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## Influence of Monsoon on the Distribution of Organic Carbon in Inner Continental Shelf Core Sediments, South China Sea, Malaysia

(Pengaruh Monsun ke atas Taburan Karbon Organik dalam Sedimen Teras Pelantar Benua Dalam di Laut China Selatan, Malaysia)

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### ABSTRACT

*Three short sediment cores (12–32 cm) from South China Sea off Southern Terengganu were collected during May (post-Northeast monsoon) and September (pre-Northeast monsoon) 2007. The concentration of total organic carbon (TOC) obtained ranged from 0.41–2.23 and 0.38–2.31% during post and pre-monsoon, respectively. TOC concentration was found to decrease with depth and distance from the coast and river mouth. In particular, station with close proximity to the coast exhibits most pronounced variation of TOC with depth. Besides spatial variation, it is noted that the seasonal variations also considerably affect the distribution and concentrations of TOC, where both near and offshore sampling stations showed significant variations in TOC content during May and September sampling. These findings suggest the importance of terrestrial organic carbon flux, physical mixing and seasonal variations in regulating the concentration and distribution of the organic carbon in the study area.*

*Keywords: Autochthonous organic carbon; fluvial transport; land-based organic matter; seasonal influence; Southern South China Sea*

### ABSTRAK

*Tiga turus sedimen pendek (12–32 cm) telah diambil di Laut China Selatan dalam bulan Mei (pos-Monsun Timur Laut) dan September 2007 (pra-Monsun Timur Laut). Kepekatan jumlah karbon organik (TOC) yang diperolehi adalah antara 0.41–2.23% bagi pos monsun manakala bagi pra-monsoon adalah antara 0.38–2.31%. Kepekatan TOC didapati berkurangan dengan jarak dari pesisir pantai dan muara sungai. Kepekatan TOC juga didapati berkurangan dengan kedalaman turus sedimen pada semua stesen, dengan stesen yang paling dekat dengan pesisir pantai mempamerkan perubahan kepekatan yang paling ketara. Perubahan musim juga memberi kesan kepada taburan dan kepekatan TOC dengan kedua-dua stesen berdekatan pesisir pantai dan luar pantai mempamerkan perbezaan kepekatan TOC yang signifikan pada musim Mei dan September. Penemuan ini menunjukkan bahawa fluks karbon organik daratan, percampuran fizikal dan perubahan musim adalah penting dalam mengawal kepekatan dan taburan karbon organik di kawasan kajian.*

*Kata kunci: Angkutan sungai; bahan organik daratan; karbon organik autokran; Laut China Selatan; pengaruh musim*

### INTRODUCTION

Marine sediments receive two types of organic carbon (OC), particular the terrestrial OC, which is mainly transported through river discharge and to a lesser extent through atmospheric deposition; and *in-situ* production of OC by marine organisms (i.e. autochthonous OC) (Burdige 2007; Yunker et al. 2005). Often, terrestrial organic matter (OM) is made up of living biomass, plant litter and soil organic matter while autochthonous marine OM is greatly enriched with proteins, carbohydrates and lipids which is derived from phytoplankton detritus (Burdige 2007). An estimated 75–95% of the land-derived sediment was brought to the oceans worldwide by the rivers (Milliman & Syvitski 1992) and about 1% of the total organic carbon carried by rivers is derived from the terrestrial productivity (Hedges & Keil 1995). Of all the terrestrial and marine originated OM, it is found that only less than 10% of these OM reach the ocean floor and less than 0.5% is preserved in the marine sediments

(Hedges & Keil 1995). In terms of its spatial distribution, organic carbon in marine sediment tends to decrease both with distance offshore and distance from major rivers (Hedges & Keil 1995; Yunker et al. 2005) due to particle settling and dilution effect by mineral matters (Prahel et al. 1994). Therefore, it is generally known that the continental margins play an important role in regulating the global OC cycle as over 80% of the global OC is found in these shallow marine environment (Hedges & Keil 1995). In view of its great importance, studies on source, distribution and composition of sedimentary OM are often crucial for the understanding the mechanisms and roles of OM in the global organic carbon cycle (Hu et al. 2009).

In Malaysia, the distribution of OM in riverine, estuarine and mangrove sediments is well established (Bakhtiari et al. 2010; Kamaruzzaman et al. 2010; Mohd Tahir et al. 2009). However, there is still very limited information on the distribution of OM in the marine environment off Southern

Terengganu coast (Hasrizal et al. 2009; Mohd Ali et al. 2011). In view of this, the present study has been undertaken to determine the distribution of organic carbon in the inner continental shelf core sediments (within 50 km from the coast) off Southern Terengganu coast. In addition, this study also aimed to examine the influence of terrestrial input and monsoon seasons on the organic carbon distribution in the Southern South China Sea.

MATERIALS AND METHODS

STUDY AREA

The sampling area lies on the Sunda shelf with shallow waters (< 50 m). It is located in the monsoon belt, thus, experiencing a unique climatic feature created by the Northeast monsoon (from November or early December through March) and Southwest monsoon (from the later half of May or early June and ends in September or early October) (Morton & Blackmore 2001). These two monsoons are separated by two relatively shorter inter monsoon periods (April-May and October through to early November). Several rivers discharge its waters into the study area where main rivers include Sungai Dungun (1399 km<sup>2</sup>), Sungai Paka (746 km<sup>2</sup>) and Sungai Kemaman (1399 km<sup>2</sup>); smaller rivers include Sungai Kerteh, Sungai Chukai and Sungai Kemasik with total drainage area of

approximately 653 km<sup>2</sup> (DOE 1986). A <sup>210</sup>Pb profile for cores taken in the South China Sea off the coast of Kuala Terengganu and Kuantan (approximately 100 km to the north and 40 km to the south of the present study area) showed sedimentation rate ranging between 1.2 and 1.4 mm yr<sup>-1</sup> with surface mixed layer limited to the upper 10 cm of the core (Wan Mahmood et al. 2010). For this study, three short sediment cores (12-32 cm) were collected during May 22-26, 2007 (post Northeast monsoon) and September 4-9, 2007 (pre-Northeast monsoon) cruises, respectively, using a gravity corer. The sampling stations were located in the inner continental shelf off Dungun and Kemaman coast, covering an area of approximately 2464 km<sup>2</sup> (56 km in width × 45 km in length) (Figure 1). Samples were collected at the same locations during May and September; station coordinates, distance from the coastline and core length collected at each sampling station are outlined Table 1.

SAMPLE ANALYSIS

Once collected, core samples were kept refrigerated (-4°C) during transport to the laboratory. In the laboratory, the cores were stored at -4°C until further analysis. Once thawed, each core was sectioned into 2 cm intervals and every section was then packed in an aluminium foil bag prior to freeze-drying. Freeze-dried sediments were then

TABLE 1. Coordinates and core lengths of sampling stations

Station	Coordinates		Approximate distance from coastline/km	Core lengths (cm)	
	Latitude	Longitude		Post Northeast Monsoon 2007	Pre-Northeast monsoon 2007
ST1	4° 45.000' N	103° 28.500' E	6	16	22
ST2	4° 45.000' N	103° 42.021' E	30	32	32
ST3	4° 15.000' N	103° 52.620' E	45	12	16

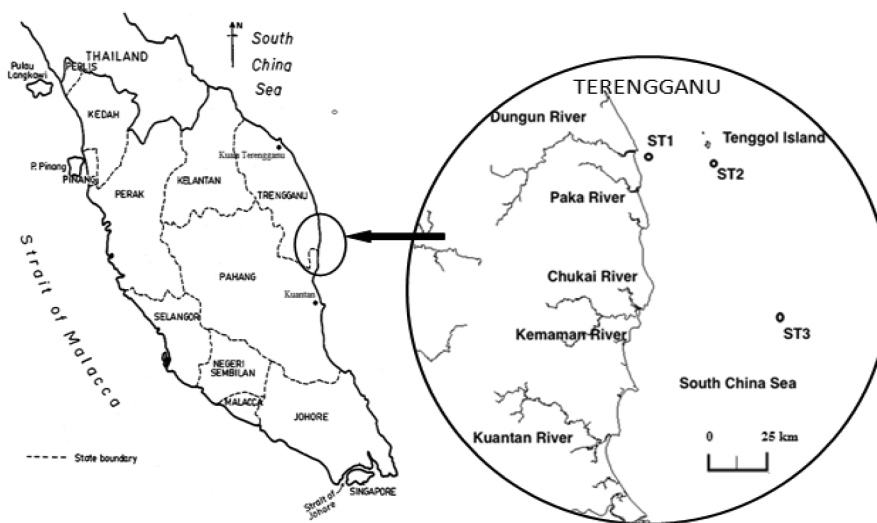


FIGURE 1. Location map of sampling sites

homogenized and sieved through 600 µm mesh. Only the sediment with fraction less than 600 µm was used for the total organic carbon (TOC) analysis. The TOC in sediment was determined using the Walkley-Black's rapid titration method (Moris & Singh 1971). The OC was oxidized with acidic dichromate solution followed by back titration of the excess dichromate solution with ferrous ammonium sulphate using diphenylamine as indicator. This method has a detection limit of approximately 0.10% and on homogeneous sample material, is generally reproducible within 8% (Nelson & Sommers 1982). Statistical analyses were conducted using Statplus and Microsoft Excel. The data were subjected to a two-way ANOVA to determine differences of TOC content among locations and depths. Significance of difference between means was then tested by post hoc Scheffe's test.

## RESULTS AND DISCUSSION

Figure 2 shows the vertical profile of TOC in sediment cores for the two sampling occasions. In general, the TOC obtained for the three cores ranged from 0.41-2.23% and 0.38-2.31% during the post Northeast monsoon and pre-Northeast monsoon sampling period, respectively (Table 2). For both sampling periods, highest TOC was found in

core ST 1 followed by core ST2 and ST3. In station ST1, the highest TOC was observed at the surface (0-2 cm) for post Northeast monsoon sampling and at sub-surface (2-4 cm) for pre-Northeast monsoon sampling. For ST2 and ST3, the highest TOC was recorded at depth 2-4 cm for post Northeast monsoon sampling and at 6-8 cm for pre-Northeast monsoon sampling. The TOC content observed at these two offshore stations were generally lower than the ST1 core. The TOC content at ST1 was significantly different from ST2 and ST3 ( $p < 0.05$ ) but no significant difference in the TOC content was found between ST2 and ST3 ( $p > 0.05$ ) for post monsoon sampling period. For pre-Northeast monsoon sampling period, all three stations showed significant difference ( $p < 0.05$ ) in TOC content from each other. Vertical profile of TOC at station ST1 shows an obvious variation in TOC ( $p < 0.05$ ) for both post and pre-Northeast monsoon sampling periods. In contrast, little variation of TOC content was observed in ST2 and ST3 cores despite the significant variation of TOC ( $p < 0.05$ ) with depth (Table 2). Interestingly, ST1 and ST2 cores exhibited higher TOC values during pre-Northeast monsoon relative to post monsoon sampling whereas ST3 behaved differently with lower values observed during pre-monsoon sampling.

The trend of decreasing TOC content with distance from the coast and rivers observed in this study is

TABLE 2. Comparison of TOC contents in sediment under different environment

Areas	TOC Values	References
Southern Terengganu waters, Malaysia (5-50 km off Dungun-Kemaman coast), Southern South China Sea	Post Northeast sampling	Present study
	0.77-2.23% (surface, 0-2 cm)	
	0.59-2.23% (ST1 core)	
	0.41-0.96% (ST2 core)	
	0.47-0.83% (ST3 core)	
	Pre-Northeast sampling	
	0.50-1.95% (surface, 0-2 cm)	
	1.01-2.31% (ST1 core)	
Terengganu coastal waters (from Besut to Marang), Malaysia, Southern South China Sea. North of present study site	surface	Hasrizal et al. (2009)
	Pre-monsoon: 0.80-1.80%	
	Post monsoon: 0.24-1.32%	
Setiu Wetland (estuary-lagoon environment)	surface 1.43-1.99	Mohd Tahir et al. (2009)
Pahang river, Malaysia (estuary)	surface	Kamaruzzaman et al. (2010)
	Pre-monsoon: 1.61±0.55%	
	Post monsoon: 0.88±0.63%	
Pulau Tinggi, island in southern South China Sea off Johor (estuarine - coastal environment)	surface 2.00-13.0%	Mohd Ali et al. (2011)
Klang River, Malaysia (estuary)	surface 1.24-2.82%	Bakhtiari et al. (2010)
Nanshua Sea, South China Sea (continental slope)	Core 103 (19-174 cm depth)	Duan (2000)
	0.64-0.74	
	Core 102 (35-351 cm depth)	
Bohai Strait, North China (Gulf, coastal)	0.34-0.74%	Hu et al. (2009)
	surface 0.04-0.69%	

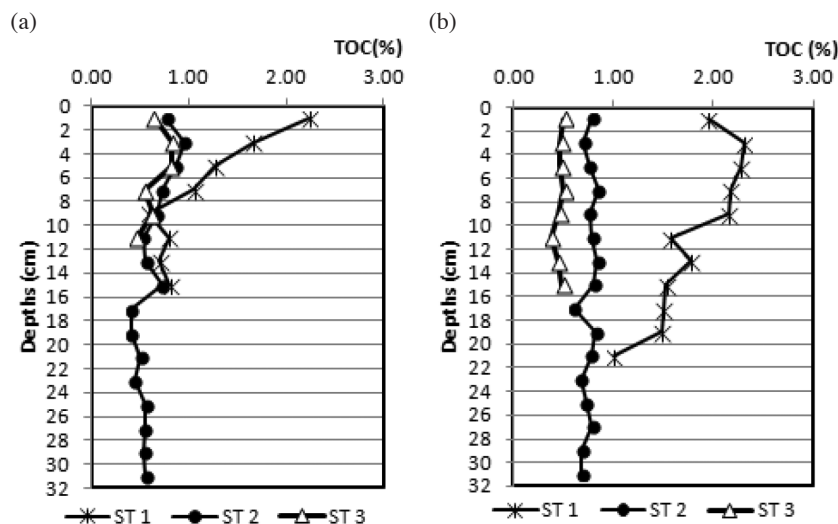


FIGURE 2. Vertical profile of total organic carbon (TOC) in core sediments for: (a) post Northeast monsoon and; (b) pre-Northeast monsoon sampling periods in year 2007

consistent with earlier reports (Hedges & Keil 1995; Prahl et al. 1994; Yunker et al. 2005). Pronounced difference in TOC levels at the upper layer of ST1 compared with ST2 and ST3, especially during the post monsoon, suggest a stronger influence of riverine input to ST1; whereas lower TOC concentration observed in offshore stations is not surprising as these stations were located further away from the coast. Therefore, it is expected that the influence of fluvial transport would be relatively less significant at these stations (ST2 and ST3). *In-situ* production of OM becomes increasingly important with distance from the coastline as shown by the narrow range of OM with depth for ST2 and ST3. Such slight difference in TOC pattern between both stations could be explained by the presence of Pulau Tenggol in the sampling vicinity, which might have contributed additional source of terrestrial OC to ST2 despite the predominant marine based (autochthonous) OC. A substantial decrease in TOC with core depth, particularly in ST1 core, reflects the decomposition of OM. Similar observation was also reported by Duan (2000) and Venkatesan (1988). Episodic input of more concentrated biogenic material to the study area, bioturbation, physical mixing in the core sediments or some combination of these processes, could not be ruled out as demonstrated by variations in the TOC depth profile particularly for ST1 core during pre-Northeast monsoon sampling which exhibited a sub-surface maxima. In this case, the TOC values initially increased and maximized at 4 cm depth before it gradually decreased down the core.

Comparison between seasons showed that the TOC content at the surface sediments (0-2 cm) ranged from 0.64-2.23% during post Northeast monsoon and 0.50-1.95% during pre-Northeast monsoon, indicating that the TOC content in the surface marine sediments during post monsoon was slightly higher than the pre-monsoon. Such enrichment of OC in the post-monsoon samples could be explained by the higher river discharge/run off

that flushes appreciable amount of OM into the open sea during the Northeast monsoon, whereas reason for the lower organic carbon in sediments during the pre-Northeast monsoon may be caused by the dispersion of OM during the intensified Southwest monsoon. Hasrizal et al. (2009) also reported that the OC content in sediments varied with monsoon changes; however, their results showed higher TOC values during pre-Northeast monsoon. Besides mentioning the input of OM from river, the authors also suggested possible OM contribution from autochthonous production. In general, the surface TOC values (0-2 cm) found in the present study were comparable to other studies done in Malaysia and areas within the South China Sea as reported in Table 2.

#### CONCLUSION

The results obtained from this study suggested the importance of fluvial transport of terrestrial OM into near coastal areas. In addition, significant variation of TOC concentration with depth and the seasonal and spatial variation of TOC vertical profile suggest processes such as monsoon seasons, physical mixing, biodegradation and/or episodic input of high concentration of OM might played an important role in regulating the concentration and distribution of the organic carbon in the study area.

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