

# Monosaccharide composition of marine particles and sediments from the Bering Sea and northern North Pacific

Monosaccharide composition  
Suspended particles  
Sinking particles  
North Pacific  
Bering Sea

Composition en monosaccharides  
Particules en suspension  
Particules en voie de sédimentation  
Pacifique Nord  
Mer de Béring

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## ABSTRACT

Phytoplankton, suspended particles, sinking particles and bottom sediments were collected from the Bering Sea and northern North Pacific. These samples were analyzed for neutral monosaccharides by gas chromatography after acid hydrolysis. Several distinctive features of monosaccharide composition of these marine samples were discerned:

- 1) Glucose was the most abundant monosaccharide in most of the marine samples and accounted for more than 70% of total particulate carbohydrate, especially in the suspended particles from deep waters.
- 2) Relative abundances of fucose, rhamnose, ribose, arabinose and galactose in the suspended particles decreased with depth, resulting in only trace amounts of fucose, rhamnose and ribose in the suspended particles from deep waters.
- 3) Monosaccharide composition of the sinking particles is essentially similar to those of the phytoplankton and suspended particles of the surface waters collected at the site where the sediment trap experiment was conducted. However, no extensive increment of glucose abundance with no decrements of deoxyhexoses, some pentoses and galactose abundances were evident throughout the sinking particles collected from the surface to deep waters.
- 4) Increased relative abundances of fucose, rhamnose and galactose were found in the bottom sediments as compared with those of the sinking particles and the suspended particles from deep waters.

The fate of carbohydrates during particles sedimentation is discussed on the bases of deoxyhexoses, pentoses and hexoses (DPH) composition, and hexoses composition of phytoplanktons, suspended particles, sinking particles and bottom sediments, indicating that sinking particles exclusively play an important role to transport carbohydrate from the surface to the deep waters and deep ocean floor. These processes must be extremely favorable to the biological organisms inhabiting in the deep waters and sediments.

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## RÉSUMÉ

Composition en monosaccharides des particules en suspension et des sédiments de la Mer de Béring et du Pacifique Nord septentrional

Du phytoplancton, des particules en suspension, des particules en voie de sédimentation et des sédiments du fond de la Mer de Béring et de la partie septentrionale de l'Océan Pacifique Nord ont été prélevés. Dans ces échantillons, les monosaccharides neutres ont été analysés par chromatographie en phase gazeuse après hydrolyse par acide sulfurique. Plusieurs caractéristiques de la composition en monosaccharides des échantillons ont été mises en évidence :

- 1) Le glucose est, sauf exceptions, le plus abondant dans tous les échantillons, et représente plus de 70% de glucides particulaires totaux, en particulier dans les particules en suspension dans les eaux profondes.

2) L'abondance relative en fucose, rhamnose, ribose, arabinose et galactose dans les particules en suspension diminue avec la profondeur; fucose, rhamnose et ribose ne figurent qu'à l'état de traces dans les particules en suspension dans les eaux profondes.

3) La composition en monosaccharides des particules en voie de sédimentation est largement comparable à celle du phytoplancton et des particules en suspension dans l'eau de surface où sont utilisés des pièges à particules. Toutefois, on n'a observé aucune augmentation en glucose ni diminution en déoxyhexose, mais seulement un peu de pentose et galactose dans toutes les particules en voie de sédimentation recueillies de la surface au fond.

4) Une augmentation relative en fucose, rhamnose et galactose a été observée dans les sédiments du fond par rapport aux particules en voie de sédimentation et aux particules en suspension dans les eaux profondes.

Au cours de la sédimentation des particules, l'évolution des glucides est spécialement observée. Elle montre le rôle essentiel des particules en voie de sédimentation dans le transport des glucides de la surface à l'eau de profondeur et dans les fonds abyssaux, à partir de la composition en déoxyhexoses, pentoses et hexoses (DPH) et la composition en hexoses des phytoplanctons, des particules en suspension, des particules en voie de sédimentation et des sédiments profonds. Ces processus se révèlent extrêmement favorables aux organismes vivant dans l'eau et le sédiment profonds.

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## INTRODUCTION

Carbohydrates are one of the main constituents of marine phytoplankton (Handa, 1967; Hecky *et al.*, 1973; Haug, Myklestad, 1976) and are produced during photosynthesis by phytoplankton growing in the euphotic layer of the oceans (Handa, 1975; Hitchcock, 1978). When phytoplankton is placed in the dark, some of the carbohydrate is rapidly respired (Handa, 1969; Liebezeit, 1984) while some is excreted to the surrounding medium as dissolved carbohydrate (Ittekkot *et al.*, 1982; Lancelot, 1984). These processes result in extensive changes in the monosaccharide composition of the phytoplankton.

Recently, it has been reported that carbohydrates are rapidly transported to the mid-depth and deeper waters from the euphotic layer by the sinking of large particles (sinking particles; Ittekkot *et al.*, 1984 *a*; *b*). These sinking particles consist of fecal pellets (Lisitzin, 1972; Honjo, 1976; Bishop *et al.*, 1977), phytodetritus (Billett *et al.*, 1983) and "marine snow" (Silver *et al.*, 1978; Alldredge, 1979), as shown by the composition of the lipid materials (Tanoue, Handa, 1980; Wakeham *et al.*, 1980; DeBaar *et al.*, 1983) and amino acids (Wakeham *et al.*, 1980; Lee, Cronin, 1982; Lee *et al.*, 1983). The sinking particles from the mid-depth and deeper waters have also been analyzed for carbohydrates. The monosaccharide composition on these particles is governed primarily by cell wall polysaccharides of phytoplankton living in the euphotic layer (Ittekkot *et al.*, 1984 *a*). Considering the rapid microbial decay of algal polysaccharides (Handa, 1970; Matsunaga, 1981), phytoplankton and suspended particles from the surface waters probably show extensive changes in their monosaccharide composition and carbohydrate content during sedimentation.

The aims of the present study are, first, to identify the features of monosaccharide composition characteristic

of phytoplankton, suspended particles, sinking particles and bottom sediments collected from the Bering Sea and northern North Pacific, and second, to clarify the fate of the carbohydrate associated with the phytoplankton and the suspended particles from the surface waters during sedimentation.

## MATERIALS AND METHODS

### Sample

Samples were collected from the Bering Sea and northern North Pacific by the cruises of R/V Hakuho Maru in 1975 (KH-75-4) and 1978 (KH-78-3) (Fig. 1). Phytoplankton samples were collected at stations 7 and 11, and station 30 located in the Bering Sea in KH-75-4 and the northern North Pacific in KH-78-3 respectively, by vertical haul of a Norpac net (GG-54, 0.32 mm mesh) in the water layers from the surface to the depth of 100 m.

Suspended particles were obtained by filtration of water samples collected from various depths through glass fiber filter (Whatman GF/C), which was precombusted at 450°C for 4 hrs.

Sinking particles were collected by sediment trap system (Tanoue, Handa, 1980) at station 3 (47°51.1'N, 176°20.6'E, 5300 m deep) during the cruise of R/V Hakuho Maru to the northern North Pacific in 1978. Each sediment trap consisted of six polyvinyl chloride (PVC) cylinders (25 cm id × 60 cm high) with the lids operated by a time releaser.

Bottom sediments were collected with Okean type grab sampler at stations 14 and 19 of KH-75-4 and station 3 of KH-78-3. A piston corer was used to collect sediment samples from stations 7 and 11 of KH-75-4. All samples were kept frozen at -20°C until analysis.

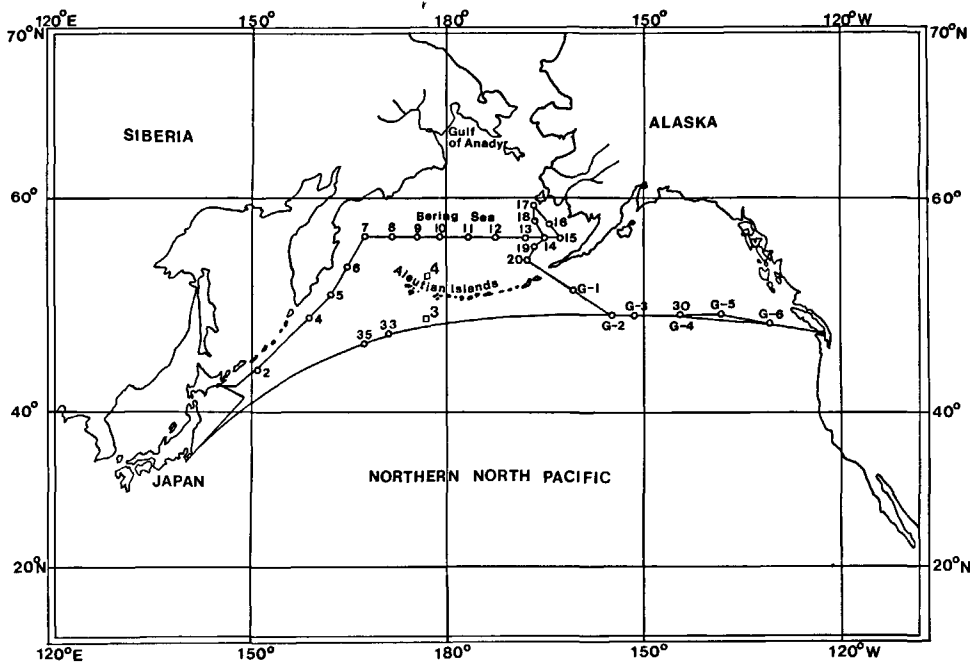


Figure 1

The track chart of R/V Hakuho Maru in 1975 (KH-75-4). Each of the numbers represent the station occupied. Stations 3 and 4 represented in were occupied in the cruise conducted in 1978 (KH-78-3).

## Chemical analysis

### Organic carbon analysis

A glass fiber filter (Whatman GF/C) with suspended particles was left in an aquarium filled with HCl vapour for 1 hour to remove carbonate materials, dried in an oven for 2 hours at 80°C and then analyzed for organic carbon by CHN-Corder, Yanaco MTS-2.

Sinking particles and bottom sediment were treated with 0.6 N HCl overnight at room temperature to remove carbonate materials, washed with distilled water several times until the washings became neutral and then dried in an oven at 110°C overnight. The dried materials and combined washings were analyzed for organic carbon separately by the dry combustion method using the CHN-Corder and the wet combustion method (Menzel, Vaccaro, 1964), respectively. The organic carbons of the dried materials and washings were combined for the determination of total organic carbon of the sinking particles and the bottom sediments.

### Monosaccharide analysis

Monosaccharide composition was determined by gas chromatography upon acid hydrolysis of the phytoplankton, suspended particles, sinking particles and bottom sediment separately. Analytical procedures were described elsewhere (Handa, Tominaga, 1969).

Prior to the monosaccharide analysis, the sinking particles were treated with chloroform-methanol (2/1, v/v) to extract lipid materials and then filtered through a precombusted glass fiber filter (Whatman GF/C) as reported previously (Tanoue, Handa, 1980). The resulting glass fiber filter was dried to remove organic solvents and then analyzed for monosaccharides as stated before. The chloroform-methanol extract was washed with one half portion of distilled water thrice. Combined washings were evaporated to a small volume, which

was transferred to the glass fiber filter and subjected to the carbohydrate analysis.

### Gas chromatography

Analyses of the alditol acetates were performed by gas chromatography (Yanaco Model G-8) equipped with flame ionization detector under the conditions as follows: glass column (1.5 m length  $\times$  3 mm inner diameter) packed with 3% ECNSS-M on Gas Chrom Q (100-200 mesh); carrier gas, nitrogen (flow rate of 30 ml/min.); oven temperature, 120-210°C programmed at 2°C/min.; injection port temperature, 300°C; detection port temperature, 280°C.

## RESULTS

### Phytoplankton

Phytoplankton samples were collected from the surface and subsurface waters of stations 7 and 11, and station 30 of the cruise of KH-75-4 and KH-78-3, respectively. Phytoplankton samples from these stations consisted of exclusively diatom (Furuya *et al.*, 1979), but some dinoflagellates were also detected in the phytoplankton sample from station 30.

Carbohydrate carbon accounted for 7.9-8.4% of total organic carbon of the phytoplankton samples. These values were not much different from those obtained by phytoplankton samples in the northern North Pacific (Handa, Yanagi, 1969). Glucose was a predominant monosaccharide component of the samples (Tab. 1), while mannose was one of the major monomeric components of carbohydrate of the phytoplankton, however its relative abundance was variable depending on the samples. Xylose was abundant in the sample of station 11, whereas rhamnose, fucose, ribose and arabinose were minor monosaccharide components of the phytoplankton samples from these stations.

Table 1

Monosaccharide composition of phytoplankton collected from the surface waters by the plankton net (GG 54, 0.32 mm mesh) during the cruise of R/V Hakuho Maru in 1975 (KH-75-4) and in 1978 (KH-78-3).

Stations	7	11	30
Sample No.	1	2	3
		Mol. %	
Rhamnose	1.18	3.46	4.49
Fucose	2.14	6.53	2.32
Ribose	2.64	3.63	8.67
Arabinose	8.74	5.32	1.57
Xylose	1.90	16.7	3.32
Mannose	38.6	18.7	8.00
Galactose	4.94	9.35	13.2
Glucose	39.8	36.4	58.4
HCHO-C/TOC* (%)	8.55	8.38	7.93

\* Total organic carbon of phytoplankton.

Table 2

Monosaccharide composition of the suspended particles from the Bering Sea and northern North Pacific during the cruise of R/V Hakuho Maru in 1975 (KH-75-4).

Areas	Bering Sea					Northern North Pacific		
	Deep Bering Sea		Continental shelf					
Stations	9, 10, 11	9, 10, 11	12, 16, 17, 19	12, 19	19	30	30	30
Depths (m)	0-175	1750-3500	0-50	50-80	100-130	0-200	200-1750	2000-4000
Number of the samples combined	25	13	17	5	2	10	9	6
Total volume of water samples (l)	230	152	74	78	35	405	318	208
Sample No.	4	5	6	7	8	9	10	11
		Mol. %						
Rhamnose	6.24	1.55	3.01	6.31	5.02	3.91	5.91	tr.*
Fucose	19.1	7.03	3.33	7.81	5.37	5.21	tr.	tr.
Ribose	2.42	tr.	tr.	tr.	tr.	5.56	4.46	tr.
Arabinose	5.71	3.23	5.68	2.00	6.87	2.60	5.35	2.77
Xylose	3.90	2.55	2.80	5.74	11.0	2.34	7.15	5.22
Mannose	20.8	19.0	14.5	5.80	8.11	26.9	5.91	6.98
Galactose	5.48	1.25	5.39	7.14	10.6	12.6	2.35	2.18
Glucose	36.2	65.4	65.3	65.2	53.0	40.9	68.9	81.5
HCHO-C ( $\mu\text{gC l}^{-1}$ )	85.0	26.6	26.3	11.5	11.1	6.00	5.30	2.70
HCHO-C/POC (%)	10.4	7.33	13.5	8.10	9.51	8.30	11.0	8.73

\* tr. : Trace.

Table 3

Monosaccharide composition of the particulate matter collected at station 3 of the northern North Pacific during the cruise of R/V Hakuho Maru in 1978 (KH-78-3).

Depth (m)	0	10	20	500	2500
Sample No.	12	13	14	15	16
		Mol. %			
Rhamnose	7.75	5.29	4.17	1.73	tr.
Fucose	4.04	2.48	4.28	tr.	tr.
Ribose	2.68	4.78	4.45	ND*	ND
Arabinose	5.67	7.08	3.92	1.29	2.05
Xylose	10.0	15.4	6.23	11.3	3.80
Mannose	18.5	9.39	11.4	7.93	18.2
Galactose	13.7	9.62	14.2	5.10	2.50
Glucose	37.5	45.9	48.0	72.6	73.4
HCHO-C ( $\mu\text{gC l}^{-1}$ )	8.38	20.1	21.1	1.47	1.62
HCHO-C/POC (%)	12.9	12.5	13.0	6.59	6.59

\* ND: Not detected.

## Suspended particles

Suspended particles from different depths were combined to obtain sufficient amounts of carbohydrate to analyze on the basis of the distribution profiles of chlorophyll *a* and C/N values of the suspended particles (Tanoue, Handa, 1979).

Carbohydrate concentration and monosaccharide composition of the suspended particles varied regionally, but the ratio of carbohydrate carbon (HCHO-C) to total organic carbon (TOC) of the suspended particles did not change substantially with depth and space (Tab. 2).

Glucose was extremely abundant in monosaccharide components of the carbohydrate in the suspended parti-

cles from the deep waters. Mannose was also abundant in the samples from the surface and subsurface waters as observed in the samples No. 4, 6 and 9, but not in the samples from the intermediate through deep waters. The suspended particles from the deep water of the deep Bering Sea were abundant in mannose, but this might be a special case for the reasons mentioned later. Rhamnose, fucose, ribose, arabinose, xylose and galactose were minor monosaccharide components throughout the samples. Fucose, however, accounted for 19% of the carbohydrate in the sample No. 4 from the surface and subsurface waters of the deep Bering Sea.

Suspended particles from the surface to deep waters at station 3 of the northern North Pacific in the cruise of KH-78-4 were analyzed for carbohydrate and organic carbon (Tab. 3). The carbohydrate concentration tended to decrease from the euphotic layer to the deep

waters with a steep gradient, resulting in the vertical decrease in HCHO-C/TOC value.

A marked difference was found in the monosaccharide composition between the suspended particles from the euphotic and deep waters. Glucose accounted for 38-48% of the total carbohydrate in the suspended particles from the euphotic layer, while a much higher relative abundance of glucose was found in the samples from the deep waters. Galactose, mannose and xylose were also abundant, but their percentages to total carbohydrate varied with the depth. Pentoses and deoxyhexoses were only minor monosaccharide components of the suspended particles from the surface through deep waters. Only trace amounts of rhamnose and fucose were measured in the suspended particles from 2 500 m depth.

Suspended particles collected at station 4 of the Bering Sea were analyzed for carbohydrate (Tab. 4). The carbohydrate concentration decreased with depth as observed at station 3 of the northern North Pacific, while HCHO-C/TOC increased slightly with depth.

Table 4

Monosaccharide composition of the particulate matter collected at station 4 of the Bering Sea during the cruise of R/V Hakuho Maru in 1978 (KH-78-3).

Depth (m) Sample No.	1 17	50 18	110 19	177 20	500 21	2000 22
	Mol. %					
Rhamnose	6.98	6.10	4.00	2.96	1.10	0.65
Fucose	4.09	3.04	1.70	1.38	1.22	0.95
Ribose	tr.	1.86	tr.	tr.	ND	ND
Arabinose	2.14	2.03	1.98	1.52	1.62	tr.
Xylose	4.64	3.44	5.39	10.1	8.21	8.21
Mannose	12.3	11.0	6.26	9.72	16.7	3.85
Galactose	11.0	10.0	10.7	10.5	2.84	1.09
Glucose	58.8	62.5	70.0	63.8	68.3	85.2
HCHO-C ( $\mu\text{gC l}^{-1}$ )	6.78	4.56	1.47	1.86	2.14	3.46
HCHO-C/POC (%)	5.20	7.91	6.92	7.74	9.54	10.9

Glucose was the most abundant among the monosaccharide components of the suspended particles from the depths of 1 through 2000 m as observed in the northern North Pacific. Galactose and mannose were a little abundant in the surface and subsurface waters, while these values decreased with depth. Increased values of xylose were found in the suspended particles from the deep waters relative to those from the euphotic layer, while pentoses and deoxyhexoses were only minor monosaccharide components. Only trace amounts of deoxyhexoses, ribose and arabinose were found in the suspended particles from 2000 m depth.

#### Sinking particles

Sinking particles collected at station 3 in the northern North Pacific were analyzed for monosaccharide components (Tab. 5). The carbohydrate and HCHO-C/TOC of the sinking particles exhibited no significant vertical variability. Flux of HCHO-C ranged from 0.24 to 0.51  $\text{mgC m}^{-2} \text{day}^{-1}$ , which was almost comparable with the range found in the Panama basin by Ittekkot *et al.* (1984).

Glucose, galactose, mannose and xylose were major monosaccharide components of these particles

Table 5

Monosaccharide composition of the sinking particles collected from the depths of 100 to 5250 m at station 3 in the northern North Pacific.

Depth (m) Sample No.	100 23	1 100 24	2200 25	4400 26	5250 27
	Mol. %				
Rhamnose	8.74	18.9	9.05	9.74	9.97
Fucose	6.16	8.28	3.78	4.85	2.57
Ribose	5.71	1.37	1.63	3.14	3.36
Arabinose	4.95	8.87	4.21	7.42	9.50
Xylose	35.6	8.21	9.70	17.7	22.0
Mannose	23.2	17.9	14.8	20.0	35.0
Galactose	4.99	18.1	23.6	13.9	4.95
Glucose	10.7	24.3	33.2	23.2	12.7
HCHO-C [ $\text{mgC}(\text{g dry sed.})^{-1}$ ]	6.21	4.74	2.92	3.28	4.60
HCHO-C/TOC* (%)	10.1	7.01	8.39	8.13	8.52
Flux:					
POC ( $\text{mgC m}^{-2} \text{day}^{-1}$ )	—	7.27	7.30	2.70	2.38
HCHO-C ( $\text{mgC m}^{-2} \text{day}^{-1}$ )	—	0.51	0.65	0.25	0.24

\* Total organic carbon.

throughout the depths with some exceptions. The abundance of such monosaccharide components in the sinking particles is much different from those of the suspended particles collected in the Bering Sea and northern North Pacific. Ribose, arabinose and deoxyhexoses were relatively minor monosaccharide components as observed in the suspended particles, although a rather higher rhamnose level was observed in the sinking particles from the depth of 1 100 m.

#### Bottom sediments

Sedimentary samples collected from the Bering Sea and the northern North Pacific were analyzed for carbohydrate (Tab. 6). The carbohydrate concentration of the bottom sediment was much lower than those of the sinking particles, while HCHO-C/TOC of the bottom sediments was obviously lower than that of the suspended particles.

The most notable feature of the monosaccharide composition of the bottom sediments as compared with those of the suspended particles and the sinking particles is the considerably low relative abundance of glucose, which results in the increase in those of galactose, mannose, pentoses and deoxyhexoses. Only trace amounts of ribose were detected in all of the sedimentary samples. This is another distinctive feature of the monosaccharide composition of the samples of bottom sediment.

## DISCUSSION

#### Features of monosaccharide components

Eight neutral monosaccharides were identified in the phytoplankton, suspended and sinking particles and bottom sediments collected from the Bering Sea and northern North Pacific upon acid hydrolysis. The main features of the monosaccharide composition of these samples are as follows: 1) Glucose was the most abundant monosaccharide component of all of these samples, while this monosaccharide shows rather less rela-

Table 6

Monosaccharide composition of the sedimentary samples from the Bering Sea and northern North Pacific during the cruises of R/V *hakuho Maru* in 1975 (KH-75-4) and 1978 (KH-78-3).

Stations	7*					11*				14**	19**	3***
	0-5	20-25	172-177	55-60	110-115	391-396	461-466	809-814				
Depth from the top of the core sampler (cm)												
Sample No.	28	29	30	31	32	33	34	35	36	37	38	
						Mol. %						
Rhamnose	12.0	13.2	11.7	9.48	8.72	8.44	11.9	13.1	10.2	17.7	12.1	
Fucose	11.1	11.2	10.0	8.18	4.60	4.09	9.85	10.1	9.48	6.80	12.7	
Ribose	tr.	tr.	tr.	tr.	1.31	tr.	tr.	tr.	tr.	tr.	tr.	
Arabinose	7.04	10.1	9.23	12.4	12.1	12.1	10.5	11.4	8.32	15.4	11.6	
Xylose	9.33	10.2	11.4	14.2	24.2	21.6	15.6	12.4	9.08	18.8	12.1	
Mannose	12.5	11.6	11.9	11.2	11.7	11.6	13.0	13.2	7.38	11.6	10.7	
Galactose	20.6	18.9	18.3	23.4	15.9	16.0	18.2	18.1	15.1	13.1	18.5	
Glucose	28.5	24.8	27.3	21.1	21.5	26.2	20.9	21.6	20.5	16.5	22.4	
HCHO-C [mgC(g dry sed.) <sup>-1</sup> ]	0.62	0.60	0.65	0.59	0.67	0.94	0.96	0.72	0.73	0.78	0.90	
HCHO-C/TOC (%)	5.46	5.88	5.34	5.80	6.36	6.66	5.13	10.6	9.61	6.04	8.92	

\* Samples were collected by a core sampler in KH-75-4.

\*\* Samples were collected by a okean type grab sampler in KH-75-4.

\*\*\* Sample was collected by a okean type grab sampler in KH-78-3.

tive abundance in the sinking particles; 2) Mannose was one of the major monosaccharide components in the phytoplankton, suspended particles from the surface waters and sinking particles with some exceptions; 3) Relative abundances of fucose, rhamnose, ribose, arabinose and galactose in the suspended particles tended to decrease with the depth, while that of xylose was variable without any significant vertical trends; 4) A much higher value of the relative abundance of fucose and rhamnose was observed in the bottom sediments as compared with those of the suspended particles from the deep waters; 5) Only trace amounts of ribose were detected in the bottom sediment samples as well as the suspended particles from the deep waters. Low ribose abundance was found in the suspended particles even from the surface and subsurface waters in the Bering Sea.

Carbohydrates of diatoms can be divided into the following 3 groups in terms of the structural and biochemical functions; reserved polysaccharide consisting of glucose (Ford, Percival, 1965; Handa, 1969; Haug, Myklestad, 1976), cell wall polysaccharide(s) consisting of rhamnose, fucose, ribose, arabinose, xylose, mannose, galactose and glucose (Handa, Yanagi, 1969; Ikari, 1973; Haug *et al.*, 1973; Haug, Myklestad, 1976) and extracellular polysaccharides consisting of rhamnose, fucose and galactose with small amounts of xylose, mannose and galactose (Smestad *et al.*, 1975; Haug, Myklestad, 1976; Percival *et al.*, 1980). However, extracellular polysaccharides are assumed to be rapidly removed from the phytoplankton cells to disseminate in the ambient waters during the photosynthetic processes.

Dinoflagellates were found in the suspended particles from the surface water as minor phytoplankton population and consisted of the carbohydrate fractions with same monosaccharide composition as those of diatoms (Ikari, 1973).

The biochemical decay of these polysaccharides obeyed first order reaction kinetics. Reaction rate constants of

the reserved and cell wall polysaccharides were reportedly  $0.290 \text{ day}^{-1}$  for *Skeletonema costatum* (Handa, 1970) and  $0.005 \text{ day}^{-1}$  for mixed diatoms cultured in the laboratory (Matsunaga, 1981). Considering the half-lives of these polysaccharides and sinking rate of diatom particles, the reserved glucan will be thoroughly decayed before diatom particles reach deep water layers. Thus, it is most likely that cell wall polysaccharides of phytoplankton living in the surface waters are the most important source materials of the carbohydrate for the suspended particles of the deep waters, sinking particles and bottom sediments.

An increased relative abundance of glucose was found in the suspended particles from the deep waters. According to Haug *et al.* (1973), the cell wall polysaccharides of diatoms consist of alkali soluble heteropolysaccharides and alkali insoluble glucan. Judging from the solubility in alkali, the glucan is most likely a polysaccharide with the  $\beta$ -(1,4)- and  $\beta$ -(1,3)-linkages found in the cell wall of the dinoflagellate, *Peridinium westii* (Nevo, Sharon, 1969). Cellulose or cellulose-like glucan also is the most highly stable to the biological attack as compared to hemicellulose materials (Sowden, Ivarson, 1962; Hedges *et al.*, 1985). These facts suggest that rapid decay of the alkali soluble heteropolysaccharides due to biological agents leaves the alkali insoluble glucan. This results in the increased relative abundance of glucose in the suspended particles as observed in the deep waters of the Bering Sea and northern North Pacific. Glucose was rather less abundant in the sinking particles comparing to phytoplankton and suspended particles. This may be due to the rapid decay of reserved glucan and biological stabilities of the cell wall polysaccharides, both of which result in much less abundance of glucose in the sinking particles relative to phytoplankton and suspended particles from deep waters.

Mannose, which is abundant in the phytoplankton and the suspended particles from the surface waters, results

primarily from the glucuronomannan occurring in diatom (Ford, Percival, 1965). Cellular content of the glucuronomannan varied mainly with the growth phase (Haug, Myklestad, 1976) and species (Ikari, 1973) of diatoms, which may be the most important factors controlling the abundance of mannose in the suspended particles from the surface layers at station 3 of northern North Pacific. A high relative abundance of mannose was observed in the suspended particles from the deep waters of stations 9, 10 and 11 of the deep Bering Sea in KH-75-4. Considering the fact that the particulate organic carbon concentration in the deep waters of stations 9, 10 and 11 was several times higher than those at station 4 of the Bering Sea in KH-78-3, it is most likely that combined suspended particles from the deep waters of stations 9, 10 and 11 are more affected by phytodetritus which are rich in the cellular organic materials of diatoms than those of station 4. This resulted in the greater abundance of mannose in the suspended particles from the deep waters of the deep Bering Sea in 1975.

Sinking particles from 0.1 km depths showed a high relative abundance of mannose, which was presumably due to the sedimentation of the diatom cells abundant in glucuronomannan to the sediment traps. However, the high abundance of mannose in the sinking particles from 5.25 km depth may be due to the sedimentation of the phytodetritus which was produced in early spring, when diatom bloom used to occur in this oceanic area (Niebauer *et al.*, 1981). Seasonal pulse of detrital materials to abyssal depth was found in April to July but not in other season in the North-Eastern Atlantic (Billett *et al.*, 1983).

These findings distinctively indicate that seasonality in the particulate flux to the deep ocean commonly occurs in the world ocean as reported in the Sargasso Sea (Deuser, Ross, 1980; Deuser *et al.*, 1981) and Panama Basin (Honjo, 1982).

Relative abundances of rhamnose, fucose, ribose, arabinose and galactose of the suspended particles tended to decrease sharply with depth, while that of glucose tended to increase with depth. These findings indicate that alkali soluble heteropolysaccharide(s) consisting of these monosaccharides are much more susceptible to biological agents than alkali-insoluble glucan, as stated before. The relative abundance of mannose also tended to decrease with depth, but a significant amount of mannose was observed even in the suspended particles from the deep waters, clearly indicating that glucuronomannan can survive much longer than alkali-soluble heteropolysaccharide(s).

The relative abundance of xylose is rather variable. Xylose may not be so much susceptible to the biological agents as monosaccharide constituents of the alkali-soluble heteropolysaccharide(s), because the concentration of xylose in the suspended particle did not change so much vertically at station 30 (KH-75-4) and 4 (KH-78-3), although those values at station 3 (KH-78-3) varied in terms of the depth of the sample collection.

Fucose accounted for 19% of total carbohydrate in the combined suspended particles from the surface and subsurface waters of stations 9, 10 and 11, where *Thalassiosira* sp. was most abundant among the phytoplankton community (Ishimaru, Nemoto, 1977). Handa, Yanagi (1969) found that fucose was abundant in the hydrolysate of the suspended particles from the surface waters of the northern North Pacific off the Aleutian Islands where the phytoplankton community was dominated by the diatom, *Thalassiosira* sp. Later, Ikari (1973) and Haug and Myklestad (1976) reported that fucose was one of the main monosaccharide constituents of the cell wall polysaccharide(s) of *Thalassiosira* sp., *Skeletonema* sp. and *Corethron* sp. In view of these facts, it is most likely that the high fucose content in the suspended particles of the surface and subsurface waters at stations 9, 10 and 11 may largely be due to the abundance of *Thalassiosira* sp.

Fucose was not abundant in the suspended particles from the continental shelf and northern North Pacific areas. This may be due to diatoms consisting of *Chaetoceros* sp., *Coscinodiscus* sp., *Denticula* sp. and *Melosira* sp., because analytical data on these diatoms reportedly indicate no preferential occurrence of fucose in their cellular carbohydrates (Parsons *et al.*, 1961; Handa, Yanagi, 1969; Ikari, 1973; Haug, Myklestad, 1976).

Distribution of ribose in diatom cells is mostly confined to RNA and water soluble carbohydrates which are readily degraded by microbial organisms in natural water and sediment environments (Cranwell, 1976), but not to cell wall carbohydrates (Hecky *et al.*, 1973), which are fairly resistant to microbial attack (Matsunaga, 1981). Thus, such a rapid decay of cellular RNA and water soluble carbohydrates of phytoplankton most likely results in only trace amounts of ribose in the suspended particles from the deep waters and bottom sediment. Such less abundance of ribose is also suggested that these samples are much less contaminated by bacteria because of abundant occurrence of this monosaccharide in bacteria (Cowie, Hedges, 1984).

#### Fate of carbohydrate during particle sedimentation

Percentage composition of deoxyhexoses, pentoses and hexoses (DPH composition) for phytoplankton, suspended particles, sinking particles and bottom sediments from the Bering Sea and northern North Pacific was plotted in a triangular diagram to understand more clearly the fate of the carbohydrate of phytoplanktons during the course of its sedimentation.

Figure 2 indicates that DPH compositions of phytoplankton from the surface waters distribute closely in relation to those of the suspended particles from the euphotic layers, while DPH compositions of the suspended particles from the deep waters are much different from those of phytoplankton with an increase in the relative abundance of hexose but a decrease in those of deoxyhexose and pentose. Sinking particles are also characterized by low hexose abundance and high deoxyhexose and pentose abundances relative to

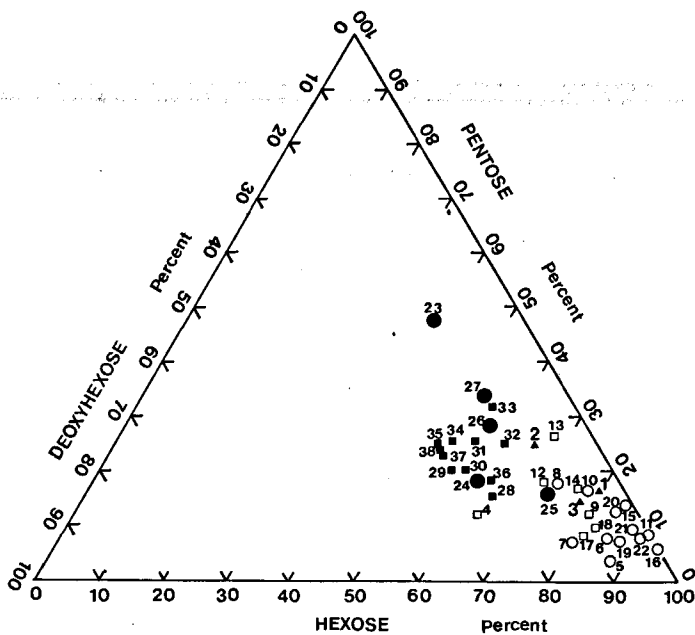


Figure 2  
Hexose-pentose-deoxyhexose composition of the phytoplankton (▲), suspended particles from the euphotic layer (□) and deep waters (○), sinking particles (●) and bottom sediments (■) collected in the Bering Sea and northern North Pacific.

those of phytoplankton. Their feature of the DPH composition resemble closely those of phytoplanktons and bottom sediments, although the DPH composition of sinking particles shows a wide range of variation.

The hexose composition of phytoplankton, suspended particles and sinking particles and bottom sediments give more clear indications for the fate of carbohydrates during the course of the sedimentation of phytoplankton and suspended particles from the surface waters. Figure 3 shows that the phytoplankton and suspended particles from the surface waters tend to change their hexose composition in two ways in the marine environment. One is by the increase in the relative abundance of glucose with the decrease in the abundances of mannose and galactose. This tends to change hexose composition of the suspended particles from the surface waters to that of these particles from the deep waters, of which carbohydrate consisted of largely cellulose-like glucan most likely derived from diatoms and/or dinoflagellates (Nevo, Sharon, 1969; Haug, Myklestad, 1973) with removal of water and alkali soluble glucan and heteropolysaccharides from the suspended particles due to mainly biological degradation. Cellulose from wood fiber is also considered for the amplification of this trend because of the terrestrial supply of plant debris which may be significant in this oceanic area. Another is by the increments of the relative abundance of fucose, rhamnose and galactose as observed in the bottom sediments. This type of transformation of marine plant polysaccharides of the sinking particles is almost similar with that of the transformation of terrestrial plant polysaccharides as observed in micro-biological degradation of the polysaccharides in soil (Oades *et al.*, 1971; Cheshire *et al.*, 1973). Sinking particles from 0.1 and 5.25 km depths (sample numbers 23 and 27, respectively) were rich in mannose

as shown in Figure 4. However, degradation of glucuronomannan will change the hexose composition of these sinking particles to those of the bottom sediment.

From these findings of DPH and hexose compositions, it can be seen that the carbohydrates of the sinking particles are intermediary substances between those of the suspended particles from the surface waters including phytoplankton, and bottom sediments. DPH and hexose compositions of the suspended particles from the deep waters are much different from those of the suspended particles from the surface waters, sinking particles and bottom sediments, indicating that the suspended particles from the deep waters do not play so significant role for the vertical transport of carbohydrates from the surface waters to the deep ocean floor.

CHO-C/TOC of the sinking particles is a range of 8.13-10.1% (Tab. 5), which are less than twice as much as those of the bottom sediments (Tab. 6). However, concentrations of carbohydrate in the sinking particles are almost 10 times higher than in the bottom sediments. These findings simply suggest that the sinking particles have an important role in supplying organic materials which are fully available for the biological organisms inhabiting in the deep waters and bottom sediments.

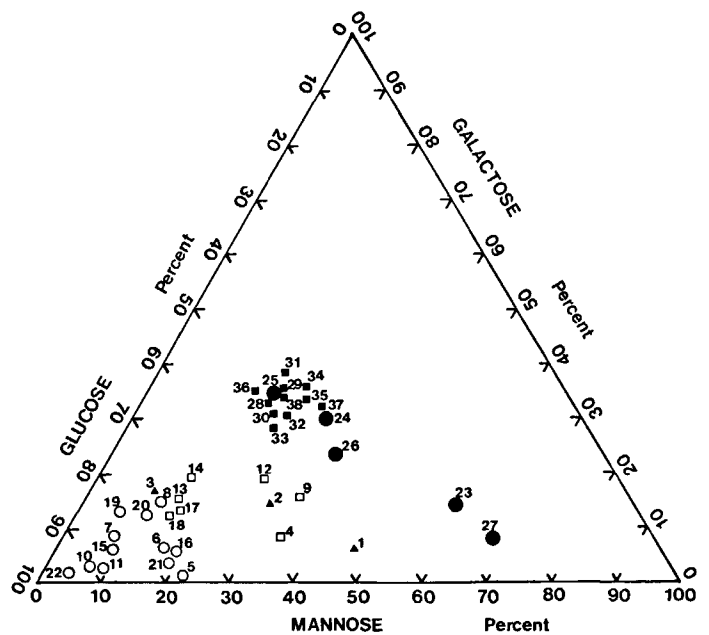


Figure 3  
Glucose-galactose-mannose composition of the phytoplankton (▲), suspended particles from the euphotic layer (□) and deep waters (○), sinking particles (●) and bottom sediments (■) in the Bering Sea and northern North Pacific.

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