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Sedimantation Rate and Behavior of Particulate Phosphorus in Eutrophic Coastal Environment

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(Figs. 1 – 4, Tables 1 – 3)

In studying the phosphorus budget in coastal seas, one must take into account the interplay between the water- and the sediment-phases. For this reason the rate of phosphorus transport from the water column to the bottom is a parameter worthy of measurement.

It may be said that the nature and quantity of precipitating particles have not been so intensively studied in the sea as they have been in the lake where various devices of collecting precipitating material have been already practised and evaluated.1) 2)

Quantitative collection of precipitating matter in the sea has often involved elaborate procedures.3) 4) In addition, some of the methods hitherto employed (for example, a sedimentation trap exposed for a period of over a week) may not be quite effective for a phosphorus study, because a considerable portion of phosphorus compounds contained in suspended particles is often liberated into the sea water rather quickly; yet by an exposure of a shorter period only a small quantity of precipitates may be obtained.

In recent years eutrophication is in rapid progress in certain coastal seas caused by the increased nutrient load from land sources. It is presumed that sedimentation rate of particulate matter must have augmented so much in these seas that a sufficient amount of precipitates for analyses may be collected in a sedimentation trap during a relatively short exposure.

Taking into account all these circumstances, a quantitative collection of sedimenting matter was attempted in a eutrophic coastal sea with a sedimentation trap of simplified design. The sampling sites were those where we had examined the seasonal variation of dissolved and particulate phosphorus during the preceding two years.5) 6)

Total phosphorus content, chlorophyll *a* content and dry weight were measured of the particulate matter collected in the trap. The results were compared with the corresponding data either on the seston crop in the overlying water column or on the uppermost layer of the bottom sediment.

MATERIALS AND METHODS

Sedimentation Trap

Our sedimentation trap (Fig. 1A) consisted of a polyethylene medical irrigator of 2-liter capacity (i.d. 11.7 cm, height 24 cm), to which were fastened a supporting rod across the mouth, a collar float around the upper part, a rubber drain tube with a pinch cock at the tapered lower end, and a longitudinal frame for attachment of an anchor rope. All metal parts were of stainless steel.

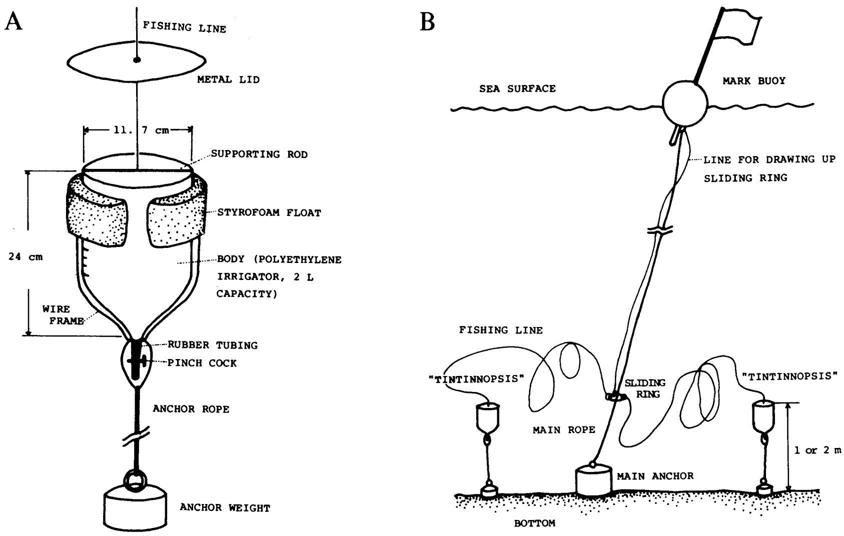

Fig. 1 The sedimentation trap "Tintinnopsis."
A. A sketch showing the general construction of a "Tintinnopsis".
B. Schematic view of a pair of "Tintinnopsis" being set in position.

The setting process was as follows. With the research ship arriving at a sampling station, the mooring device for the trap, consisting of a main anchor, a main rope and a surface mark buoy, was installed firstly (Fig. 1B). On board, an anchor weight (0.5 kg) was attached to a trap by means of an anchor rope, and the lower end of a fishing line of nylon (somewhat longer than the water depth; dia. 1.2 mm) was fastened to the supporting rod. The trap was filled with sea water and slowly lowered into the sea by extending the fishing line, until the anchor weight settled in the muddy sea bottom. The upper end of the fishing line was fastened to a sliding ring, which was passed over the main rope and was now held over the ship's railing. As this type of trap was always set in a pair, the same procedure was repeated for lowering of the second trap. When a pair of traps were set ready in position, the sliding ring, connected to the mark buoy by another piece of nylon line, was dropped into the water.

The trap was usually hauled in after an exposure of one or two days in the following way. The ship was slowly brought to the mark buoy. The sliding ring was pulled up on board, the nylon line leading to the trap was unfastened and passed through the central holes of a metal lid and a messenger weight, the latter being placed upon the former. Holding the line nearly vertically, the lid was dropped into the water together with the messanger weight. Then each trap was carefully hauled up on board, and its contents were drained into separate jars by means of the drain tube.

This trap has been nicknamed "Tintinnopsis" for its general appearance.

Station, Sampling Period and Simultaneous Field Data

Precipitating particulate matter was collected with this "Tintinnopsis" trap on 11 occasions during April 1975 – January 1977 at two stations, namely, Sts. 2 and BG-1 [5] (ca. 7 and 24 m deep, 2 and 10 km off the shore, respectively) located in the northern Bingo-nada region of the Seto Inland Sea (Table 1). The vertical distance from the sea floor to the trap's mouth was 1 m at St. 2 and 2 m at St. BG-1 by preadjustment of the length of the anchor rope.

When the trap was hauled in, the water depth and the Secchi disk visibility were recorded, and measurements were made of the water temperature, chlorinity, dissolved oxygen, turbidity, and dissloved inorganic and organic phosphorus at different depths (0 and 5 m at St. 2 and 0, 10 and 20 m at St. BG-1, at least).

The seston was quantitatively sampled also at the above-mentioned depths to determine dry weight and phosphorus and chlorophyll *a* contents.

Sediment Sample

On the 5 occasions in the second half of the sampling period, sediment samples were taken at each station (Table 3). A column of muddy sediment, usually 10 to 20 cm high, filled the lower portion of the 40 cm long plastic pipe i.d. 3.7 cm, which was the sampling sheath of the core sampler. Immediately, the overlying sea water was carefully siphoned out of the pipe, and a known volume of filtered sea water (usually 150 ml) was introduced without disturbing the surface of the sediment column.

By holding the pipe in a nearly vertical position and spinning it slowly upon its lower end, the water inside was caused to move around gently, stirring up the loose uppermost layer of the sediment. These stirred-up sediment particles were collected, together with the water, for analyses.

Analyses of Particulate Samples

Either the contents of a recovered "Tintinnopsis" or the turbid water produced in a sediment pipe by stirring was more or less densely loaded with particulate matter. Aliquots of them were filtered through the tared filter*, and the retained particulate matter was washed free from salts, then dried for 1 hr at 75°C, and finally weighed. The dry weight of the seston was also determined in the same way by filtering a few liters of sea water.

For determining the phosphorus content of particulater matter, a watery sample was filtered through a filter preparatively covered with a thin layer of fine magnesium

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* The filters used in the analytical procedures were exclusively HA-type Millipore filters 47 mm dia.

carbonate powder. The particulate matter was removed from the filter together with the powder layer, put into a Kjeldahl flask, and analyzed by the method described by Strickland and Parsons.7)

Chlorophyll *a* content of particulate matter was determined by collecting the particles on a filter and by subjecting the 90% acetone extract to the trichromatic absorptiometry.7)

Seston Error

On the assumption that the particulate material contained in a recovered sedimentation trap consisted of the real precipitates from the water column plus the seston contained in the 2 ℓ (which was the capaicty of the trap) of sea water, the seston portion was calculated from the simultaneous seston data and substracted from the 'gross' catch in the trap. The trap catch thus corrected regarding the seston error was divided by the trap's collecting area (107.5 cm^2) and by the length of exposure period. In this way the precipitation rate per cm^2 per day was obtained. Seston error was corrected in dry weight as well as in particulate phosphorus.

RESULTS

Recovery of Traps and Amounts of Precipitates Collected

A total of 44 exposures of the "Tintinnopsis" trap were made at the two stations during the study period, and in 31 (70.5%) of these the precipitated material was successfully obtained from the recovered traps (Table 1). In the other 13 exposures, the sampling was not successful because the trap was either lost or hauled up on board upside down being caught in the nylon line.

The paired traps were successfully recovered in 12 of the 22 collecting occasions, allowing the mean and standard devistion (SD) of the dry weight of precipitated matter to be calculated for each pair. The ratio SD/mean varied between 0.04 and 1.22 (Table 1), showing clearly that in certain cases the amount of entrapped material differed considerably between the two traps.

Most of the recovered traps contained particulate material weighing tens or hundreds of milligrams in dry weight.

Precipitation Rate and Phosphorus Content of Precipitates

Precipitation rates in terms of dry weight and particulate phosphorus, and the phosphorus content of precipitated matter were derived from the trap catches and shown in columns A, B and C of Table 2.

Precipitation rates varied considerably from sampling to sampling at both stations. By excepting unusually high measurements the following all season means were obtained: 0.98 and 0.42mg dry weight/cm^2/day and 0.64 and 0.33μg P/cm^2/day, respectively for Sts. 2 and BG-1. These means indicate that the precipitation was more active at the near-

Table 1. Chronological record of the collections made with the "Tintinnopsis" sedimentation trap

Date of recovery	St.	Exposure period (hours)	No. of traps*	Dry weight of collected particulate material per trap**			Precipitation rate of dry matter** mg/cm^2/day
				Mean $\bar{X}$ mg	SD*** mg	SD/$\bar{X}$	
Apr.23,1975	2	28	1/2	69.0			0.55
	BG-1	24	2/2	15.1	5.15	0.34	0.14
May 22	2	46	1/2	105			0.51
	BG-1	46	1/2	80.4			0.39
Jun. 15	2	48	2/2	557	73.5	0.13	2.59
	BG-1	44.5	1/2	217			1.09
Sep. 19	2	48	2/2	75.3	30.5	0.41	0.35
	BG-1		0/2				
Nov. 7	2	48	2/2	1264	854	0.68	5.88
	BG-1	48	1/2	2053			9.55
Jan.14,1976	2	30	2/2	110	3.85	0.04	0.82
	BG-1	28	2/2	25.1	7.00	0.28	0.20
Apr. 23	2		0/2				
	BG-1	43.5	2/2	12.6	3.37	0.27	0.065
Jul. 8	2	45.5	1/2	324			1.59
	BG-1	45	2/2	201	108	0.54	1.00
Sep. 18	2		0/2				
	BG-1	48.5	2/2	358#	#	#	1.65
Nov. 11	2	23.5	2/2	214	178	0.83	2.04
	BG-1	19.5	2/2	170	11.4	0.07	1.95
Jan.21,1977	2	48	2/2	93.1	114	1.22	0.43
	BG-1	45	1/2	6.1			0.03

* Recovered/Installed.
** "Seston error" corrected.
*** Standard deviation.
\# In this case duplicate samples were combined and dry weight was determined.

shore station in shallower waters.

In calculating the means for St. 2, the trap catch data obtained in November of both 1975 and 1976 were excluded on purpose, because precipitation in one day (in terms of dry weight) exceeded the seston crop found in the water column above the trap.

In the case of the means for St. BG-1, trap catch data obtained on the following three occasions were not taken into calculation, because they were suspected to have been unusual. On the two ocations (i.e., November of 1975 and 1976), the daily precipitation was very high (though it did not exceed the seston crop) and the phosphorus content of the precipitates was very close to that of the uppermost layer of the sediment, so that considerable contamination by resuspended sediment particles was suspected. The third elimination was the trap catch datum obtained in September 1976, when the sea was discolored by a red tide which occurred after a heavy rainfall caused by a typhoon; the sea condition was proved by such measurements as a low surface chlorinity (14.95‰), a high chlorophyll *a* content (15.3 μg/l) and a low transparency (1.8 m).

Table 2. The precipitated matter, the seston crop and the precipitation ratio as expressed in dry weight (DW) and particulate phosphorus (PP)

Date or season	St.	Tr.*	Precipitated matter**			Seston crop***			Precipitation ratio per day****		Comparison of P contents
		m	DW mg/cm²/d (A)	PP μg/cm²/d (B)	PP/DW mg/g (C)	DW mg/cm² (D)	PP μg/cm² (E)	PP/DW mg/g (F)	DW % (G)	PP % (H)	(I)
Apr.23	2	3.7	0.55	0.22	0.40	5.6	7.0	1.25	9.8	3.1	0.32
	BG-1	10.0	0.14	0.14	1.00	4.0	17.9	4.48	3.4	0.8	0.22
May 22	2		0.51	0.16	0.31	2.3	2.7	1.17	22.2	5.9	0.26
	BG-1		0.39	0.25	0.64	7.2	10.0	1.40	5.4	2.5	0.46
Jun. 15	2	3.0	2.59	1.47	0.57	3.1	8.1	2.61	83.5	18.1	0.21
	BG-1	10.0	1.09	0.80	0.73	3.9	10.1	2.59	27.9	8.2	0.28
Sep. 19	2	2.5	0.35	0.50	1.43	4.2	14.7	3.51	8.3	3.4	0.41
	BG-1	5.2				5.3	10.3	1.94			
Nov. 7	2	3.5	5.88	3.27	0.56	3.4	6.6	1.92	173	49.5	0.29
	BG-1	6.5	9.55	2.91	0.31	6.4	12.9	2.02	149	22.6	0.15
Jan. 14	2	3.5	0.82	0.52	0.63	3.0	5.6	1.88	27.3	9.3	0.34
	BG-1	4.7	0.20	0.19	0.95	9.8	8.0	0.81	2.0	2.4	1.17
Apr. 23	2	3.5				1.5	6.4	4.37			
	BG-1	6.2	0.065	0.053	0.82	5.5	19.5	3.57	1.2	2.1	0.23
Jul. 8	2	2.2	1.59	1.35	0.85	2.4	9.9	4.16	66.8	13.7	0.20
	BG-1	6.0	1.00	0.87	0.87	12.0	15.9	1.33	8.4	5.5	0.65
Sep. 18	2	1.4				11.0	16.1	1.46			
	BG-1	1.8	1.65	0.80	0.48	27.4	27.7	1.01	6.0	2.9	0.48
Nov. 11	2	2.9	2.04	0.30	0.15	1.6	5.6	3.48	126	5.3	0.043
	BG-1	4.7	1.95	1.00	0.51	6.6	12.4	1.86	29.4	8.1	0.27
Jan. 21	2	3.4	0.43	0.26	0.59	2.4	8.8	3.67	18.1	2.9	0.16
	BG-1	6.3	0.03	0.005	0.18	5.9	14.5	2.48	0.5	0.04	0.073
Means# for:											
H.T.S.	2		1.26	0.87	0.69	4.6	10.3	2.24	27.4	8.4	0.31
L.T.S.	2		0.60	0.33	0.55	3.1	7.0	2.26	19.4	4.7	0.24
All-season	2		0.98	0.64	0.65	3.9	8.8	2.26	25.1	7.3	0.29
H.T.S.	BG-1		0.83	0.64	0.77	7.1	11.6	1.63	11.7	5.5	0.47
L.T.S.	BG-1		0.11	0.094	0.88	6.3	15.0	2.38	1.75	0.65	0.37
All-season	BG-1		0.42	0.33	0.79	6.7	13.3	1.99	6.27	2.48	0.40

* Tr: Transparency or visible range of 30 cm diam. Secchi disk.
** Particulate matter collected in the sedimentation trap. "Seston error" corrected.
*** Standing crop of seston in the water column.
**** Percentage of the daily precipitation to the seston crop.
\# The data for St. BG-1 in Sept. 1976 and all data in November of both years are excluded from computation. See text.
(A) Dry weight of the particulate matter precipitated on a unit area of the sedimentation trap per day.
(B) Phosphorus contained in the particulate matter as indicated by (A)
(C) = (B)/(A) Phosphorus content of precipitated matter.
(D) Dry weight of the seston integrated for the water column ranging from the sea surface down to the mouth of the sedimentation trap.
(E) Particulate phosphorus contained in the seston crop as indicated by (D).
(F) = (E)/(D) Phosphorus content of the seston crop.
(G) Precipitation ratio in terms of dry weight.
(H) Precipitation ratio in terms of particulate phosphorus.
(I) = (C)/(F) The ratio of the phosphorus content of precipitated matter to that of seston crop.

Seasonal variations in precipitation rates were examined by dividing the annual cycle into the following two seasons[5)] and calculating the mean precipitation rates for the seasons (Table 2):

High temperature season (H.T.S.): Water temperature above 15°C; May ot October.

Low temperature season (L.T.S.): Water temperature under 15°C; November to April.

Mean precipitation rates in terms of dry weight for the high and the low temperature season were 1.26 and 0.60 mg/cm^2/day at St. 2, and 0.83 and 0.11 mg/cm^2/day at St. BG-1. The corresponding means of the precipitation rates of particulate phosphorus were 0.87 and 0.33 μg/cm^2/day at St. 2 and 0.64 and 0.094 μg/cm^2/day at St. BG-1.

These means suggest that the precipitation was more abundant in the warm season than in the cold season and also that it was scare at the offshore station in the cold season.

All these regional and seasonal differences in the precipitation rate are most probably due to the differences in biological productivity within the water column and to the influx of terrigenous particulate matter.

The phosphorus content of the precipitated matter varied from sampling to sampling, ranging between 0.15 and 1.43 mg P/g on dry basis (Table 2). Its seasonal and all-season means were calculated from those samples for which the mean precipitation rates had been calculated. The all-season means for Sts. 2 and BG-1 were respectively 0.65 and 0.79 mg P/g, and the seasonal means too were close to these results at both stations.

Relationship between Precipitates and Seston

The standing crop of seston within the water column (with a base area of 1 cm^2) above the trap's mouth) was calculated from the results of field measurements in terms of dry weight and particulate phosphorus, as shown in columns D and E of Table 2. Column F of the same table shows the phosphorus content of the seston crop.

Seasonal variation of the last-named variable is indicated in graph A of Fig. 2, while graph B stands for the variation of the phosphorus content of precipitates. It appears from these graphs that in the course of time the two variables varied rather much in parallel, and that the former was usually much higher than the latter. The all-season means for the two stations combined were 2.1 and 0.72 mg P/g respectively for seston and precipitates. This result may be interpreted in the sense that about 70% of the phosphorus compounds originally incorportated in sestonic particulate matter had been lost before the particles were collected in the sedimentation trap.

The daily precipitation ratio, i.e., the ratio of the daily precipitation to the standing crop of seston in the water column (Table 2), averaged 7.3 and 2.5% in terms of particulate phosphorus (25.1 and 6.3% in terms of dry weight) respectively for St. 2 and BG-1. The noticeably higher precipitation ratio of dry weight at St. 2 may have been the result of an abundant precipitation of particles of low phosphorus content. The location and the water depth of this station seem to prove that the source of such particles shoud be both the terrigenous soil particles carried down by the river waters and the resuspended sediment particles.

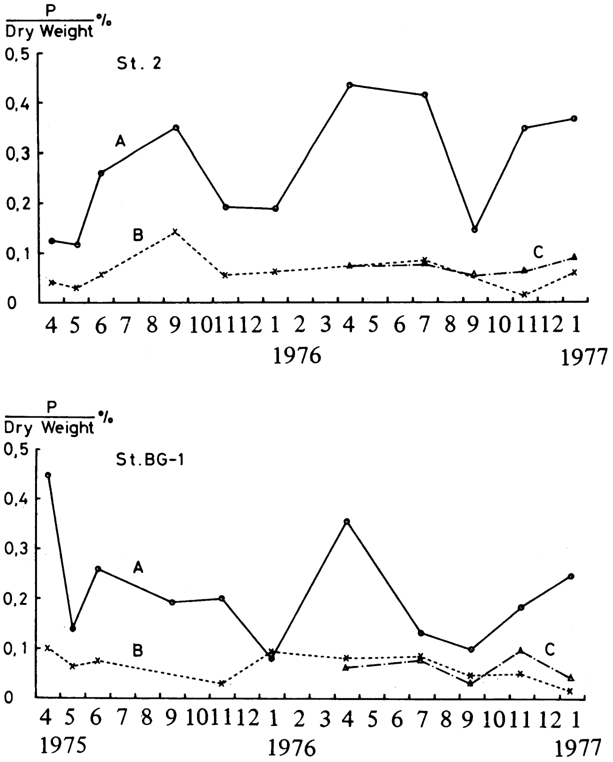

Fig. 2 Seasonal variation of phosphorus content in the three kinds of particulate material obtained at St. 2 and St. BG-1.
A, seston; B, precipitates collected in the "Tintinnopsis" trap; C, uppermost layer of the bottom sediment.

Relationship between Precipitates and the Uppermost layer of Sediment

Partirulate matter was sampled from the uppermost layer of the sediment by the method already described. The thickness of the sampled layer ranged between 4 and 11 mg (dry weight)/cm^2 (Table 3), or from several times to dozens of times as much as daily precipitation. Consequently, the estimeted age of the oldest sediment material incorporated differed according to the samples, ranging from one to several weeks, with few exceptions.

The phosphorus content of a sediment sample was usually very close to that of the simultaneously obtained precipitated matter, as is indicated in graphs B and C in Fig. 3. From this result it may be inferred that the sharp drop in phosphorus content characteristic of the primary decomposition step of organic matter had already happened in the particulate matter before it was either collected by the sedimentation trap or had settled down on the sea bed, and that the subsequenc decrease in phosphorus content continued at a lower pace. The phosphorus contents of the three different kinds of particulate material are illustrated in Fig. 3, where the means for the samples obtained during April 1976 – January 1977 are plotted againest the water depth.

Table 3. Phosphorus and chlorophyll *a* contents of the uppermost layer of sediment on dry weight basis

Date	Station	Chl. *a* mg/g	Phosphorus mg/g	*Th** mg/cm^2
Apr. 21, 1976	St. 2	0.0911	0.731	5.11
	St. BG-1	0.0726	0.628	4.12
Jul. 6	St. 2	0.0566	0.763	7.55
	St. BG-1	0.0487	0.778	9.54
Sep. 16	St. 2	0.0238	0.536	8.46
	St. BG-1	0.1190	0.311	3.89
Nov. 10	St. 2	0.0655	0.630	10.89
	St. BG-1	0.1253	1.021	7.15
Jan. 1,1977	St. 2	0.0869	0.899	5.38
	St. BG-1	0.1120	0.450	6.11

**Th*: Thickness of the sampled layer in terms of dry weight.

In Fig. 3 chlorophyll *a* contents of the three kinds of particulate material presented a different feature. While the seston contained an average of 0.1 – 0.26% of chlorophyll *a* on the dry weight basis, the precipitates collected in the sedimentation trap contained only 0.03 – 0.05%. This sharp decline was comparable to the case of the phosphorus content. The uppermost layer of the sediment showed, in contrast to the case of phosphorus, furthermore lower chlorophyll *a* contents, namely, 0.02 – 0.12% (Table 3). This result suggests that agents destructive of particulate chlorophyll *a* were active not only in the water column but also on the sea bottom.

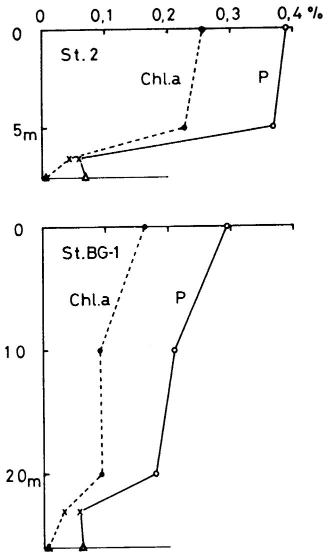

Fig. 3 Vertical profiles of phosphorus and chlorophyll *a* contents of particulate materials at St. 2 and St. BG-1: ○ ● – seston; x – precipitates collected in the "Tintinnopsis" trap; △ ▲ – uppermost layer of the bottom sediment.
Arithmetic means for the samples taken during April 1976 – January 1977 are plotted.

DISCUSSION

Adequacy of Trap Catch Data for the Measure of Precipitation Rate

The advantages of the "Tintinnopsis" trap were: (1) it could be laid out and recovered easily; (2) it could be laid out without stirring up the bottom and usually kept above the turbid near-bottom water (see below); and (3) the exposure period was relatively short. The trap was laid in waters where tidal currents were slower than 1 knot, and the exposures were made mostly in calm weather. However, we have not conducted any field observation or experiment for checking whether all precipitating particles were quantitatively collected. We therefore lack critical information about possible precipitating particles that were hindered from falling into the trap nor of particles that were once precipitated in the trap but were partially lost by the time of recovery. We tentatively assume that these unchecked effects may have been insignificant.

Contamination by resuspended sediment material is another factor to be considered when interpreting the trap catch data. Various evidences suggested that the muddy sea bottom of our sampling stations was overlaid with a layer of somewhat turbid sea water ca. 1–1.5 m in thickness during the most part of the year. The turbudity of this layer, detectable with a submerged transmittance meter, was probably due to resuspended sediment particles and to an accumulation of seston or precipitating particles. We presume that the influences of this water layer may have been avoided by our sedimantation trap, because it was set 1 or 2 m above the sea bed.

The water samples obtained at short vertical intervals within this near-bottom water layer indicated that the amount of particulate matter increased while dissolved oxygen decreased towards the bottom in the summer. This appears to be in line with the research of Davis8) who found that the redeposition of sediment particles decreased during the season of thermal stratification in a lake.

On the other hand, unusually abundant trap catches were obtained at both stations in November of both 1975 and 1976. Since suspended particles were abundant in the lower part of the water column on these occasions, it is suspected that resuspension of sediment material had augmented due to certain causes in this particular season of the year. These trap catch data, as well as the datum obtained on the occasion of the red tide (St. BG-1 in September 1976) were not made use of when estimating the precipitation rates as mentioned before.

We take the mean trap catches calculated with the foregoing precautions as approximate estimates of the precipitation rate.

Precipitation and Dissolution of Particulate Phosphorus

As was illustrated in Fig. 3, comparison of phosphrus content among various particulate materials indicated a very slight decrease, if any, with increasing water depths (in the case of seston) and, on the other hand, discontinuously lower contents in precipitates and bottom sediment than in the seston. Such a situation would not have resulted, if the suspended particles represented by our seston samples had sunk unselectively and if their phosphorus contents had decreased in proportion to the vertical distance of the sinking.

A possible explanation for the above situation might be to postulate a tendency in particles with lower phosphorus contents to sink faster. We can suggest three probable cases of such selective sinking. The first one is for the terrigenous soil particles carried in by rivers; these particles are lower in phosphorus content and sink faster than the indigenous suspended particles produced by biological processes. The second case is the decaying indigenous particles whose sinking rate accelerates by aggregating; such aggregates are probably lower in phosphorus content than living suspended microorganisms. The third case is the fecal pellets of zooplankton. It is well known that the seston is converted into these fast-sinking grains of lesser phosphorus contents by the filter-feeding activity of zooplankters, although a quantitative study of this activity has not been carried out at our stations. By preliminary microscopic examination of trap catches, an abundance of minute grains reminiscent of fecal pellets, as well as the presence of amorphorus aggregates of detrital matter, was detected.

Apart from the possibility of selective sinking, precipitation rates of phosphorus of 0.64 and 0.33 μg/cm^2/day were estimated respectively for St. 2 and BG-1 as mentioned before. Seki et al.[9] reported a corresponding rate of 4.9 g/cm^2/year (1.34 μg P/cm^2/day) for Departure Bay, British Columbia. Ketchum and Corwin[10] suggested the possibility that some phosphorus compounds in suspended particles may be more labile than chlorophyll *a* when the particles are precipitated toward the sea bottom. It is presumed that in the precipitated particles on the sea bottom phosphorus compounds are subject to lesser decrease than many other organic substances.

The difference in phosphorus content between seston and precipitates can be regarded as the measure of the phosphorus removed from particles in the course of the sinking. It is presumed that the removed phosphorus is largely returned into sea water in dissolved forms. The rate of this removal has been calculated through multiplying the above difference by the precipitation rate of dry matter, and has been plotted in Fig. 4. Although the data are not so numerous, the graphs suggest a tendency of the rate to be higher in the warm season than in the cold season, which is probably a reflection of higher rates of primary production, grazing and decomposition in the former season.

Sedimentation Rate of Dry Matter

The precipitation rate determined from the catch of a sedimentation trap cannot always be regarded as the sedimentation rate, that is defined as the accumulation rate of solid substances on the sea bottom. This is because the particulate matter precipitated in a trap, especially the organic matter, may be partially lost while being on the sea bottom as a result of decomposition into soluble or volatile substances. In an incubation experiment at 20°C, in which the particles

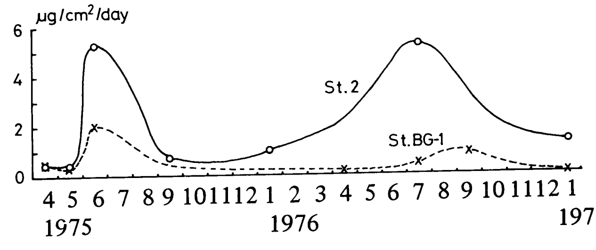

Fig. 4 The rate of phosphorus removal from precipitating seston, as inferred from the phosphrus contents of the seston and of the sedimantation trap catch. Data for a water column with the base area of 1cm^2 are shown.

precipitated in the trap were enclosed in the Winkler bottle together with filtered sea water, partial mineralization of particulate phsophrus, consumption of dissolved oxygen and lowering of pH continued for at least 25 days. It must therefore be admitted that the sedimentation rate will be somewhat smaller than the precipitation rate when both are expressed in dry weight.

Making allowance for the above error, we tentatively take the all-season means of precipitation rate, namely, 0.98 and 0.42 mg of day matter/cm^2/day (Table 2), as available estimates of the sedimentation rate at Sts. 2 and BG-1.

As for sedimentation rates of dry matter in coastal seas, Stephens et al.[4)] obtained ca. 100–550 g/m^2/month (0.3–1.8 mg/cm^2/day) by a trap method in Departure Bay in 1965-66. In the late 1920's, Moore[11)] obtained an estimate of ca. 207 mg/cm^2/year (0.57 mg/cm^2/day) from both the trap catch and the stratified structure of the sediment column in Loch Striven, Scotland. Our estimates are comparable to these figures. Yoshida[12)] obtained precipitation rates of particulate nitrogen of 1.05, 0.24 and 0.080 g N/m^2/day respectively for the estuarine, inner, and central parts of Osaka Bay in 1972-73. Since nitrogen content of precipitates was reported as 6.0, 6.0 and 4.0 mg/g for these respective waters, the above precipitation rates are equivalent to 17.5, 5.7 and 2.0 mg of dry matter/cm^2/day. These are considerably higher than our results. Part of this discrepancy may be due to the more polluted and eutrophic conditions in Osaka Bay than in the Bingo-nada region.

Since annual sedimentation rate expressed in terms of thickness is useful for practical purposes, it was calculated from the all-seacon mean of the precipitation rate. The sedimentation rates of 10.6 and 4.6 mm/year were obtained respectively for Sts. 2 and BG-1 according to the equation of Koyama et al.[13)] on the assumption that the trap catches did not contain resuspended sediment material and that they would pile up to form a sediment column with a moisture content of 72% and a specific gravity of 2.2 for the dry matter.

SUMMARY

Precipitation rates of particulate matter, as expressed in terms of dry weight and particulate phosphrus, were measured on 11 occasions at each of Sts. 2 and BG-1 in the central part of the Seto Inland Sea (water depths ca. 7 and 24 m, and 2 and 10 km from shore, respectively) during April 1975 – January 1977 with a sedimentation trap that does not require diving operations (collecting area 107.5 cm^2; exposure period 1 or 2 days). On the overall average, 0.98 and 0.42 mg of dry matter and 0.64 and 0.33 μg of P were found to precipitate onto each cm^2 of collecting area per day at the respective stations.

The foregoing daily precipitation corresponded on the average to 25.1 and 6.3% in terms of dry weight (7.3 and 2.5% in terms of particulate phosphorus) of the seston crop simultaneously present in the overlying water column at the respective stations. P content of the precipitates collected in the trap averaged 0.072%, or only 1/3 of the average P content of the seston. The loose uppermost layer of muddy sediment showed the P content similar to, and the chlorophyll *a* content lower than the precipitates in the trap.

It was preliminarily estimated that the bottom sediment augments in thickness by 10.6 and 4.6 mm per year at the respective stations.

Geographical and seasonal variation in the precipitation rates and the possibility of resuspended sediment particles to be collected in the trap were discussed.

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富栄養海域における新生沈殿物量とその性状からみたリンの動態

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湖沼に比べて海域でのリン沈積速度の実測例は多くない。浅海の海水・底土間のリン循環を検討するため，潜水作業を要しない沈降物捕集装置（Fig. 1）を考案し，瀬戸内海備後灘で1975年4月～1977年1月の約2年間にわたって沈積速度（1日1㎠当りの乾重量（DW）および粒子態リン（PP）の沈降量）を測定した。捕集された沈降物の性状（リン含有率，chl.a 含有率など）を同時に採取した海水中懸濁物（セストン）および底土最表層部の性状と比較し，また水中懸濁量と沈積量とを比較して，リンの動態を考察した。

1. 特別に高い捕集値を除くと，沈降量の平均は，DWでは，水深の浅い岸寄りのSt. 2で0.98，沖側のSt. BG－1で0.42㎎/㎠/day となった。PPではそれぞれ0.64，0.33μg/㎠/dayであった（Table 2）。

2. 季節別にみると，沈降量は概ね5～10月の高水温期に大きく，11～4月の低水温期に小さい。両期におけるDWの平均沈降量はSt. 2で1.26および0.60㎎/㎠/day，St. BG－1で0.83および0.11㎎/㎠/day で，低水温期のSt. BG－1 で特に低かった。これらは，水柱中での粒子態有機物生産や，流入陸水が搬入する陸源の土粒子量などの季節変化を反映したものと考えられた（Table 2）。

3. 水中懸濁物のリン含有率（乾重比）に比べ，沈降物のそれは格段に低いことが特徴であり，平均で，0.21％対0.072％であった。従って，水中懸濁物は，沈降物（いわゆる新生堆積物）として捕集されるまでの過程で，7割近いリンを溶存態として海水中に放出していたことになる（Fig. 3）。

4. 底土最表層部の試料は，5～65日間の沈降量に相当する厚さを採取して用いたが，そのリン含有率は沈降物と差がなく，両者のリン含有率の季節変化もほぼ一致した（Fig. 2，Table 3）。一方，chl.a含有率は底土最表層よりも沈降物で高かった（Fig. 3）。

5. 水柱中の懸濁量に対する1日間沈降量の割合は，平均で，リンの場合7.3（St. 2）および2.5％（St. BG－1）であった。DWの場合には地点間の差が大きく，25.1（St. 2）および6.3％（St. BG－1）であり，St. 2ではDW沈降量が懸濁物に対して顕著に高い割合を示した（Table 2）。

6. 水中懸濁物のリン含有率の鉛直的変化，沈降物のリン・chl.a 含有率，捕集物の予備的検鏡結果などから，PPの沈積には，デトリタス状物質の凝集大型化および動物プランクトン等による糞塊生成作用が重要な役割りを果すと推測された。

7. 水柱中の懸濁物が新生堆積物となるまでに海水中に放出するリン量（即ち沈降過程における粒子態リンから溶存態リンへの移行量）を上記の3と5の結果から計算し，St. 2で0.43～5.3，St. BG－1で0.07～0.3μgP/㎠/dayの値を得た（Fig. 4）。

8. 上記1の平均値にもとずき，一定の仮定を設けて堆積速度を厚さで試算したところ，St. 2で10.6㎜/yr，St. BG－1で4.6㎜/yrとなった。実際には，捕集器中への再懸濁物の混入，堆積後の溶出を多少とも見込む必要があるので長期的に見た底土の堆積速度はこれをやや下まわると推定される。