifera were assumed to be brought from other areas by the currents. The situation at Station 4 must be further studied from oceanographic and ecological points of view.

Based on the frequency of the total amount of individual and species of benthic foraminifera collected from the seven stations in Dumai coastal waters, a clusters analysis was carried out. Benthic foraminifera of seven stations can be classified by the cluster analysis into three clusters (I to III) at the level of 8 Rescaled Distance in the dendrogram (Figure 3).

Cluster I (Station 2, 3, 6 and 7) is characterised by predominantly *Ammonia beccarii* forma A, *Ammonia beccarii* forma B, *Aromalina glabrata, Eggerella scabra, Reophax scotti*, mainly distributed rather far from the coastal area of Dumai Coastal Waters. The water depth of the area ranges from 14 to 21 metres and organic matter content in surface sediments range from 11.3 to 28.57 %. The values of L/Tl (relative sedimentation rates) of the area range from relatively high to the highest.

Cluster II (Station 1 and 5) is characterised by *Ammonia beccarii* forma A, *Eggerella scabra, Aromalina glabrata, Reophax scotti,* distributed in the areas both near to the coast (Station 1) and further from the coast (Station 5). Bottom characters of sediments in these areas were dominantly occupied by sand fraction. Water depth of the area ranged from 5 to 12 metres and organic matter content in surface sediments range from 5 to 10%. The values of L/Tl (relative sedimentation rates) of the area ranged from relatively high to high.

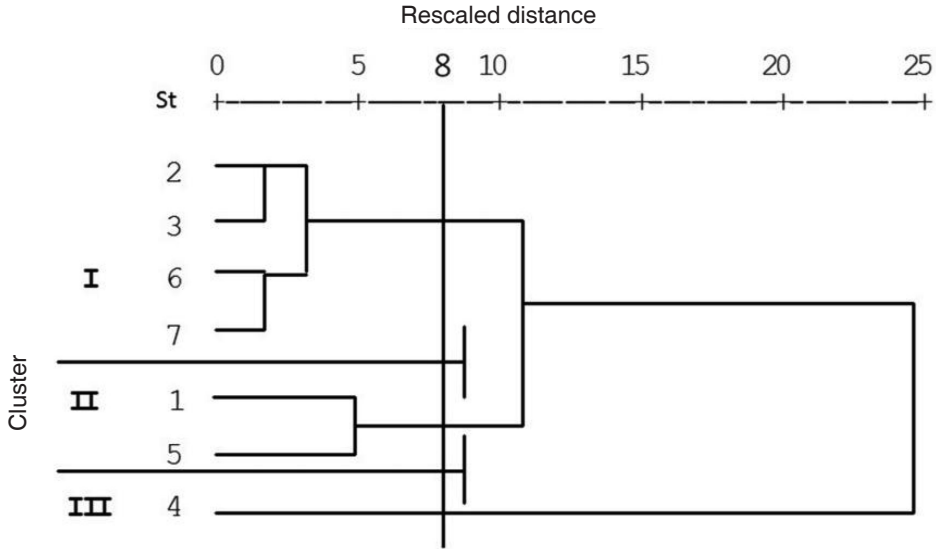

Figure 3. Dendrogram for benthic foraminifera

Cluster III (Station 4) was characterised by predominantly *Ammonia beccarii* forma A, and *Aromalina glabrata,* was found in an area next to the mangrove, which was characterised by strong tidal currents. As explained above, the living benthic foraminifers were not found in Station 4 where empty (dead) tests of benthic foraminifera were assumed to be brought from other areas by the currents. For this reason, The values of L/TI (relative sedimentation rates) could not be determined.

DISCUSSION

The Dumai coastal waters is divided into the following three areas according to the character of the bottom sediments: (1) The area near the coast and central area of the waters (Station 1 and 2) were characterised by coarse-grained sediments; (2) The area off the coast (central part) as characterised by the finest-grained sediments; and (3) The areas relatively close to the coast of the waters are characterised by fine-grained sediments. Geographical distribution of these areas is shown in Figure 4. The relationship between the characters of bottom sediments and depositional environmental in these three areas is discussed below.

Station 1 and 2. The area near the coast and central area of the waters was characterised by coarse-grained sediments. The stations included in the area near the coast and central area of the waters showed the bottom sediment character (Md: 0.61–0.73Ø) which were influenced by rather strong tidal currents (>0.22 meter/second). High crude oil content in the sediment indicated that sediments were polluted by wastes of anthropogenic activities discharged into these areas. Some of the activities are such as industries, waste water discharged and ship transportation, as explained above. This indication was strongly supported by low organic matter content in sediment (1–5%) meaning that these areas area under the influence dominated by terrigenous sediments even though relative sedimentation rates ranged from low (Station 2) to high (Station 1). Rifardi and Ujiee (1993) also found that terrigenous sediments were characterised by a low content of organic matter. High relative sedimentation rate in Station 1 were assumed due to the station being located very close to the coastal area which was eroded by the current.

Central part: Station 3. The area off the coast was characterised by the finest-grained sediments. The area showed the bottom sediment character (Md Ø: 5.5) which was influenced by weak tidal current (>0.16 metre/second). Judging from the highest relative sedimentation rates (L/TI = 10.5%), suspended sediments accumulate in this area. This area might correspond to the boundary between the water masses derived from the Rupat Strait and from the Dumai Waters. Suspended sediments might have accumulated downstream along the frontal interface which occurs in a rip current area (Sakamoto 1982; Oki 1989; Rifardi *et al.* 1998; Rifardi & Oki 1998).

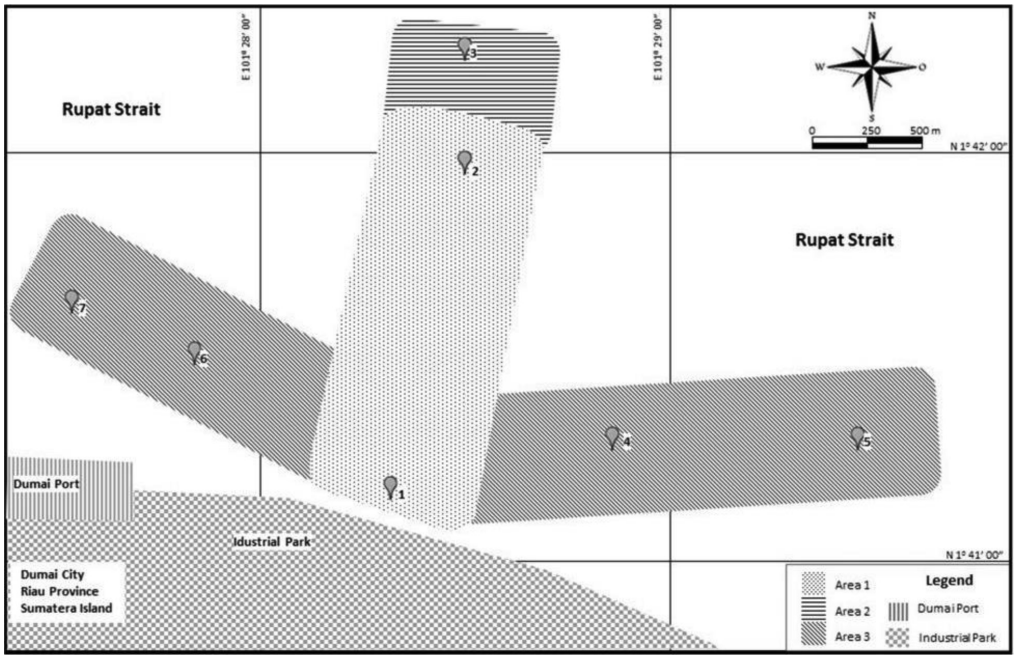

Figure 4. Geographical distribution of the three areas of study (Areas 1–3)

High crude oil content in the sediment (10, 953 ppm) indicated polluted sediments were transported to this area as suspended sediments and accumulated in the above situation. The sediment of this area is occupied by terrigeneous sediments as shown by low organic matter content in sediments (<5%). Therefore, it could be concluded that sediments were polluted by crude oil which flowed through Station 1 and 2, and accumulated in Station 3.

Station 4, 5, 6 and 7. The areas relatively close to the coast of the waters (the eastern and western parts of the waters) were characterised by relatively fine-grained sediments.

The areas with relatively high median diameters (MdØ: 2–3 Ø) were seen in the eastern and western parts of the waters (relatively close to the coastal area) which were influenced by longshore currents. In general, the currents flow through the study area from the west (Malacca Strait) to the east (Malacca Strait) in periods of the high tide and flow through the study area from the east (Malacca Strait) to the west (Malacca Strait) during the ebb tide, (Pplh 2002). The velocity of the currents in the eastern parts (0.25–0.67 metre/second) was stronger than the western parts (0.11–0.12 metre/second).

High organic matter contents in the sediments were recognised in the eastern part (Station 4 = 23.53%) and western part (Station 6 = 28.57%). These stations are located close to mangrove areas and to areas of the anthropogenic activities. Organic matters were assumed to be discharged from these areas and had accumulated them at these stations. Rather high relative sedimentation rates (L/Tl = 6.9% in Station 6) and total amount of empty (dead) tests of benthic foraminifera (Table 3: Station 6 = 246 individuals and Station 7 = 281 individuals) supported the assumption. Strong relationship between accumulated materials and sedimentation rates is also clarified by Rifardi (2008a) in Yatsushiro Sea, Japan and by Rifardi (2008b) in Paya Sea, Kondur-Riau, Indonesia.

CONCLUSION

General feature of the bottom sediments in the Dumai coastal waters was characterised by coarse sand to medium silt. The waters was dominantly occupied by sand fractions except for the area off the coast.

The Dumai coastal waters is divided into the following three areas based on the bottom sediment characters:

1. The area near the coast and central area of the waters were characterised by coarse-grained sediments. The sediments polluted by crude oil were accumulated in this part as shown by high relative sedimentation rates.
2. The area off the coast (central part) were characterised by the finest-grained sediments. The highest relative sedimentation rates in this area might correspond to the boundary between the water masses.
3. The areas relatively close to the coast of the waters (the eastern and western parts of the waters) were characterised by relatively fine-grained sediments. The sediments were discharged to these partss from their vicinity areas.

Judging from the distribution pattern of crude oil content in sediments, sediments polluted by crude oil were transported northwestward and northeastward by longshore currents and spread toward north by tidal currents of the Dumai coastal waters.

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