Trace Metals in the Surface Sediments of the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia

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ABSTRACT

The trace metal distribution in the surface sediments of the Gulf of Thailand and the South China Sea were studied. Samples were obtained from two cruises of the MV SEAFDEC Total metal content were measured in the 63mm fraction of dried sediment. For the first cruise (Pre-Northeast monsoon) results, metal concentration ranges were between 0.41- 0.19mgg^{-1}Cd, 10-36mgg^{-1}Cu, 7.02-27.8mgg^{-1}Pb, 15.3-352mgg^{-1}Zn, 20.5-122mgg^{-1} Cr, 209-720mgg^{-1}Mn, 0.79-5.96%Al and 0.71-2.82%Fe. Similar results were obtained for the second cruise (Post-Northeast monsoon) results, with metal concentrations in the range of 0.10-0.94 mgg^{-1}Cd, 10.3-61.4 mgg^{-1}Cu, 5.24-78.2 mgg^{-1}Pb, 18.1-98 mgg^{-1}Zn, 21.1-101 mgg^{-1}Cr, 117-797 mgg^{-1}Mn, 1.89-7.22 %Al and 0.70-2.38 %Fe.

The concentrations of Al, Cr, Cu and Mn were significantly higher in the Gulf of Thailand in the pre-monsoon while concentrations of Fe, Cd and Zn were similar for both areas. For the post-monsoon Al, Cu and Mn concentrations were higher in Gulf sediments. Differences in metal concentrations were noted between the pre- and the post monsoon samples. Fe, Cr and Mn concentrations were generally higher in the pre-monsoon period for both areas but the distribution of Pb was higher in the post-monsoon while Zn and Cu distribution differed between the Gulf and the South China Sea areas.

However normalisation of the metal data to aluminium content of the sediment showed generally uniform concentration of the metals studied over most of the area studied. Some enrichment by Cu in sediments from two sampling stations in the upper Gulf of Thailand is indicated by Cu:Al ratios exceeding normal crustal abundances of these metals. However low Cu:Al ratios in sediments from some areas of the South China Sea may indicate depletion of Cu in the sediments.

Key words: Metals, Gulf of Thailand, South China Sea, normalisation

Introduction

The trace metal concentrations in sediments from the Gulf of Thailand and the South China Sea have only been sporadically studied in the past. Hungspreugs and Yuangthong (1983) found high Cd and Pb concentrations in surface collected from the Chao Phraya estuary. Studies in the Upper Gulf of Thailand found sedimentation rate of sediments of about 4 to 11 mm yr^{-1} and mean total metal levels of 0.015 mg g^{-1} Cd, 6.5 mg g^{-1} Pb and 9.8 mg g^{-1}Co (Windom et al., 1984).

Shazili et al. (1989) reported strong acid leachable trace metal levels in surface sediments for some areas of the South China Sea off Terengganu and Pahang. Mean levels were 1.8-8.8 mg g^{-1} for Cu, 1.6 - 26 mg g^{-1} Pb, 12-47 mg g^{-1} Zn and 2.5 - 25 mg g^{-1} Ni.

For purposes of comparisons, total dissolution of sediments would provide measurements of metal concentrations that can be compared with other studies as well as allowing quality control of the measurements to be assessed against standard reference materials.

In this study, total metal levels in surface sediments from the Gulf of Thailand and the South China Sea were examined with the aim of characterising the geochemistry of the sediments. The effect of the monsoon seasons on sediment geochemistry has not been studied in any detail for the Gulf of Thailand and the South China Sea and this study provides an opportunity to compare the effects of the monsoon on metal distribution.

Methods

Sample collection and preparation

Sediment was collected with a Smith McIntyre grab in two cruises of the MV SEAFDEC in a joint oceanographic study between the Training Department of SEAFDEC Thailand and MFRMD in Malaysia. The first cruise was in September 1995 and the second in April 1996. A total of 81 stations were sampled in the Gulf of Thailand and the South China Sea off East Coast Malaysia (Fig. 1).

A portion of sediment from the top 3 cm was removed with a clean polyethylene spatula, avoiding sediment in contact with the grab surface. The samples were then stored in clean glass bottles at -20ϒC until ready for analysis. Large shell fragments were removed and the samples dried at 105ϒC, after which the samples were lightly ground in a mortar and pestle to break up the particles. The samples were then sieved through a stainless steel mesh of size 63 μm. Aliquots of about 1g of the 63 μm fraction sediment were then totally digested in open PTFE beakers with a mixture of nitric, perchloric and hydrofluoric acids at about 120ϒC (Katz and Jenniss, 1983). The final residue was redissolved in 10% nitric acid and made up to 50 ml with Milli-Q water.

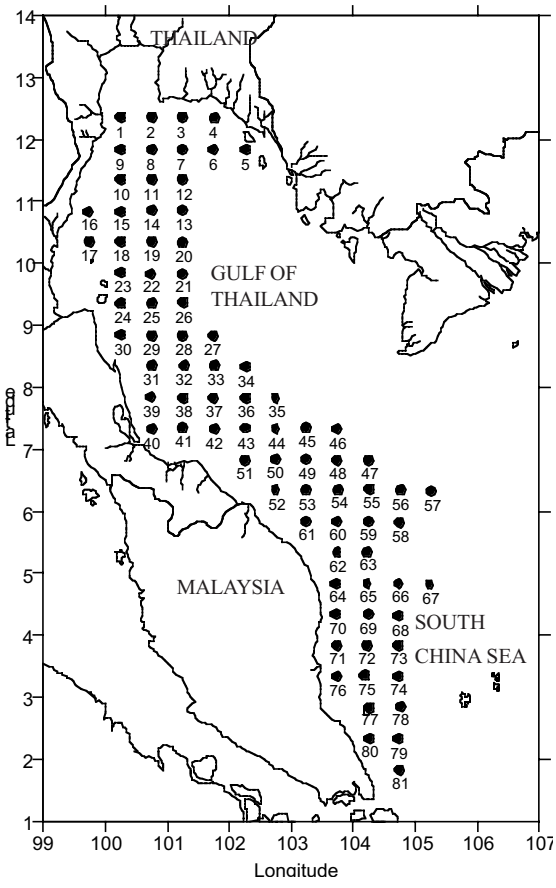

Fig. 1. Sediment sampling locations in the Gulf of Thailand and the East Coast of Peninsular Malaysia

Metal analyses

Metal concentrations were determined with a flame AAS with Deuterium background correction (Perkin-Elmer 3100) except Cd and Pb which were measured with a graphite furnace (Hitachi Z-8270) equipped with Zeeman background correction.

Quality Assurance

Certified sediment reference material (NBS 1646a) from the National Bureau of Standards were similarly prepared and analysis of the metals showed acceptable recoveries for most of the metals (Table 1) but low recoveries were obtained for Mn and Pb while some contamination was found for Cd.

Results and Discussion

The total metal concentrations for the first and second cruises are shown in Tables 2 and 3 respectively. For the pre-monsoon results, metal concentration ranges were between 0.41-0.19μg g^{-1}Cd, 10-36μg g^{-1}Cu, 7.02-27.8μg g^{-1}Pb, 15.3-352μg g^{-1}Zn, 20.5-122μg g^{-1}Cr, 209-720μg g^{-1}Mn, 0.79-5.96%Al and 0.71-2.82%Fe. For the post-monsoon results, Cd ranged between 0.10-0.94μg g^{-1}, 10.3-61.4μg g^{-1}Cu, 18.1-98μg g^{-1}Zn, 21.1-101μg g^{-1}Cr, 117-797μg g^{-1}Mn, 1.89-7.22%Al and 0.70-2.38%Fe. The distribution of these metals are shown in isopleth maps (Figure 2) for the results of the post-monsoon period only due to the incomplete Al data for the pre-monsoon. Slightly higher concentrations of Cu and Mn were measured at stations 1 and 3 at the northernmost part of the upper Gulf of Thailand but relatively little variation was seen in the distribution of the other metals measured.

ANOVA comparisons of metal concentrations between the Gulf of Thailand and the East Coast of Peninsular Malaysia indicate no significant differences (at the 95% level) in Fe, Cd and Zn for the pre-monsoon results. However Al, Cr, Cu, Mn and Pb were significantly higher in Gulf sediments. For the post-monsoon results (Table 2), Al, Cu and Mn were significantly higher in Gulf sediments while Fe, Cr and Zn levels were similar for both areas. The Cd data for the second cruise was not compared due to incomplete data. The Zn data showed a large standard deviation value for the East Coast Peninsular Malaysia due to four stations having Zn values exceeding 300μg g^{-1}.

Comparison of data for the Gulf of Thailand area between the pre-monsoon and the post-

Table 1. Analysis of certified reference material (NBS 1646a)

Metal	Certified value (ug/g)	Measured value (ug/g)	Recovery (%)
Aluminium (%)	2.297	2.13	92.7
Iron (%)	2.008	1.92	95.6
Cadmium	0.148	0.20	135.1
Chromium	40.9	39.15	95.7
Manganese	234.5	167.79	71.6
Lead	11.7	9.79	83.7
Zinc	48.90	48.94	100.01

monsoon periods indicated that concentrations of Fe, Zn, Cr and Mn were significantly higher in the pre-monsoon period while Cu and Pb were significantly higher in the post-monsoon period. For the East Coast Peninsular area, concentrations of Fe, Cr and Mn were higher in the pre-monsoon period and Pb higher in the post-monsoon period. Cu and Zn levels however were similar between the two periods.

In order to differentiate more objectively any real differences in metal distribution between the Gulf of Thailand and the East Coast Peninsular Malaysia sediments, the metal levels for the post-monsoon period were normalised against Al (Windom et al., 1989). The distribution of these normalised values is as shown in isopleth maps (Fig. 3). With reference to Pb, over 50% of the sampling locations had values exceeding 20 $\mu g\ g^{-1}$ which is the average concentration in world average shale. If these values were to be compared to average crustal material, most of the stations would then exceed these natural values. A total of eight stations in the study area had concentrations had concentrations of Pb/Al ratios of 10×10^{-4} and greater compared to natural levels of only 2.91×10^{-4} in average continental shelf sediments (Hanson et al., 1986) indicating elevated values. The Upper Gulf sediments have Pb/Al ratios of 6-17 $\times 10^{-4}$ and the higher ratio values, exceeding 10×10^{-4} here are found at stations nearest shore. The sediment here are composed mainly of silt and clay and is thus expected to bind higher amounts of metals. Anthropogenic input contributing to these elevated levels may be a factor that should not be ruled out. The higher Pb/Al ratios in the south of the study area, off Pahang and Johor however are associated with relatively low Al content in the sediment.

Over the other areas studied the observed metals concentration (except Pb) were generally uniform and reflect average or lower than average values compared with reported crustal abundances (Hanson et al., 1986). However a small number of locations showed variations from the general distribution pattern. It can be seen that Cu:Al ratios ($x10^{-4}$) are comparatively higher in sediments in the upper Gulf of Thailand with ratios of 7.5 - 12 $x10^{-4}$ and in sediments off the coast of Pahang, Malaysia with a ratio of about 6 $x10^{-4}$. As such the higher Cu:Al ratios especially that measured for

Table 2. Mean concentrations of metals in sediment for the Gulf of Thailand and East Coast Peninsular Malaysia sampled in the pre-monsoon period and the post-monsoon period.

	Mean concentration (ug g^{-1} dry wt.)	
	Gulf of Thailand	**East Coast Peninsular Malaysia**
Pre-monsoon		
Al	4.38 1.18%	3.04 1.4%
Fe	2.13 0.39%	2.03 0.45%
Cd	0.42 0.19	0.38 0.20
Cr	85.0 15.3	74.0 16.9
Cu	19.7 6.4	16.0 7.2
Pb	16.2 4.6	13.4 5.4
Zn	61.0 26.7	76.3 83
Post-monsoon		
Al	5.34 1.03%	4.57 1.34%
Fe	1.22 0.35%	1.36 0.38%
Cd	0.35 0.04	0.34 0.04
Cr	62.7 13.1	58.9 13.9
Cu	25.7 12.7	15.1 2.7
Pb	29.9 15.0	19.3 15.6
Zn	51.6 12.1	56.1 17.1
Mn	368 104	269 80

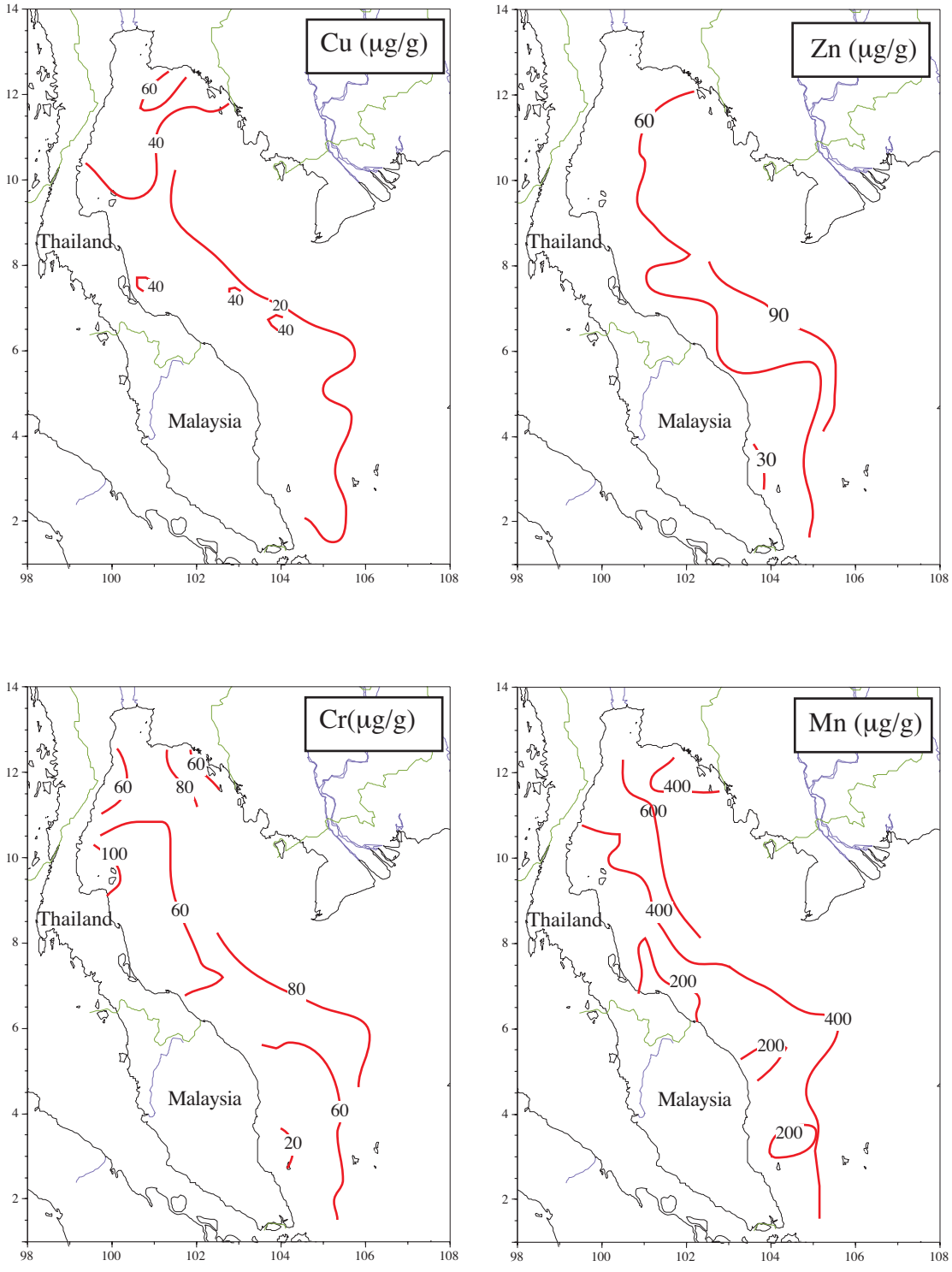

Fig. 2. Isopleths of metal concentrations in surface sediments of the Gulf of Thailand and East Coast Peninsular Malaysia.

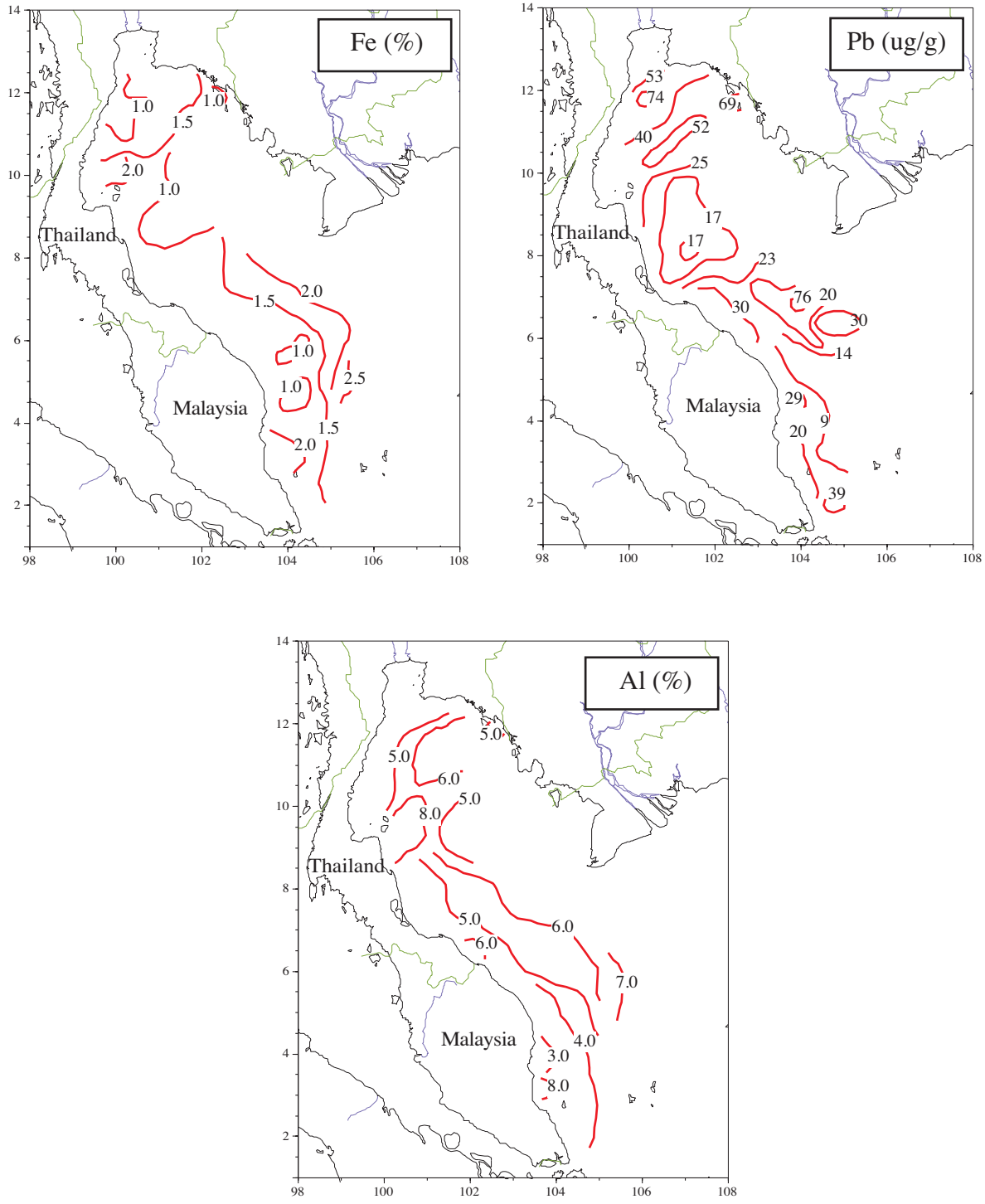

Fig. 2 (continue) Isopleths of metal concentrations in surface sediments of the Gulf of Thailand and East Coast Peninsular Malaysia.

Table 3. First cruise: Total metal concentrations in sediments from the Gulf of Thailand and the South China Sea for all sampling stations.

Stn	Cd	Cr	Cu	Mn	Pb	Zn	Al	Fe
	(ug/g)						%	%
1	0.42	54	29.1	552	51.49	45	3.97	1
2	-	-	-	-	-	-	-	-
3	0.1	67	56	798	34.9	54	4.39	1.7
4	0.14	59	40	394	38.76	38	5.25	1.51
5	0.26	58	37	249	55.44	42	4.04	0.91
6	0.24	71	40	424	51.04	44	5.35	1.28
7	0.24	86	41	340	56.46	48	5.36	1.54
8	0.19	68	61	592	34.7	46	6.33	0.99
9	0.15	52	19.7	411	78.2	38	4.41	1.4
10	0.17	61	33	450	36.71	43	5.09	0.92
11	0.57	66	27	475	47.47	49	5.56	1.21
12	0.35	74	48	501	50.85	64	5.88	1.26
13	0.55	57	44	455	36.7	46	5.23	1.17
14	0.26	60	37	345	40.88	43	5.19	1.14
15	0.33	61	23	386	38.05	46	4.3	0.89
16	0.27	69	28	377	27.96	50	5.48	1.07
17	0.33	101	31	282	33.06	69	6.84	1.85
18	0.94	72	39	322	51.22	58	4.82	1.77
19	0.32	64	26	442	27.3	80	6.16	1.11
20	0.21	46	15	304	16.84	34	3.74	0.89
21	0.25	45	17	414	10.53	40	4.32	1.03
22	0.15	71	23	309	8.83	61	6.38	1.1
23	0.15	97	25	636	35.62	78	8.47	1.61
24	0.06	71	17	262	15.72	48	6.39	0.67
25	0.16	66	17.8	351	22.58	56	6.63	1.38
26	0.13	47	19.1	387	7.15	50	4.98	1.05
27	0.13	57	17.9	447	9.55	57	4.82	0.96
28	0.19	56	17.6	213	11.3	51	5.95	1.03
29	0.06	57	13.8	375	12.5	41	5.11	0.95
30	0.1	76	13.1	336	18.99	56	7.07	1.34
31	0.14	49	12.8	266	11.26	34	3.87	0.95
32	0.08	52	16.3	191	5.99	41	4.79	0.78
33	0.08	56	18	360	24	55	5.21	1
34	0.1	66	17.9	493	19.11	59	5.18	1.34
35	-	88	21	370	19.33	81	7.22	2.38
36	-	74	22	315	11.32	72	6.24	1.68
37	-	60	17.9	405	13.23	65	5.88	1.43
38	-	50	15.1	190	6.16	40	4.44	1.54
39	-	51	24.3	221	9.62	41	4.66	1.13
40	-	43	10.5	237	21.05	33	5.26	1.4
41	-	58	14.2	167	19.77	62	5.56	1.48

Table 3. (continue)

Stn	Cd	Cr	Cu	Mn	Pb	Zn	Al	Fe
	(ug/g)						%	%
42	0.23	53	17.4	191	28.65	53	3.21	0.63
43	0.53	52	12.9	167	19.97	50	4.99	1.32
44	0.2	57	26.8	402	11.83	62	5.62	0.72
45	0.37	75	19.7	342	28.86	76	6.68	2
46	0.22	77	17.4	292	29.98	77	5.59	1.38
47	0.12	63	17	231	8.48	61	5.36	1.52
48	0.29	84	21	316	75.87	84	6.29	1.65
49	0.14	71	15.9	306	11.79	74	5.4	1.67
50	0.1	58	13.3	225	15.78	59	4.98	1.28
51	-	67	15.9	182	11.39	56	5.95	1.24
52	-	71	18.8	271	41.44	58	5.42	1.32
53	0.32	77	16	312	21.63	80	6.19	1.43
54	0.24	64	15.6	381	25.76	90	6.09	1.22
55	0.35	55	18.7	296	34.33	51	5.21	1.46
56	-	70	18	338	37.41	98	6.19	2.16
57	-	78	19	308	22.72	73	7.21	1.64
58	-	69	14.4	276	26.91	58	5.64	1.38
59	-	52	11.9	145	6.22	39	4.09	1.01
60	-	56	11.8	190	17.05	52	4.09	1.18
61	-	61	14.5	214	14.52	55	4.21	1.43
62	-	50	12.7	199	8.27	40	3.95	1.04
63	-	55	12.6	286	17.46	49	4.64	1.14
64	-	55	16	287	6.38	45	4.05	1.48
65	-	51	12	195	5.24	44	4.01	0.92
66	-	63	13.6	432	20.03	56	4.97	2.03
67	-	81	18.6	473	12.67	82	6.69	2.26
68	-	61	13.6	340	11.76	61	3.96	1.25
69	-	51	12.9	297	12.95	42	3.88	0.88
70	-	45	16.7	412	13.16	38	3.02	0.77
71	-	21	16.9	312	21.11	30	2.16	1.06
72	-	47	12.4	147	13.94	38	3.35	1.2
73	-	43	10.3	117	12.42	41	2.46	1.14
74	-	54	11.5	220	17.32	47	3.55	1.01
75	-	45	12.9	227	15.89	40	3.6	0.7
76		23	11	162	20.07	18	1.89	1.71
77	-	61	15.1	286	6.79	58	4.19	1.8
78	-	61	13.5	243	12.82	58	3.86	1.14
79	-	62	16.9	244	23.69	62	3.95	1.6
80	-	47	13.4	234	9.34	47	3.08	0.99
81	-	54	16.6	215	42.92	37	3.16	1.17

Table 4. Second cruise: Total metal concentrations in sediments from the Gulf of Thailand and the South China Sea for all sampling stations.

Stn	Cd	Cr	Cu	Mn	Pb	Zn	Al	Fe
	(ug/g)						%	%
1	0.24	86	110	424	17.5	90	3.66	2.82
2	0.51	96	210.9	428	16.4	38.1	5.63	2.29
3	0.24	104	18.9	428	21.7	40.5	-	3.1
4	0.26	60	17.5	410	16.7	125	1.72	2.17
5	0.48	92	25.5	367	27.8	82	3.59	2.55
6	0.53	100	19.4	4.31	20.2	46	-	2.31
7	0.47	118	28.9	477	17.7	63	-	1.91
8	0.52	92	29.5	549	17.6	91	4.38	2.49
9	0.34	78	13	509	17.9	16.4	3.31	1.97
10	0.45	84	23.4	460	15	57	3.96	1.79
11	0.3	91	23.7	452	14.5	54	-	1.73
12	0.34	87	17	563	16.3	28	2.76	1.75
13	0.29	78	19	597	13.9	47	-	1.86
14	0.53	75	18.3	531	18.1	53	-	1.86
15	0.71	89	19.4	476	15.2	39	5.21	2.01
16	1.03	101	39	416	23.3	56	5.14	2.58
17	0.6	101	32.3	450	23.1	102	5.96	2.56
18	0.39	97	23.2	646	24	63	-	2.47
19	0.3	76	16.8	571	15.4	56	-	2.01
20	0.35	65	19.3	504	14.4	42.5	-	1.6
21	0.36	65	16.5	396	11.8	41.9	-	1.56
22	0.65	81	31.6	422	14.9	86	4.76	2.3
23	0.8	121	31.9	617	14.5	136	6.32	2.57
24	0.27	92	10.8	349	12.6	118	4.42	2.21
25	0.3	92	11.7	383	22.9	104	5.94	2.54
26	0.32	83	15.9	409	9.01	60	-	2.09
27	-	-	-	-	-	-	-	-
28	0.3	76	15.6	324	7.02	53	-	1.86
29	0.83	79	15.7	362	8.26	49	-	2.04
30	0.4	101	11.4	318	19.3	43	5.94	2.49
31	0.42	66	7.77	307	14.3	44	3.52	1.71
32	0.58	67	15.2	301	19.2	47	-	1.7
33	0.39	72	19.5	463	9.1	49	-	1.55
34	0.29	89	23.6	720	17	67	-	2.22
35	0.81	122	25.9	447	18.4	89	-	3.09
36	0.42	92	21.4	485	16.6	68	-	2.17
37	0.26	85	19.6	503	18.6	58	-	2.48
38	0.27	69	12.8	236	10.6	15	3.81	1.63
39	0.38	63	17.9	293	18.1	67	4.41	1,95
40	0.39	58	16.4	262	20.4	53	3.77	2.18
41	0.24	79	15.4	264	9.88	51	-	2

Table 4. (continue.)

Stn	Cd	Cr	Cu	Mn	Pb	Zn	Al	Fe
	(ug/g)						%	%
42	0.86	80	19.8	375	10.1	61	-	2.24
43	0.26	68	14.4	259	10.7	47	-	1.65
44	0.44	80	19	338	13	61	-	1.9
45	0.3	97	20.1	520	19.6	67	-	3.04
46	0.32	102	19.5	379	18.1	67	-	2.57
47	0.29	80	16	307	12.8	62	-	2.14
48	0.33	97	17.2	374	9.24	74	-	2.77
49	0.3	87	18.6	395	11	71	-	2.54
50	0.36	82	15.9	278	18.2	57	-	1.81
51	0.4	85	15.6	297	18.6	34	3.77	2.08
52	0.39	74	45.8	319	10.1	15.5	4.93	1.81
53	0.48	94	36.6	394	2.49	131	4.57	2.27
54	0.24	84	15.2	342	19.1	66	-	2.17
55	0.3	79	15	289	7.3	61	-	2.02
56	0.31	79	28.8	308	14.6	65	-	2.18
57	0.27	82	16.3	329	14.4	67	-	2.27
58	0.36	67	13.8	299	16.1	55	-	1.7
59	0.26	55	13.5	209	14.3	44	-	1.42
60	0.39	69	12.8	256	17.2	45	3.05	1.89
61	0.64	74	11.5	307	6.84	339	2.73	1.96
62	0.22	67	9.7	258	12.4	15.3	2.48	1.9
63	0.31	72	10.8	279	8.17	21.2	3.54	2.04
64	0.27	84	13.1	335	16.5	21.6	3.91	2.03
65	0.23	64	14.1	308	6.78	49	-	1.9
66	0.54	81	18.1	405	9.05	76	-	2.45
67	0.24	95	13.9	440	4.17	40	5.95	2.57
68	0.25	70	10.8	355	7.43	23	2.44	2.16
69	0.17	68	13.8	288	11	63	-	2.23
70	0.69	59	14.1	516	17.9	26.1	1.15	1.89
71	1.02	27	13.1	298	21.8	29.7	0.79	0.71
72	0.54	67	13.8	249	21.6	50	-	2.11
73	0.32	54	13.1	261	12.3	13	1.35	1.33
74	1.1	73	15.3	292	10.4	29.6	3.77	1.87
75	0.35	73	16.1	288	12.8	65	-	2.31
76	0.43	20	10	246	13.3	25.1	0.76	1.03
77	0.28	74	12.3	301	17.8	28.6	2.88	1.95
78	0.36	74	12	293	13.2	308	2.71	1.96
79	0.31	84	11.3	308	17.4	352	3.45	2.44
80	0.37	64	12.1	273	27.2	137	2.97	1.56
81	0.23	78	11.3	317	8.9	86	4.3	2.14

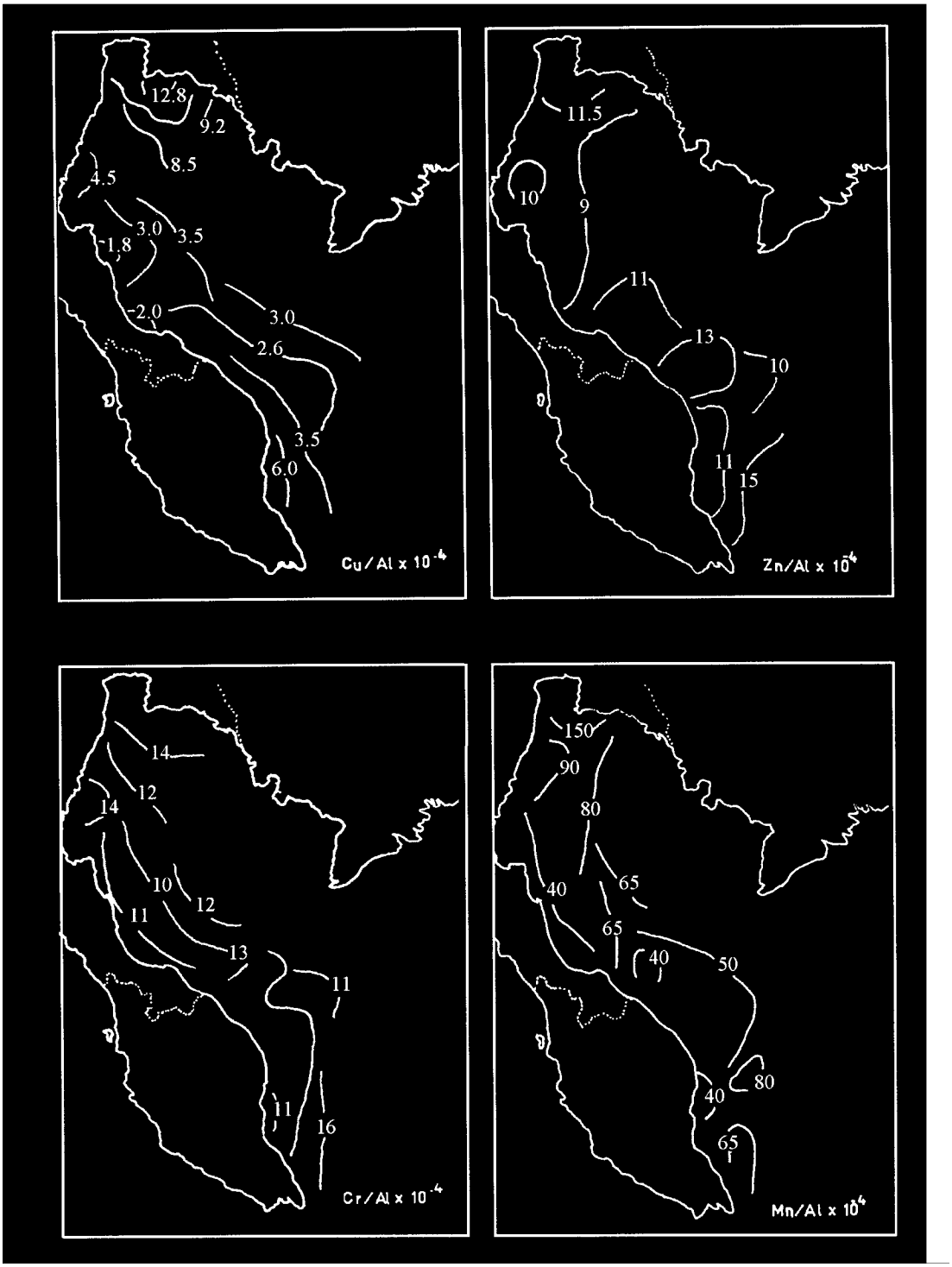

Fig. 3. Isopleths of metal to aluminium concentration ratios for surface sediments in the Gulf of Thailand and East Coast Peninsular Malaysia.

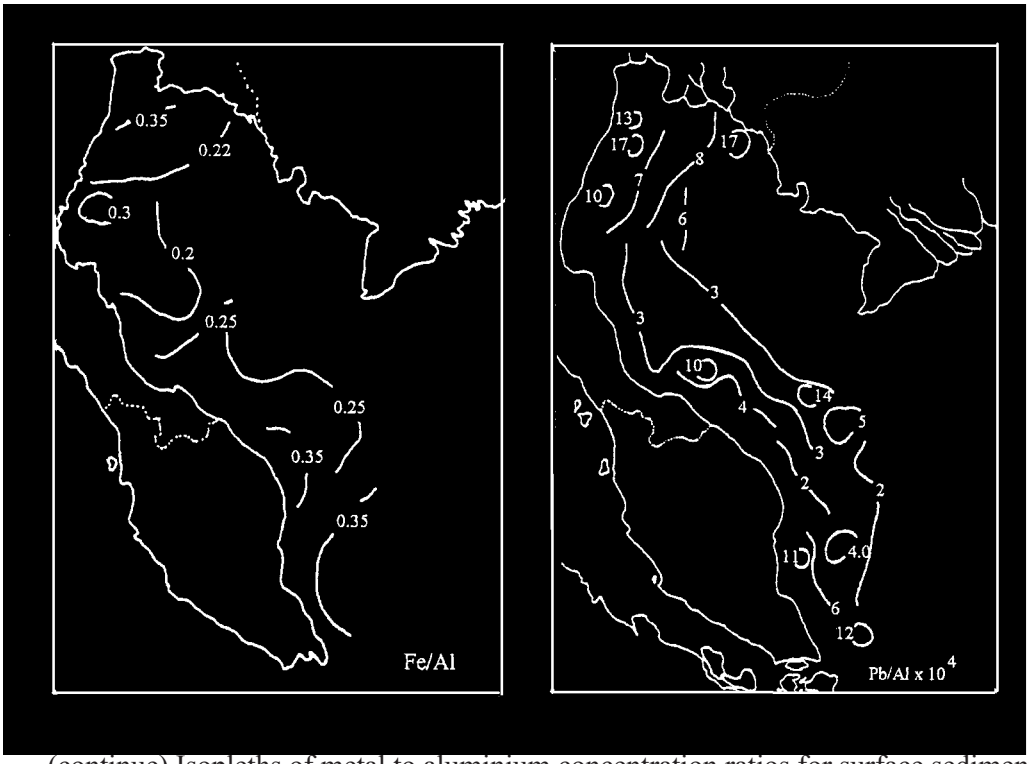

Fig. 3. (continue) Isopleths of metal to aluminium concentration ratios for surface sediments in the Gulf of Thailand and East Coast Peninsular Malaysia.

stations 1 and 3 in the upper Gulf area, may indicate enrichment by Cu in the upper Gulf region closest to shore. The high ratio of Cu/Al off Pahang is associated with low Al content in the sediment. The ratios for the lower Gulf region and the South China Sea of between 2.6-3.5 $x10^{-4}$ over most of the area studied indicate concentrations lower than the natural value for continental shelf sediments of 8.14 $x10^{-4}$ (Hanson et al., 1986). The concentrations of Cr and Mn are similarly lower than "global average" earth crust and shale. Such a finding, of lower than average crustal material of Cu, Cr and Mn was also noted in a recent study of elements in the coastal environment off Penang and in the Johor Strait (Wood et al., 1997). They suggested that this might be due to increased solubility of these elements in the tropical environment.

The Mn:Al ratios for the Gulf of Thailand differed somewhat to the values for the East Coast Peninsular Malaysia, with values of 80-90 $x10^{-4}$ for the upper Gulf region, 50-95 $x10^{-4}$ for the lower Gulf region and 40-65 $x10^{-4}$ for the East Coast Peninsular Malaysia region. The Zn:Al ratios were similar for all sampling locations, ranging between 9 $x10^{-4}$ and 11 $x10^{-4}$ for the Gulf area and 10-15 $x10^{-4}$ for East Coast Peninsular Malaysia. Iron:Al ratios for all areas were in the range of 0.20-0.35 thus indicating uniform Fe concentration over the whole study area.

Pb:Al ratios varied between 2 $x10^{-4}$ and $18x10^{-4}$. The higher ratios were found at four locations in the Upper Gulf of Thailand with values of between 10 $x10^{-4}$ and 18 $x10^{-4}$ and two locations in the South China Sea off Peninsular Malaysia. With values of 10 $x10^{-4}$ and 14 $x10^{-4}$. These ratios are much higher than world average continental crust values but generally are within the Pb:Al ratios for near-shore detrital sands and muddy sands (Hanson *et al*., 1986).

Conclusions

The normalised elemental concentration data for the Gulf of Thailand and East Coast Peninsular Malaysia sediments from this study showed generally uniform distribution of metals over most of the area studied. Elevated Cu and Pb levels in a number of isolated sites in the Upper Gulf of Thailand and in the South China Sea off Peninsular Malaysia can be attributed to higher content of fine sized

sediment (Calvert *et al*., 1993) and low Al content. The levels of Cr, Mn and Cu are lower than in average earth material and are probably due ti increased solubilities of these elements.

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