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I–P$_2$O$_5$ diagrams as an indicator of depositional environment in marine sediments: preliminary findings (Sri Lanka)

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Abstract

The concentrations of Br and I in marine sediments have been used to categorize the sedimentary environments of different coastal regions of the world with respect to organic matter contents. The present study uses the concentrations of Br, I and P$_2$O$_5$ of different marine settings as a new proxy to interpret the depositional environments. A total of 150 coastal lagoon sediment samples (suspended sediments, surface sediments and sediment cores) were analyzed for Br, I and P$_2$O$_5$ concentrations by X-ray fluorescence spectrometry. They were compared with the Br, I and P$_2$O$_5$ concentrations of the 2004 Indian Ocean tsunami sediments. Sediments from various sources are separately clustered in I–Br plot and a trivial negative correlation is found for the whole plot. A similar correlation pattern exists in the I–P$_2$O$_5$ diagram. This correlation is explained by the distribution of marine plants (higher and lower) in different sedimentary environments of the coastal profile. Therefore, the concentration of I and its relation to P$_2$O$_5$ can be used as a tool to identify sediment depositional environments in marine settings.

Keywords Bromine · Iodine · Phosphates · Marine sediments · Environmental evaluations

Introduction

Numerous studies have been performed over the last decades, to understand the biogeochemical processes of marine sedimentary environments using many sedimentary geochemical proxies. The most commonly used proxies are ratios of redox sensitive trace elements such as V, Ni, Mo, U, Zn, and Mn (Tribovillard et al. 2012; Gilleaudeau and Kah 2015; Zhang et al. 2016), relationships of total organic carbon (TOC), sulfur and iron (Leventhal 1983; Dean and Arthur 1989), carbon, nitrogen and sulfur (Sampei et al. 1997; Ratnayake et al. 2017), and Mo and TOC (Algeo and Lyons 2006; Rowe et al. 2009).

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Abundances of halogens and organic matter (OM) content in marine sediments have also been used to interpret different environmental settings since they are rich in marine sediments (Harvey 1980; Chagué-GoffC 1996; Muramatsu et al. 2004). Ratios of halogens (Br and I) to OM have been used to demarcate marine and terrestrial sediments (Malcolm and Price 1984; Mayer et al. 2007). Further, halogens to TOC ratio has also been used to interpret the redox condition from shallow to deep marine sediments (Price and Calvert 1973, 1977). Since TOC represents the actual organic carbon content, the results much validate the environmental conditions in shallow to deep marine sediments than the OM contents. In particular, Br in sediments combining with diatom and plant materials has been used to evaluate the paleo-tsunami and paleo-climates as they associated entirely with organic matter (Harvey 1980; Schlichting and Peterson 2006; Moreno et al. 2015).

Since I is a redox sensitive element, ratio of I and Ca has been used as a proxy of paleo-anoxic events (Lu et al. 2010). However, the application of I is limited due to its controversial chemical behavior in different marine environments (Harvey 1980; Malcolm and Price 1984). Price and Calvert (1973, 1977) identified that the influence of planktons is the fundamental reason for such behavior of

I in oxidizing-reducing environments. However, the relationship between halogens and types of plants in different marine settings has rarely been used to interpret the diverse depositional environments.

Variations of euphotic conditions and oxygen availability in different depositional environments are reflected by characteristics of the plant materials in those environments. This study considers phosphorus, an essential macronutrient of plants, and halogen concentrations in different depositional environments of the coastal and shallow sea regions.

The objective of present study is to understand the relationship of Br, I, and P_2O_5 concentrations of OM bearing sediments of different marine settings, with the variable nutrient competition. Findings of the study can be used to interpret unknown depositional environments associated with marine influences.

Materials and methods

Study area

Quaternary sedimentation along the Sri Lankan coastal region indicates a unique character due to its position in a tectonically inactive zone and absence of sediment transportation modes such as ice calving and volcanic eruptions. The major sources of coastal sedimentation are the weathering products formed under tropical monsoonal climates and coastal currents.

The study was conducted on the eastern coast of Sri Lanka, and sampling was performed at the well-developed barrier lagoons at Batticaloa and Kiran (Fig. 1). The eastern coast is topographically flat with low surface undulations (Cooray 1984), and the basement of the area consists of hornblende-biotite migmatites, granite gneisses, alkali feldspar migmatites, augen gneisses, and minor amphibolite layers with meta-sedimentary enclaves (Cooray 1994; Kröner et al. 2012). Thin Quaternary sediments cover the basement rocks, and weathered exposures of rocks are rarely present in coastal margins (Cooray and Katupotha 1991).

The climate of the study area is typically drier than other areas of the country. The average temperature ranges from 22 to 32 °C, and annual rainfall ranges from 1500 to 2000 mm (Chandrapala and Wimalasuriya 2003). In general, high rainfall is recorded during November to February due to winter monsoons while the other months are mostly dry.

The tidal range of the eastern coast of Sri Lanka is between 0.2 and 0.8 m. The average wind speed varies from 3 to 4 m/sec and humidity is above 75% throughout the year (Chandrapala and Wimalasuriya 2003).

Sampling method

Sediment sampling was carried out during the post-monsoon period in May 2016.

Suspended sediments (SPM)

Suspended sediment samples were collected from 16 locations of the Batticaloa lagoon (Fig. 1; Adikaram et al. 2017). The ambient temperatures during the sampling period were in a range of 26 to 33 °C and wind speed was very low (< 1 m/sec). Sampling locations were carefully selected assuming similar hydrological conditions in general currents and wind speeds. Each sampling point was 50 cm below the water surface in places where water height was approximately 1 m. Sampling locations were selected considering salt water inputs, freshwater inputs and mixing zones of the lagoon. Water samples (5 L) from each location were collected in pre-cleaned polypropylene containers and stored immediately in a cooling box at temperatures less than 4 °C for laboratory analyses.

Lagoon bottom sediments (BLS)

Using a standard Ekman Grab sampler, 34 superficial sediment samples were collected from the bottom of the Batticaloa lagoon (Fig. 1). The Ekman Grab sampler has the capacity to penetrate to a depth of about 15 cm and can catch a volume of 3.5 L of sediment sample (Jayawardana et al. 2012). Based on the prevalent hydrodynamic stresses, the sampling locations were carefully selected, which can represent the wide sediment distribution of the lagoon. Three to four kilograms of the surface fraction of each sediment sample was sealed in polyethylene bags and transported to the laboratory.

Sediment cores

Sediment cores BLC 01, BLC 02 and BLC 04 were collected from Batticaloa lagoon while CR 01 was collected from Kiran lagoon (Fig. 1). Both BLC 01 and BLC 02 were collected from the northern part of the lagoon. The first core is located 5 km away from the lagoon mouth, and the second is covered from the direct coastal effect due to the sedimentary barrier. BLC 04 was collected from the central part of the lagoon, which does not have high influence from the lagoon mouth and the main rivers. CR 01 is in an undisturbed area with mangrove cover at Kiran lagoon. Hand-pushed PVC pipes (5 cm diameter and 2 m height) were employed to collect the cores.
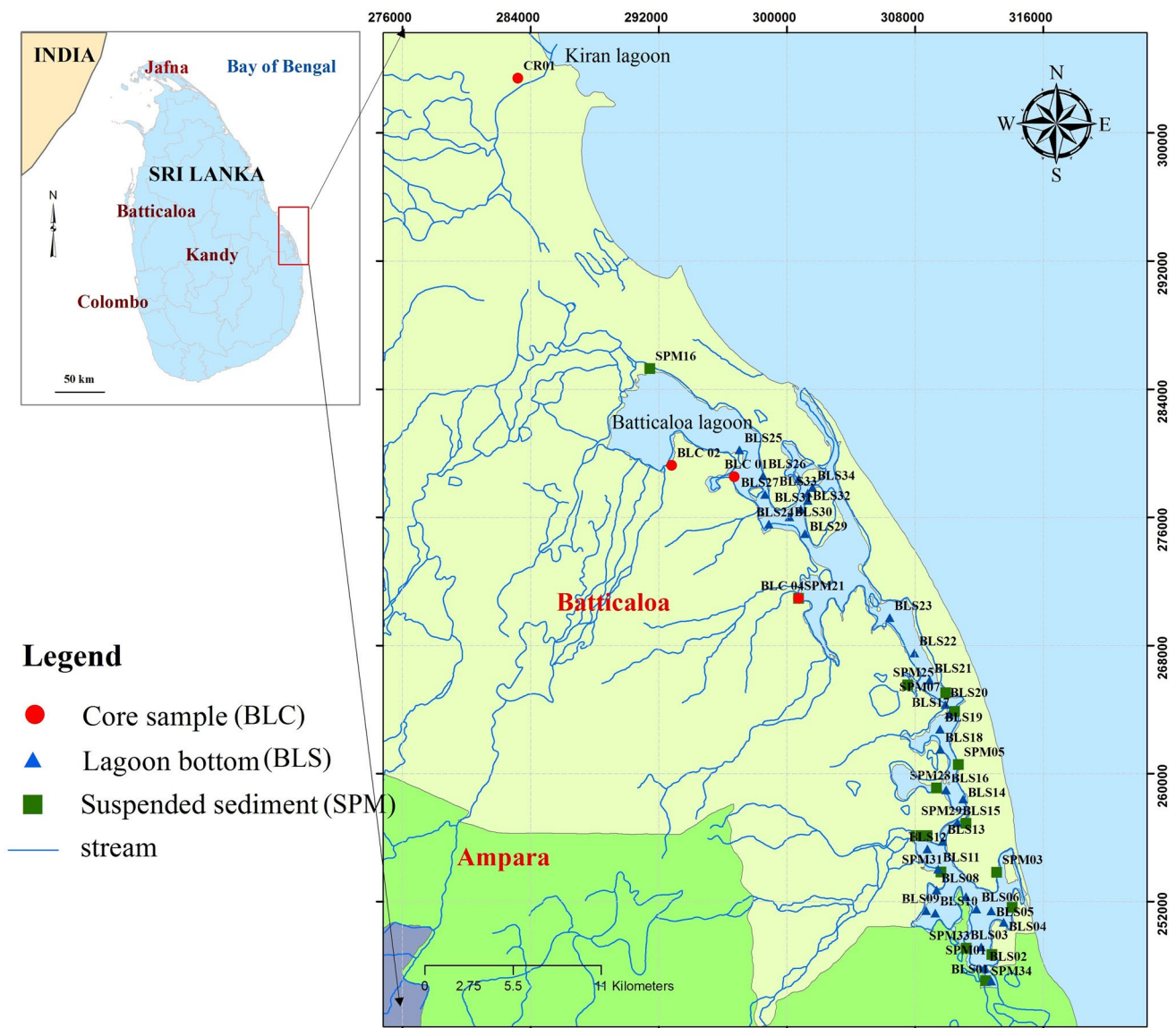
Fig. 1 Location map of the suspended sediments, lagoon bottom sediments and core samples in eastern coast, Sri Lanka

Visual observations and digital photography were performed on the split cores to identify the stratigraphy. Each core was subsampled in 2 cm resolutions and sealed in polyethylene bags for laboratory analysis.

Analytical techniques

XRF analysis

Water samples were vacuum filtered using pre-weighed 0.45 μm Whatman quartz filters. Remaining sediments and Whatman quartz filters were oven-dried at 60 °C. The oven-dried filters were sealed (air tight) and sent to Shimane University, Japan, for chemical analysis. The Br, I, and P_2O_5 concentrations of SPM were determined directly from

loaded quartz filters into the Rigaku RIX-2000 spectrometer equipped with a Rh-anode tube. The average error for these elements is less than $\pm$ 10%.

The oven-dried (105 °C for 24 h) subsamples of cores and lagoon bottom sediments used for geochemical analysis were ground using a RETSCH ball mill at the Department of Geology, University of Peradeniya. The homogenized powdered samples were packed in sealed polyethylene bags and transported to Shimane University, Japan, for XRF analysis. Samples were pressed into a disk with a 200 kN force for 60 s, and the disk was analyzed for I, Br, and P_2O_5 with standard conditions using a Rigaku RIX-2000 spectrometer equipped with an end-window 4KW Rh-anode X-ray tube (Jayawardana et al. 2012). The instrument calibrations, sample preparations, and concentrations of the elements

were determined by the Press powder method (Ogasawara 1987). Average errors for all elements were less than $\pm 10\%$ relatively, and the range of uncertainties for each element was based on the standards of Geological Survey of Japan (Ogasawara 1987).

Loss on ignition test

Loss on ignition test was carried out for each subsample of the cores to determine the OM content and carbonate contents (Dean 1974; Heiri et al. 2001). Approximately 1 g of dry sample was heated up to 105 °C (24 h) and 550 °C (4 h) in a muffle furnace to provide OM contents. Carbonate content was calculated using the weight of heated sample up to 1000 °C.

Radiocarbon dating

Three subsamples from BLC 04 and two subsamples from CR 01 were radiocarbon dated (AMS) at Beta analytic, Miami, Florida. The samples consisted of plant and shell materials found in selected layers. Intcal13 database calibrated the dates (Reimer et al. 2013).

Comparison

The chemical results of sediments obtained from Batticaloa lagoon and Kiran lagoon were compared with that of tsunami sediments in Hambanthota and Hikkaduwa lagoons (Jayawardana et al. 2012). The sampling procedures and analysis techniques were performed in a similar manner.

Results

Geochemistry of suspended and lagoon bottom sediments

Concentrations of Br in both SPM and BLS sediments are comparable except for two SPM sampling locations (Table 1). The Br concentration of BLS sediments gradually increases toward the lagoon mouth as observed in other studies where the sea water concentration is high (Mayer et al. 2007). In contrast to the behavior of Br, the SPM contain higher concentrations of I and P_2O_5 than those in BLS sediments.

Geochemistry of core sediment samples

Stratigraphy of BLC 01, BLC 02, and BLC 04 indicates homogeneous sandy sedimentation except in the OM-rich (peat) layer observed at the 18 to 38 cm depth of BLC 04 (Fig. 2). The OM and carbonate contents of the peat layer

Table 1 Concentrations of Br, I, and P_2O_5 in suspended sediments and lagoon bottom sediments of Batticaloa lagoon

Sample	Br (ppm)	I (ppm)	P_2O_5 (wt%)	Remarks
Suspended sediments				
SS 01	16	nd	0.41	Suspended sediments
SS 02	6	nd	0.25	Suspended sediments
SS 03	6	nd	0.17	Suspended sediments
SS 05	157	nd	0.15	Suspended sediments
SS 06	7	nd	0.14	Suspended sediments
SS 07	35	14	0.28	Suspended sediments
SS 16	2	nd	0.25	Suspended sediments
SS 21	131	15	0.22	Suspended sediments
SS 25	6	nd	0.18	Suspended sediments
SS 28	4	nd	0.22	Suspended sediments
SS 29	4	nd	0.22	Suspended sediments
SS 30	9	nd	0.20	Suspended sediments
SS 31	7	nd	0.20	Suspended sediments
SS 32	11	21	0.27	Suspended sediments
SS 33	22	18	0.31	Suspended sediments
SS 34	3	nd	0.21	Suspended sediments
Min	2	14	0.14	
Max	157	21	0.41	
Average	32	17	0.23	
SD	47	3	0.07	
Lagoon bottom				
LB 01	7	nd	0.16	Sand
LB 02	8	nd	0.15	Sand
LB 03	7	nd	0.21	Sand
LB 04	16	5	0.12	Sand
LB 05	13	nd	0.11	Sand
LB 06	7	nd	0.12	Sand
LB 07	7	nd	0.12	Sand
LB 08	8	nd	0.12	Sand
LB 09	4	nd	0.31	Sand
LB 10	8	nd	0.09	Sand
LB 11	6	nd	0.10	Sand
LB 12	6	nd	0.13	Sand
LB 13	8	nd	0.13	Sand
LB 14	8	nd	0.12	Sand
LB 15	14	nd	0.17	Sand
LB 16	13	nd	0.14	Sand
LB 17	8	nd	0.10	Sand
LB 18	3	nd	0.11	Sand
LB 19	8	nd	0.10	Sand
LB 20	7	2	0.10	Sand
LB 21	9	nd	0.09	Sand
LB 22	9	nd	0.09	Sand
LB 23	15	nd	0.08	Sand
LB 24	11	15	0.09	Sand
LB 25	15	3	0.15	Sand
LB 26	16	12	0.10	Sand
LB 27	17	2	0.10	Sand

Table 1 (continued)

Sample	Br (ppm)	I (ppm)	P_2O_5 (wt%)	Remarks
LB 28	50	4	0.09	Sand
LB 29	34	15	0.10	Sand
LB 30	23	7	0.10	Sand
LB 31	16	12	0.10	Sand
LB 32	27	14	0.11	Sand
LB 33	52	6	0.11	Sand
LB 34	52	6	0.12	Sand
Min	3	2	0.08	
Max	52	15	0.31	
Average	15	8	0.12	
SD	13	5	0.04	

nd not detected, *SD* standard deviation

are high compared to other sediment units of the Batticaloa lagoon. The calibrated age of the peat layer (BLC 04-30-32) is older than the below deposits, suggesting it is of a different origin (Table 2).

In general, CR 01 shows sandy sedimentation with three stratigraphic units devoted by grain sizes (Fig. 2). The coarse sand layer from 72 to 88 cm depth is characterized by higher amounts of shells. Fine sands are observed from 20 to 72 cm depths, whereas shell-rich coarse sands are present from 16 to 20 cm depths. The OM content of the stratigraphic units remains unchanged and slightly higher carbonate content is recorded around the depths of 90 cm. The sedimentation history of CR 01 is about 3500 years BP (Table 2).

Sandy sediment units of all core samples of the eastern coast have similar concentrations of Br and variable concentrations of I (Fig. 3; Table 3). The peat layer of BLC 04
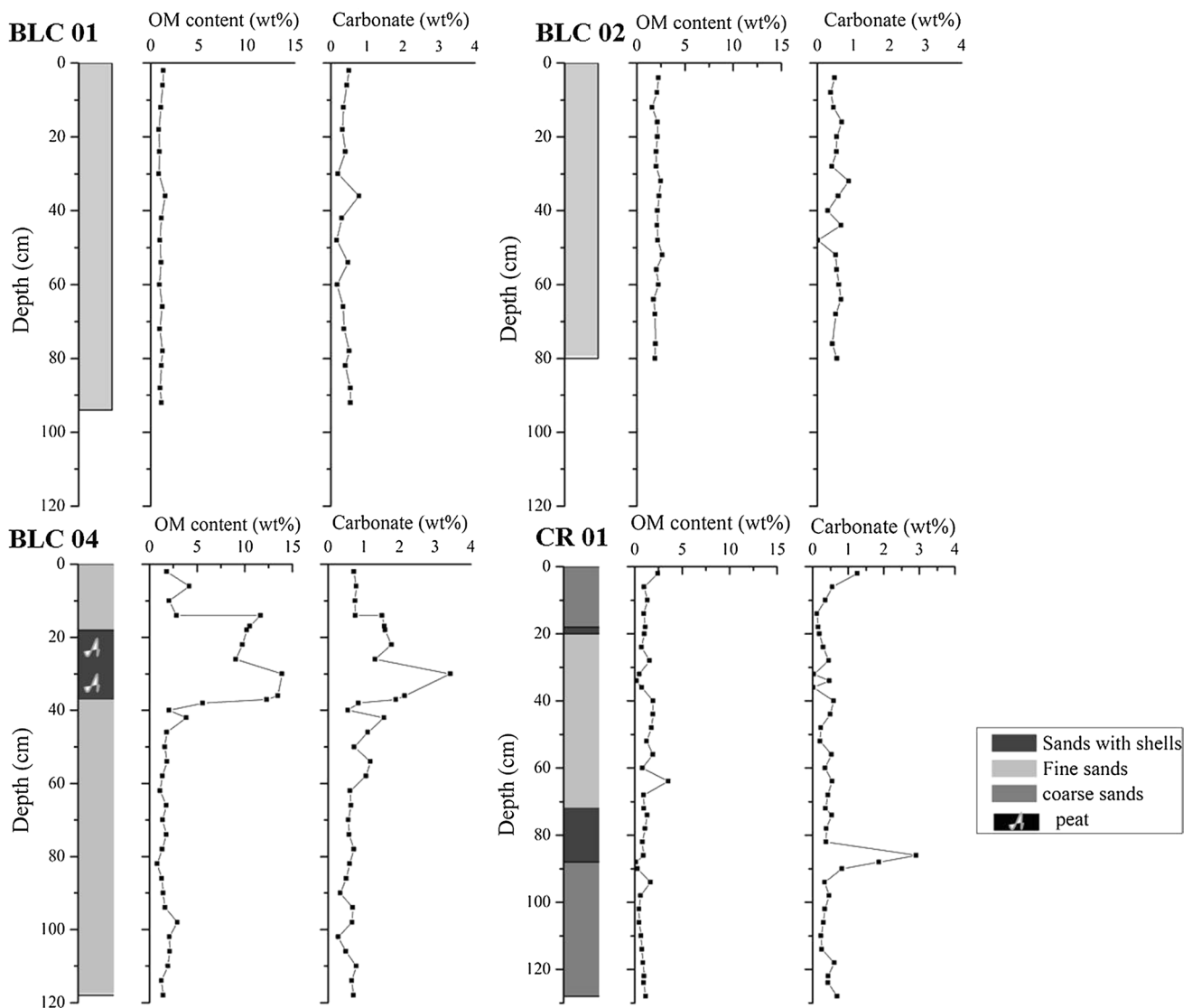

Fig. 2 Stratigraphy, OM content and carbonate content of the core samples obtained from eastern coast

Table 2 Radiocarbon dating results of sediment cores from eastern coast

Core sample	Depth (cm)	Sample number	Laboratory no.[a]	Material	Cal AD[b]	Cal BC[b]	Cal BP years
BLC 04	30–32	BLC 04-30-32	Beta-449200	Plant	1485–1650		300–465
	52–54	BLC 04-52-54	Beta-454044	Plant	1735–1806		145–215
	102–104	BLC 04-102-104	Beta-449201	Plant	1670–1780		170–280
CR 01	16–18	CR 01-16-18	Beta-449198	Shell	1475–1185		475–765
	124–126	CR 01-124-126	Beta-449199	Shell		1690–1380	3640–3330

[a]Radiocarbon laboratory ID

[b]Calendar ages determined by BetaCal 3.12 provided by Beta Analytic using the INTCAL13 database

Fig. 3 Concentrations of Br, I, and P_2O_5 in sediment core samples of eastern coast, Sri Lanka
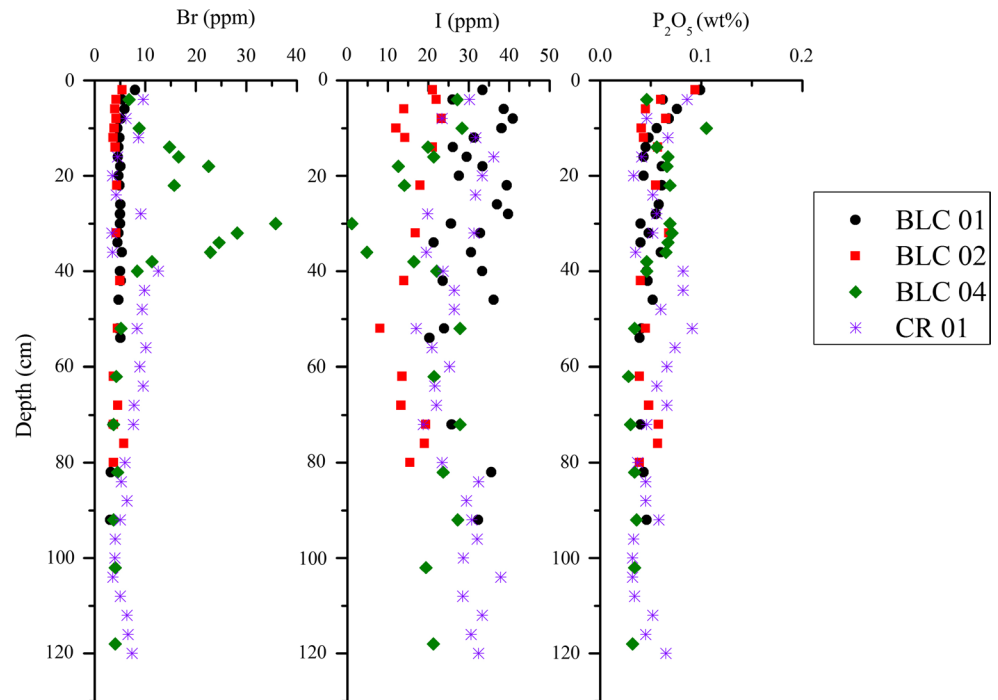
is characterized by higher concentrations of Br and lower concentrations for I. All core samples have less than 0.1 wt% of P_2O_5 including the peat layer found in BLC 04.

Comparison of eastern sediments with southern tsunami sediments

The SPM and BLS of Batticaloa lagoon have higher Br concentration compared to that of sediment core samples of the eastern lagoons. The Br concentration of tsunami sediments is higher compared to all sediment types of the eastern lagoons (Table 4).

Chemical behavior of I in lagoon sediments is different to that of Br (Table 4). Low I values of the peat layer are comparable with I concentrations of BLS sediments and tsunami sediments of southern lagoons. In general, tsunami sediments have the highest P_2O_5 concentration while sediment core samples have the lowest. The OM contents of the

eastern lagoon sediments and in the peat layer of BLC 04 core were very low compared to the tsunami sediments of southern lagoons (Table 4; Jayawardana et al. 2012).

Discussion

Characteristics of sediment types

The recent tsunami sediments (2004) deposited in Sri Lankan coast are generally brownish yellow in color and are rich in OM with about 50 wt% (Dahanayake and Kulasena 2008; Matsumoto et al. 2010; Jayawardana et al. 2012). The peat layer found in BLC 04 contains a comparatively low content of OM compared to that of the recent tsunami sediments (Table 3). This suggests a storm-surge origin for the peat layer as explained by Dahanayake and Kulasena (2008). This is further revealed by chronological data and

Table 3 Concentrations of Br, I, and P_2O_5 in subsamples of sediment cores of Batticaloa lagoon (BLC 01, BLC 02 and BLC 04) and Kiran lagoon (CR 01)

Sample depth (cm)	Br (ppm)				I (ppm)				P_2O_5 (wt %)			
	BLC 01	BLC 02	BLC 04	CR 01	BLC 01	BLC 02	BLC 04	CR 01	BLC 01	BLC 02	BLC 04	CR 01
2	8	6	nd	nd	33	21	nd	nd	0.10	0.09	nd	nd
4	6	4	7	10	26	22	27	30	0.06	0.06	0.05	0.09
6	6	4	nd	nd	39	14	nd	nd	0.08	0.05	nd	nd
8	5	4	nd	6	41	23	nd	23	0.07	0.07	nd	0.05
10	5	4	9	nd	38	12	28	nd	0.06	0.04	0.11	nd
12	5	4	nd	9	31	14	nd	32	0.05	0.04	nd	0.07
14	5	4	15	nd	26	21	20	nd	0.05	0.06	0.06	nd
16	5	nd	17	5	30	nd	21	36	0.04	nd	0.07	0.04
18	5	nd	23	nd	33	nd	13	nd	0.06	nd	0.07	nd
20	5	nd	nd	4	28	nd	nd	33	0.04	nd	nd	0.03
22	5	4	16	nd	39	18	14	nd	0.06	0.06	0.07	nd
24	nd	nd	nd	4	nd	nd	nd	32	nd	nd	nd	0.05
26	5	nd	nd	nd	37	nd	nd	nd	0.06	nd	nd	nd
28	5	nd	nd	9	40	nd	nd	20	0.06	nd	nd	0.06
30	5	nd	36	nd	26	nd	1	nd	0.04	nd	0.07	nd
32	5	4	28	3	33	17	nd	31	0.05	0.07	0.07	0.05
34	5	nd	25	nd	21	nd	nd	nd	0.04	nd	0.07	nd
36	5	nd	23	4	31	nd	5	20	0.06	nd	0.07	0.04
38	nd	nd	11	nd	nd	nd	16	nd	nd	nd	0.05	nd
40	5	nd	8	13	33	nd	22	24	0.05	nd	0.05	0.08
42	5	5	nd	nd	24	14	nd	nd	0.05	0.04	nd	nd
44	nd	nd	nd	10	nd	nd	nd	26	nd	nd	nd	0.08
46	5	nd	nd	nd	36	nd	nd	nd	0.05	nd	nd	nd
48	nd	nd	nd	9	nd	nd	nd	26	nd	nd	nd	0.06
50	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
52	5	5	5	8	24	8	28	17	0.04	0.05	0.03	0.09
54	5	nd	nd	nd	20	nd	nd	nd	0.04	nd	nd	nd
56	nd	nd	nd	10	nd	nd	nd	21	nd	nd	nd	0.07
58	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
60	nd	nd	nd	9	nd	nd	nd	25	nd	nd	nd	0.07
62	nd	4	4	nd	nd	14	21	nd	nd	0.04	0.03	nd
64	nd	nd	nd	10	nd	nd	nd	22	nd	nd	nd	0.06
66	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
68	nd	5	nd	8	nd	13	nd	22	nd	0.05	nd	0.07
70	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
72	4	4	4	8	26	19	28	19	0.04	0.06	0.03	0.05
74	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
76	nd	6	nd	nd	nd	19	nd	nd	nd	0.06	nd	nd
78	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
80	nd	4	nd	6	nd	16	nd	23	nd	0.04	nd	0.04
82	3		5	nd	36		24	nd	0.04		0.03	nd
84	nd		nd	5	nd		nd	32	nd		nd	0.05
86	nd		nd	nd	nd		nd	nd	nd		nd	nd
88	nd		nd	6	nd		nd	29	nd		nd	0.05
90	nd		nd	nd	nd		nd	nd	nd		nd	nd
92	3		4	5	32		27	31	0.05		0.04	0.06
94			nd	nd			nd	nd			nd	nd

Table 3 (continued)

Sample depth (cm)	Br (ppm)				I (ppm)				P$_2$O$_5$ (wt %)			
	BLC 01	BLC 02	BLC 04	CR 01	BLC 01	BLC 02	BLC 04	CR 01	BLC 01	BLC 02	BLC 04	CR 01
96			nd	4			nd	32			nd	0.03
98			nd	nd			nd	nd			nd	nd
100			nd	4			nd	29			nd	0.03
102			4	nd			19	nd			0.03	nd
104			nd	4			nd	38			nd	0.03
106			nd	nd			nd	nd			nd	nd
108			nd	5			nd	29			nd	0.03
110			nd	nd			nd	nd			nd	nd
112			nd	6			nd	33			nd	0.05
114			nd	nd			nd	nd			nd	nd
116			nd	7			nd	31			nd	0.05
118			4	nd			21	nd			0.03	nd
120			nd	7.4			nd	32.4			nd	0.07
122			nd	nd			nd	nd			nd	nd
124				8				27.2				0.06
126				nd				nd				nd
128				nd				nd				nd
Min	3	4	4	3	20	8	1	17	0.04	0.04	0.03	0.03
Max	8	6	36	13	41	23	28	38	0.10	0.09	0.11	0.09
Average	5	4	13	7	31	17	20	28	0.05	0.05	0.05	0.05
SD	1	1	10	2	6	4	8	6	0.01	0.01	0.02	0.02

Table 4 Statistical summary of concentration of measured elements and OM in all sediment types

	BLC 01	BLC 02	BLC 04	CR 01	Lagoon bottom sediments	Suspended sediments of lagoon	Hambanthota (tsunami)	Hikkaduwa (tsunami)
Br (ppm)								
Range	3–8	4–6	4–36	3–13	3–52	2–157	7–51	3–170
Average	5	4	13	7	15	32	24	75
SD	1	1	10	2	13	47	16	47
I (ppm)								
Range	20–41	8–23	19–28	0–22	1–15	14–21	8–24	2–22
Average	31	17	20	28	8	17	18	11
SD	6	4	8	6	5	3	4	6
P$_2$O$_5$ (wt%)								
Range	0.040–0.10	0.04–0.09	0.03–0.11	0.05–0.07	0.08–0.31	0.14–0.23	0.14–0.20	0.08–0.24
Average	0.05	0.05	0.05	0.05	0.12	0.41	0.18	0.14
SD	0.01	0.01	0.02	0.02	0.04	0.07	0.01	0.04
OM content (wt%)								
Range	0.8–1.5	1.6–2.6	0.8–15.0	0.2–3.5	nm	nm	34.0–50.0	58.0–80.0
Average	1.1	2.1	4.1	1.1	nm	nm	42.0	69.0
SD	0.2	0.2	4.2	0.7	nm	nm	5.5	5.7

nm not measured, *SD* standard deviation

chemical composition of the sediments of the present study. Generally, huge ocean waves can contain fore-dune soils, backshore drifts, and bog peat deposits, which can indicate the age as an older event than the actual event (Schlichting and Peterson 2006).

The mean concentration of Br in sea water ranges from 65 to 85 ppm (Al-Mutaz 2000) and marine sediments contain more than 100 mg/kg (Leri et al. 2010). In contrast, the average Br concentrations in Sri Lankan lagoon sediments of the present study are low, except in few tsunami sediment samples (Jayawardana et al. 2012).

The relative high Br concentrations in tsunami sediments, peat layer, and SPM sediments may be due to the presence of primary products such as microalgae and diatoms in marine environments similar to observations of Gribble (1998) and Schlichting and Peterson (2006). On the other hand, Br in estuarine environment greatly depends on the type of OM (Harvey 1980; Mayer et al. 2007; Malcolm and Price 1984). For instance, halophytic plants in such environments absorb Br in sea water by roots and leaves (Moreno et al. 2015). It suggests the high Br concentrations in BLS sediments of Batticaloa lagoon are due to such activities of the marine plants that are available in the specific environment.

Lower I concentrations in peat unit and tsunami sediments suggest higher diatom contents as described by Ishiga and Sano (2015). Menzel (1974) found that deep sea surface sediments contain low I concentrations due to less accumulation of OM in bottom waters. Conversely, lower I concentrations have been recorded in other surface marine sediments where the anoxic conditions are prevailed (Harvey 1980).

Chemical correlations

For a further understanding of correlations between elements, correlation scatters plots were constructed between Br and I. In general, negative correlation is present for all sediment types (Fig. 4). Correlation of Br and I is slightly negative in sandy units of the core sediment samples. It may be due to the type of OM such as macroalgal in estuarine environments as described by Mayer et al. (2007).

Generally, ratios of Br and I to TOC in oxidizing marine environments show the proportional relationship (Price and Calvert 1977; Pedersen and Price 1980; Malcolm and Price 1984). Results of present study are in contrast to these observations.

There are two possibilities for the negative correlation between Br and I for different sediment types of the present study. One possibility is the anoxic conditions for the sedimentation processes in deep oceanic environments as described in Price and Calvert (1973, 1977). According to their findings, the decrease in I to C ratio from coastal shelf toward the deep anoxic environments is due to the inconsistency of planktonic activities in anoxic environments. Conversely, the type of OM in the sedimentary environments is variable (Ishiga and Sano 2015). Hence, plant association is further evaluated in the present study using the correlation of I and P_2O_5.
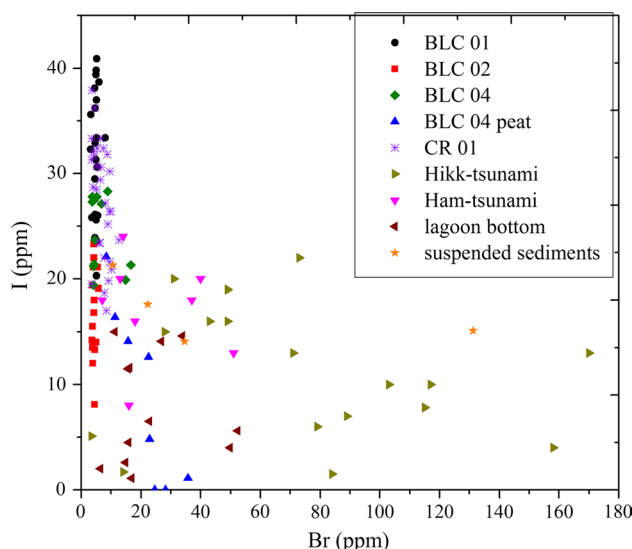
Fig. 4 Relationship of I and Br concentrations in eastern coast sediments and tsunami sediments of southern coast, Sri Lanka
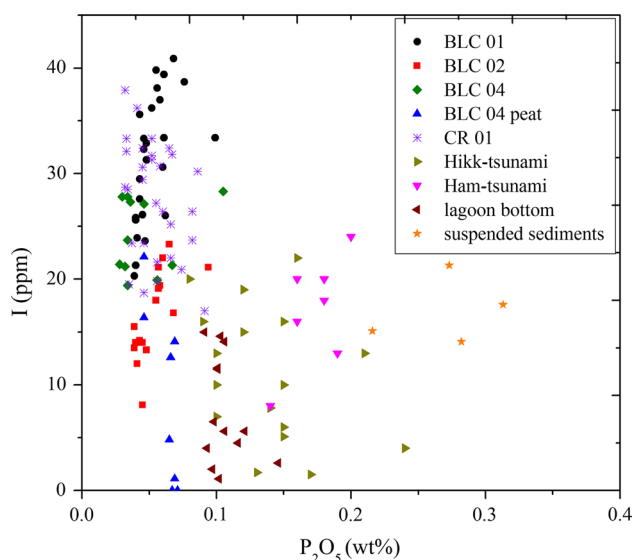
Fig. 5 I–P_2O_5 diagram for eastern coast sediments and tsunami sediments of southern coast, Sri Lanka

Phosphate is essential for plant growth and higher plants in marine environments such as mangroves and *Z. Marinas* are rich in phosphate and I (Ishiga and Sano 2015). Phosphorus is absorbed by phytoplankton at different rates under different nutrient conditions (Tantanasarit et al. 2013).

In contrast, phytoplankton has low or zero I concentration in their bodies (Butler et al. 1981; Ishiga and Sano 2015). Hence, this I–P_2O_5 relationship can be used to understand the results of the eastern lagoon sediments and tsunami sediments (Fig. 5), despite its limited use in several coastal

environments of Japan (Ishiga et al. 2010; Ishiga and Sano 2015; Ishiga et al. 2015; Okamoto et al. 2015).

The high biological productivity of the SPM samples may have resulted in increasing the P_2O_5 content with respect to the other sediment sources (Fig. 5). Therefore, SPM samples deviate from other results. Dahanayake and Kulasena (2008) noted that tsunami sediments of Sri Lanka have higher contents of microfossils (approx. 50%), which are common to open marine environments. Likewise, the high OM content (approx. 50%) of tsunami sediments in Hikkaduwa and Hambanthota suggests higher number of microfossils, which may be phytoplankton species rich in P_2O_5 concentrations (Jayawardana et al. 2012). Iodine concentration below the euphotic zone of the ocean is comparatively low where no biological productivity is present (Tsunogai and Henmi 1971; Wong 1976). Tsunami sediments and peat unit of BLC 04 show low I values and high P_2O_5 values due to the high accumulation of phytoplanktons.

Conclusions

Relationships of I, Br, and P_2O_5 concentrations in suspended sediments and bottom sediments of a lagoon, and sediment core samples from eastern coast and tsunami sediments of the southern coast of Sri Lanka, were compared in this study to differentiate the depositional environments of sediments in marine settings. The study shows negative correlation of Br and I of different marine settings. A similar negative correlation is indicated by I–P_2O_5 diagram that specifies the influence of different plant materials in different marine settings. It is due to the high contents of I in higher marine plants and low I contents in lower marine plants of a unique coastal profile. Hence, this study suggested the advantage of I–P_2O_5 diagrams to interpret the depositional environments of unknown marine sediments. Thus, the study reveals the control of plant materials over the chemical composition of sediments in different marine environments. This study can be further extended to better understand how the chemistry of sediments is controlled by marine plants in various marine environments.

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