Monosaccharide composition
Suspended particles
Bacteria
River runoff
Bay of Bengal

Composition en monosaccharides
Particules en suspension
Bactérie
Décharge fluviale
Golfe du Bengale

# Monosaccharide composition of suspended particles from the Bay of Bengal

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ABSTRACT

Neutral carbohydrates were determined as alditol acetates by capillary gas chromatography in the hydrolysates of suspended particulate samples (40) collected from 8 depths (~1 to 1,000 m) at 5 stations of the Bay of Bengal. Eight individual sugars *viz.* rhamnose, fucose, ribose, arabinose, xylose, mannose, galactose and glucose were identified in the hydrolysates of suspended particulate samples. Amongst these, glucose, mannose and galactose were the most abundant monosaccharides. Rhamnose, fucose, ribose, arabinose and xylose showed large variations and were generally abundant at greater depths (>100 m). Glucose contribution to the total carbohydrates, especially at higher depths (>100 m) was relatively less than that reported from other areas.

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RÉSUMÉ

Composition en monosaccharides des particules en suspension du golfe du Bengale

Les hydrocarbones neutres (acétate d'alditol) ont été analysés dans les particules en suspension de 40 échantillons prélevés à huit profondeurs (entre 1 et 1 000 m) en cinq stations du golfe du Bengale. Après hydrolyse et chromatographie capillaire en phase gazeuse, huit sucres ont été identifiés : rhamnose, fucose, ribose, arabinose, xylose, mannose, galactose et glucose. Parmi eux, le glucose, le mannose et le galactose sont les monosaccharides les plus abondants. Rhamnose, fucose, ribose, arabinose et xylose sont très variables, généralement abondants aux profondeurs supérieures à 100 m. La contribution de glucose aux hydrocarbones totaux est relativement inférieure aux valeurs citées dans la littérature, surtout au-delà de 100 m de profondeur.

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## INTRODUCTION

Very little is known about the distribution of organic matter and its constituent fractions including carbohydrates, proteins and lipids from the Indian Ocean in general and the Bay of Bengal in particular. The few earlier studies are restricted to the distribution of particulate organic carbon and total particulate carbohydrates (Bhosle *et al.*, 1981; 1989*a*; Nandakumar *et al.*, 1987). Nothing is known about the monosaccharide composition of particulate carbohydrates of the Bay of Bengal.

Carbohydrates are common structural and storage polysaccharides of marine and terrestrial organisms. They are also an important constituent of dissolved (Walsh and Douglass, 1966; Liebezeit *et al.*, 1980; Mopper *et al.*, 1980; Ittekkot *et al.*, 1981; Ittekkot, 1982; Dhople and Bhosle, 1987) and particulate matter (Handa and Tominaga, 1969; Handa and Yanagi, 1969; Hitchcock, 1977; Ittekkot *et al.*, 1982; Cowie and Hedges, 1984; Liebezeit, 1984; Romankevich, 1984; Thurman, 1985; Tanoue and Handa, 1987; Bhosle and Wagh, 1989). The concentration and composition of particulate carbohydrates (PCHO) of suspended particles collected by conventional sampling bottles (Handa and Tominaga, 1969; Handa and Yanagi, 1969; Ittekkot *et al.*, 1982; Liebezeit, 1984; Tanoue and Handa, 1987; Bhosle and Wagh, 1989) and sedimenting particles intercepted by sediment traps (Cowie and Hedges, 1984; Ittekkot *et al.*, 1984*a*; *b*; Liebezeit, 1987; Tanoue and Handa, 1987; Bhosle *et al.*, 1989*b*) change as the particles sink to greater depth. The observed decrease

has been attributed to be due to respiration of reserve polysaccharide and/or heterotrophic uptake (Handa, 1967; Handa and Tominaga, 1969; Tanoue and Handa, 1987).

In this paper, the monosaccharide composition of suspended particles collected from five stations in the Bay of Bengal is reported. The general features emerging from the results are compared and discussed with data collected from other marine environments.

## MATERIAL AND METHODS

Sea water samples (40) were collected from surface (~1 m) to 1,000 m depths using 10-20 l PVC Niskin bottles during cruise No. 40 of the ORV *Sagar Kanya* in March/April 1988 in the Bay of Bengal. Stations sampled during the cruise are shown in Figure 1. Immediately after collection water samples (10 to 30 l) were filtered through precombusted (450°C, 3 hrs.) 47 mm GF/F glass fibre filter for particulate organic carbon and carbohydrate analysis. A subsample (only surface water) from the surface sea water collected as above was preserved with buffered formalin (5%) for microscopic observation of phytoplankton species composition.

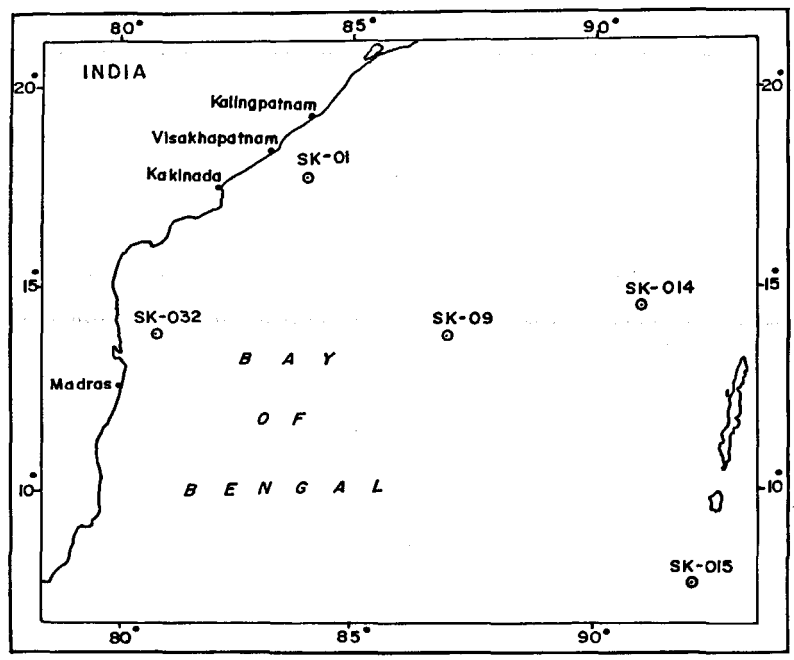


Figure 1
*Location of the sampling stations during the 40th cruise of ORV* Sagar Kanya *in the Bay of Bengal.*

### Organic carbon analysis

A glass fibre filter (GF/F) with suspended particles was analysed for particulate organic carbon (POC) as suggested by Parsons *et al.* (1984).

### Monosaccharide analysis

Samples of suspended particles obtained as above were placed in 72% $H_2SO_4$ at room temperature (28±2°C) for 2 hrs. and then diluted to 1.2 M $H_2SO_4$. Samples were then hydrolyzed for 3 hrs. at 100°C as described earlier (Bhosle *et al.*, 1990). Samples were cooled and an internal standard (myo-inositol) was added to the hydrolysate which was subsequently neutralized with $Ba(OH)_2$. The $BaSO_4$ precipitate was removed by centrifugation. The pH of the resulting solution was raised to 8-9 by adding 10% V/V−triethylamine solution in water for hydrolysis of lactones. After about 30 min. an excess of $NaBH_4$ was added to reduce the monosaccharides to the corresponding alditols. The residual $NaBH_4$ after two hours at room temperature was decomposed by addition of glacial acetic acid. After effervescence had ceased the solution was evaporated to dryness under reduced pressure. Boric acid was removed by repeated addition of methanol and evaporation to dryness. The samples were desiccated *in vacuuo* over KOH.

Acetylation was performed in closed vials in pyridine/acetic anhydride (1 : 1) for 2 hrs. at 100°C. The acetylating reagent was evaporated to dryness under reduced pressure and the samples were desiccated overnight over KOH *in vacuuo*. Subsequently, water (4 ml) was added and the solution was extracted three times with equal amounts of dichloromethane (4 ml). The combined dichloromethane extracts were dried on anhydrous sodium sulphate and concentrated. The concentrated samples were dissolved in 50 µl of dichloromethane and analysed by capillary gas chromatography.

### Capillary gas chromatography

A capillary gas chromatograph (Perkin-Elmer Model 8310) equipped with a fused silica capillary column coated with OV-275 (25 m, 0.25 mm *i.d.*) and a flame ionization detector (FID), was used to separate the

alditol acetate mixture. 1 µl of sample was injected using splitless injection when the initial injection temperature was 160°C. After 8 mn, the oven temperature was increased to 200°C at the rate 2°C/mn and held for 14 mn at 210°C. The nitrogen carrier gas was operated at 15 lb in$^2$. The injection port and detector were held at 300°C. Sample peak identities were confirmed by the retention times of authentic standard mixture. Analytical reproducibility was better than ± 6%.

## RESULTS

The distribution of temperature, salinity and nitrate at these stations is shown in Tables 1 to 5. Except for station SK 01, nitrate concentration in the upper 25 m did not show any appreciable variation. Microscopic observation of the surface seawater samples collected from these stations (Fig. 1) suggests that diatoms such as *Coscinodiscus, Rhizosolenia, Biddulphia, Chaetoceros, Navicula, Fragillaria, Surirella, Thalassiosira, Melosira, Lauderia* and *Cerataulina* were generally present. A blue-green alga *Trichodesmium* and the dinoflagellates *Exuviaella* and *Peridinium* were also observed at some of the stations.

The POC showed spatial variations. The higher concentration of POC was recorded at SK 01 in the northern region of the Bay. Furthermore, stations close to the shore showed higher values of POC. Although no particular trend was evident in the vertical distribution, the concentration of POC was higher at greater depths (Tab. 1 to 5).

As observed for the POC, the PCHO (sum of individual sugars) concentration was higher in the northern than in the southern region of the bay. The values of PCHO generally decreased in the offshore direction. Three distinct patterns were evident in the vertical distribution of PCHO (Tab. 1 to 5). With the exception of SK 09, PCHO generally decreased in the upper 50 or 100 m. This was followed by a subsurface maximum at 500 (SK 015) or 1,000 m (SK 014). This subsurface maximum was followed by a decrease throughout the water column at SK 01. The contribution of PCHO to POC also showed large variations and ranged from about 1 to 15 % with values more than 10 % rarely found.

Eight neutral monosaccharides *viz.* rhamnose, fucose, ribose, arabinose, xylose, mannose, galactose and glucose were identified in the acid hydrolysates of the suspended particles collected from the surface to

Table 1

*Monosaccharide composition (Mol %) of the suspended particulate matter at station SK-01 (17°10.10'N, 84°.00.85'E) of the Bay of Bengal during the 40th cruise of the ORV* Sagar Kanya *in March/April*, 1988.

| Depth (m) | 0 | 10 | 25 | 50 | 100 | 300 | 500 | 1,000 |
|---|---|---|---|---|---|---|---|---|
| Rhamnose | – | 11.13 | 2.89 | 7.19 | 8.20 | 9.73 | 2.53 | 6.85 |
| Fucose | – | 9.62 | 3.62 | 5.03 | 23.88 | 7.07 | 6.33 | 6.85 |
| Ribose | – | 5.31 | 2.89 | 7.19 | 4.10 | 5.31 | 2.53 | 4.11 |
| Arabinose | – | 11.13 | 15.94 | 7.91 | 13.43 | 7.07 | 3.79 | 5.48 |
| Xylose | – | 10.12 | 6.52 | 7.19 | 7.83 | 3.54 | 6.33 | 4.11 |
| Mannose | – | 20.50 | 14.49 | 12.94 | 12.31 | 19.46 | 17.72 | 26.02 |
| Galactose | – | 15.19 | 21.74 | 9.35 | 14.92 | 25.66 | 10.12 | 13.69 |
| Glucose | – | 16.96 | 31.88 | 43.16 | 15.29 | 22.12 | 50.63 | 32.88 |
| PCHO (µgl$^{-1}$) | – | 68.14 | 24.03 | 24.56 | 45.92 | 20.13 | 14.26 | 13.14 |
| POC (mgl$^{-1}$) | – | 0.76 | 0.76 | 0.91 | 1.25 | 0.66 | 0.83 | 1.03 |
| PCHO/POC (%) | – | 8.95 | 3.15 | 2.67 | 3.69 | 3.05 | 1.71 | 1.27 |
| Temperature (°C) | 29.77 | 28.22 | 27.17 | 23.24 | 17.79 | 11.24 | 9.67 | 6.73 |
| Salinity (× 10$^{-3}$) | 33.73 | 33.64 | 33.74 | 34.68 | 34.79 | 34.01 | 35.00 | 34.93 |
| Nitrate (µg.at.l$^{-1}$) | 0.56 | 0.67 | 0.79 | 0.84 | 3.96 | 16.89 | 35.31 | 38.12 |
| SIG-T | 20.97 | 21.32 | 21.60 | 23.64 | 25.18 | 26.75 | 27.02 | 27.42 |

– = No Sample

Table 2

*Monosaccharide composition (Mol %) of the suspended particulate matter at station SK-09 (13°57.49'N, 87°.00.92'E) of the Bay of Bengal during the 40th cruise of the ORV* Sagar Kanya *in March/April*, 1988.

| Depth (m) | 0 | 10 | 25 | 50 | 100 | 300 | 500 | 1,000 |
|---|---|---|---|---|---|---|---|---|
| Rhamnose | 3.75 | 3.70 | 7.86 | 6.94 | 25.58 | 35.80 | 27.47 | 18.46 |
| Fucose | 20.83 | 12.96 | 6.74 | 17.18 | 28.77 | 30.23 | 16.48 | 9.94 |
| Ribose | 8.33 | 9.26 | 22.47 | 12.15 | 19.18 | 11.93 | 15.79 | 8.52 |
| Arabinose | 8.33 | 7.40 | 11.12 | 8.68 | 9.11 | 15.91 | 6.86 | 14.20 |
| Xylose | 4.16 | 5.55 | 10.11 | 3.47 | 3.99 | 1.59 | 4.12 | 1.42 |
| Mannose | 12.50 | 11.11 | 11.23 | 13.88 | 3.19 | 2.38 | 6.86 | 11.38 |
| Galactose | 12.50 | 18.51 | 11.23 | 13.88 | 1.59 | 3.18 | 2.74 | 4.26 |
| Glucose | 29.56 | 31.48 | 19.20 | 23.78 | 8.58 | 5.33 | 19.64 | 31.81 |
| PCHO (µgl$^{-1}$) | 5.21 | 9.84 | 4.76 | 31.27 | 21.22 | 21.22 | 24.99 | 12.36 |
| POC (mgl$^{-1}$) | 0.49 | 0.91 | 0.31 | 2.89 | 2.00 | 1.02 | 0.77 | 0.84 |
| PCHO/POC (%) | 1.06 | 1.07 | 1.50 | 1.08 | 1.06 | 2.07 | 3.21 | 1.46 |
| Temperature (°C) | 29.98 | 29.51 | 28.60 | 28.14 | 24.37 | 11.14 | 9.39 | 6.21 |
| Salinity (× 10$^{-3}$) | 32.99 | 33.19 | 33.31 | 33.71 | 34.68 | 35.01 | 35.03 | 84.92 |
| Nitrate (µg.at.l$^{-1}$) | 0.35 | 0.40 | 0.37 | 0.37 | 20.94 | 35.52 | 39.15 | 39.94 |
| SIG-T | 20.24 | 20.55 | 21.03 | 21.40 | 23.31 | 26.77 | 27.09 | 27.48 |

Table 3

*Monosaccharide composition (Mol %) of the suspended particulate matter at station SK-014 (14°42.21'N, 90°.59.72'E) of the Bay of Bengal during the 40th cruise of the ORV* Sagar Kanya *in March/April*, 1988.

| Depth (m) | 0 | 10 | 25 | 50 | 100 | 300 | 500 | 1,000 |
|---|---|---|---|---|---|---|---|---|
| Rhamnose | 14.04 | 13.18 | 23.03 | 6.15 | 25.58 | 35.80 | 27.47 | 18.46 |
| Fucose | 15.74 | 23.81 | 14.54 | 6.15 | 15.84 | 11.76 | 9.52 | 11.51 |
| Ribose | 9.78 | 5.86 | 7.87 | 3.07 | 7.97 | 5.88 | 4.76 | 9.42 |
| Arabinose | 11.49 | 7.32 | 10.91 | 7.69 | 12.87 | 5.88 | 4.76 | 7.33 |
| Xylose | 5.95 | 2.56 | 3.03 | 1.53 | 4.95 | 1.47 | 3.33 | 7.33 |
| Mannose | 12.76 | 15.38 | 11.51 | 23.07 | 16.83 | 20.58 | 14.28 | 16.23 |
| Galactose | 10.21 | 9.15 | 9.09 | 12.30 | 8.91 | 11.76 | 14.28 | 11.51 |
| Glucose | 20.00 | 22.71 | 20.00 | 40.00 | 18.81 | 32.35 | 38.09 | 26.17 |
| PCHO ($\mu gl^{-1}$) | 40.46 | 47.85 | 28.85 | 12.18 | 17.58 | 6.65 | 4.26 | 13.01 |
| POC ($mgl^{-1}$) | 0.31 | 0.31 | 0.30 | 0.20 | 0.30 | 0.31 | 0.32 | 0.20 |
| PCHO/POC (%) | 12.84 | 15.09 | 9.42 | 6.00 | 5.84 | 2.08 | 1.33 | 6.36 |
| Temperature (°C) | 29.20 | 28.85 | 28.14 | 27.57 | 22.61 | 11.20 | 9.50 | 6.33 |
| Salinity ($\times 10^{-3}$) | 32.50 | 32.52 | 32.68 | 33.15 | 34.60 | 35.09 | 35.02 | 34.95 |
| Nitrate ($\mu g.at.l^{-1}$) | 0.35 | 0.31 | 0.23 | 0.27 | 21.45 | 36.23 | 39.60 | 40.12 |
| SIG-T | 20.72 | 20.71 | 20.99 | 21.51 | 23.14 | 26.74 | 26.97 | 27.45 |

Table 4

*Monosaccharide composition (Mol %) of the suspended particulate matter at station SK-015 (9°01.43'N, 93°.10.65'E) of the Bay of Bengal during the 40th cruise of the ORV* Sagar Kanya *in March/April*, 1988.

| Depth (m) | 0 | 10 | 25 | 50 | 100 | 300 | 500 | 1,000 |
|---|---|---|---|---|---|---|---|---|
| Rhamnose | 4.93 | 14.33 | 12.24 | 17.39 | 6.00 | 15.87 | 3.05 | 5.12 |
| Fucose | 3.70 | 7.16 | 4.08 | 13.04 | 2.00 | 9.52 | 2.18 | 3.84 |
| Ribose | 8.64 | 7.16 | 6.12 | 4.34 | 6.00 | 15.87 | 5.24 | 7.69 |
| Arabinose | 7.40 | 10.75 | 10.20 | 8.69 | 8.00 | 7.93 | 10.48 | 10.11 |
| Xylose | 4.93 | 3.22 | 14.28 | 4.34 | 4.00 | 7.93 | 5.67 | 5.12 |
| Mannose | 16.05 | 14.33 | 16.32 | 8.69 | 22.00 | 14.23 | 20.96 | 21.79 |
| Galactose | 11.11 | 10.75 | 12.24 | 13.04 | 8.00 | 9.52 | 8.29 | 10.25 |
| Glucose | 43.20 | 32.25 | 24.49 | 30.43 | 44.00 | 19.04 | 44.10 | 35.89 |
| PCHO ($\mu gl^{-1}$) | 14.65 | 5.13 | 9.06 | 8.61 | 9.51 | 11.08 | 40.25 | 14.16 |
| POC ($mgl^{-1}$) | 0.50 | 0.34 | 0.27 | 0.27 | 0.35 | 0.27 | 0.37 | 0.53 |
| PCHO/POC (%) | 2.89 | 1.49 | 3.24 | 3.18 | 2.70 | 4.10 | 10.67 | 2.64 |
| Temperature (°C) | 30.21 | 30.19 | 29.87 | 30.16 | 26.35 | 11.29 | 9.44 | 6.75 |
| Salinity ($\times 10^{-3}$) | 33.40 | 33.25 | 33.61 | 34.45 | 34.83 | 35.12 | 35.08 | 34.90 |
| Nitrate ($\mu g.at.l^{-1}$) | 0.34 | 0.30 | 0.33 | 0.30 | 21.80 | 33.47 | 36.05 | 37.96 |
| SIG-T | 20.47 | 20.37 | 20.95 | 21.28 | 22.81 | 26.83 | 27.12 | 27.39 |

Table 5

*Monosaccharide composition (Mol %) of the suspended particulate matter at station SK-032 (14°00.82'N, 80°58.52'E) of the Bay of Bengal during the 40th cruise of the ORV* Sagar Kanya *in March/April*, 1988.

| Depth (m) | 0 | 10 | 25 | 50 | 100 | 300 | 500 | 1,000 |
|---|---|---|---|---|---|---|---|---|
| Rhamnose | 7.87 | 3.75 | 4.21 | 20.68 | 9.70 | 12.12 | 14.73 | 10.66 |
| Fucose | 10.23 | 3.75 | 21.05 | 6.89 | 1.94 | 6.06 | 14.73 | 14.92 |
| Ribose | 7.08 | 3.75 | 9.47 | 6.89 | 6.79 | 4.54 | 2.10 | 1.92 |
| Arabinose | 15.74 | 7.50 | 5.26 | 6.89 | 8.73 | 4.54 | 29.47 | 10.66 |
| Xylose | 13.38 | 1.25 | 3.15 | 15.51 | 2.91 | 3.03 | 2.10 | 2.13 |
| Mannose | 11.81 | 25.00 | 4.21 | 10.34 | 17.47 | 25.75 | 10.52 | 17.05 |
| Galactose | 11.81 | 12.50 | 10.54 | 12.06 | 12.62 | 10.60 | 5.26 | 10.66 |
| Glucose | 22.04 | 42.50 | 42.10 | 20.68 | 39.80 | 33.33 | 21.05 | 31.98 |
| PCHO ($\mu gl^{-1}$) | 22.77 | 14.48 | 6.74 | 10.08 | 18.66 | 12.12 | 16.54 | 8.48 |
| POC ($mgl^{-1}$) | 0.20 | 0.22 | 0.30 | 0.26 | 0.23 | 0.23 | 0.27 | 0.29 |
| PCHO/POC (%) | 11.16 | 6.43 | 2.20 | 3.87 | 8.11 | 5.15 | 5.94 | 2.89 |
| Temperature (°C) | 29.65 | 29.66 | 29.09 | 27.45 | 23.70 | 11.60 | 9.60 | 6.56 |
| Salinity ($\times 10^{-3}$) | 34.12 | 34.03 | 34.18 | 33.72 | 34.63 | 35.55 | 35.55 | 35.19 |
| Nitrate ($\mu g.at.l^{-1}$) | 0.29 | 0.27 | 0.27 | 0.27 | 12.74 | 29.04 | 34.05 | 34.52 |
| SIG-T | 20.57 | 20.59 | 21.08 | 21.53 | 23.00 | 27.18 | 27.38 | 27.62 |

1,000 m depths. Glucose, mannose and galactose were the most abundant sugars with some exceptions. Higher concentrations of fucose and rhammnose were also recorded for the suspended particles collected from the surface waters of station SK 09 and SK 014. At greater depths (100 to 1,000), the abundance of rhammnose, fucose and ribose was also noticeable for these two stations. Glucose content generally increased as the depth increased with some exceptions. This effect was very evident for station SK 01, where increase in glucose content was associated with the decrease in the PCHO (Fig. 2). The increase in glucose was also associated with higher abundance of arabinose. Xylose and mannose did not show any particular trend. The

monosaccharide composition of the suspended particles observed at 1,000 m was similar to that recorded at the surface for station SK 014 and SK 015.

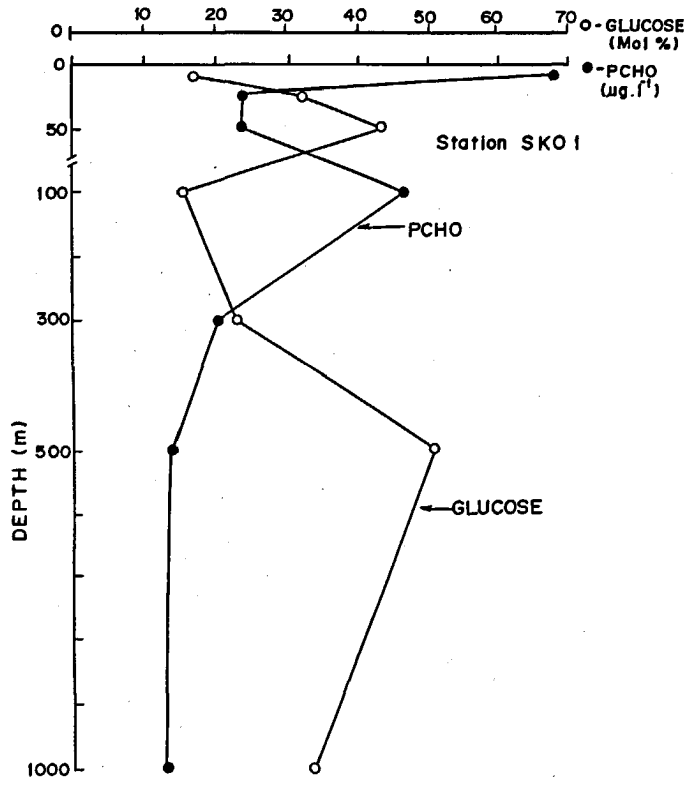


Figure 2
*Distribution of PCHO and glucose at station SK* 01 *in the Bay of Bengal.*

## DISCUSSION

The PCHO concentrations reported in the present study are relatively lower than those reported earlier for the Bay of Bengal (Bhosle *et al.*, 1981; Bhosle *et al.*, 1989 *a*). This apparent discrepancy was probably due to differences in the analytical techniques. The total technique employed in the earlier studies using the phenol-sulphuric acid method detects any cis-glycol bearing compounds such as aminosugars, uronic acids and sugars. This may result in the over-estimation of PCHO. In view of this a direct comparison between the values reported earlier and in the present study may not be advisable.

It was interesting to note that the distribution of PCHO was quite dissimilar to that of Chl *a* and primary productivity. It was observed that Chl *a* and primary productivity increased from north to south (Qasim, 1978; Bhattathiri *et al.*, 1980). Conversely, PCHO decreased from north (SK 01) to south (SK 032). The observed higher concentration of PCHO was probably due to large amount of land runoff brought in by six major rivers in the northern region of the bay. This distribution of PCHO agrees well with the earlier studies from the area (Bhosle *et al.*, 1981). In general, primary production in the offshore region of the Bay of Bengal is low (Radhakrishna, 1978). This is well supported by the PCHO distribution in the region. For example, higher concentrations of PCHO were observed for the inshore waters in comparison with offshore waters.

PCHO as percentage of POC showed large variation (~1 to 15 %) and the values higher than 10 % were rarely found. The apparent variability in the PCHO contribution to POC was probably due to nutrient limitation and/or changes in the species composition of phytoplankton community. The former seems unlikely as nitrate content in the upper 25 m water column did not show any appreciable change at these stations with the exception of SK 01. As compared with nitrate, phytoplankton species composition varied at these stations. Hecky *et al.* (1973) observed large variation in the total cell wall carbohydrate for various fresh and brakish water diatom species. It is thus likely that PCHO varied because of the variation in the phytoplankton species composition.

Eight neutral monosaccharides *viz.* rhamnose, fucose, ribose, arabinose, xylose, mannose, galactose and glucose were identified in the acid hydrolysates of the suspended particles of the Bay of Bengal. It appears that these monosaccharides are of common occurrence in the carbohydrates of suspended particles collected from various marine environments (Handa and Yanagi, 1969; Handa and Tominaga, 1969; Ittekkot *et al.*, 1982; 1984 *a*; *b*; Cowie and Hedges, 1984; Liebezeit, 1984; Tanoue and Handa, 1987). The contribution of individual sugars to the total PCHO, however varied with depths at these stations.

Glucose was generally the most abundant monosaccharide in the suspended particles. Its contribution to the PCHO varied from 5 to 50 %. A glucose content of 20 to 70 % of PCHO has been observed for the suspended particles collected from other marine environments (Handa and Yanagi, 1969; Handa, 1970; Ittekkot *et al.*, 1982; Liebezeit, 1984; Tanoue and Handa, 1987). The apparent variability in glucose content may be due to changes in phytoplankton composition, its detritus and contribution from terrestrial material.

The glucose content generally decreased in the upper 50 to 100 m. It was observed that the common carbohydrate storage polysaccharide in diatom is chrysolaminarin, a B-1-3 glucan which is easily degraded by *in situ* aquatic organisms and/or utilized during diatom cell sinking (Meeuse, 1962; Handa, 1969; Handa and Yanagi, 1969; Handa *et al.*, 1972; Hitchcock, 1977; Liebezeit, 1984; Tanoue and Handa, 1987; Bhosle and Wagh, 1989). Thus, the decrease of the glucose content with depth reflect the preferential utilization of this reserve polymer. This was also evident from the relative increase of other carbohydrate compounds.

The cell wall polysaccharides of diatoms consist of alkali soluble heteropolysaccharides and alkali insoluble glucan (Haug *et al.*, 1973). Alkali soluble polysaccharides are also rapidly removed from the phytoplankton, which results in the increased relative abundance of glucose and the decrease in PCHO at many locations and especially at SK 01 (Fig. 2). Cellulose or cellulose like glucan is another possible source for the observed abundance of glucose as this polymer is the most resist-

ant to biological attack as compared to hemicellulose materials (Hedges *et al.*, 1985; Tanoue and Handa, 1987).

The increasing abundance of glucose in the suspended particles from the deep waters (>100 or 300 m) was also associated with higher contribution from arabinose. Generally, arabinose is poor in both cell content and cell wall material of diatoms. However, arabinose is abundant in terrestrial higher plants which have arabinose as a building block of arabinoxylan and arabinoglucuronoxylan, *etc.* Thus it appears that organic material derived from terrestrial higher plants was the major source of arabinose of the suspended particles.

This seems likely as six major rivers flowing through the various geological formation of the Indian subcontinent introduce into the Bay of Bengal of about $2.0 \times 10^{15}$ g of suspended particulate matter annually, *i.e.* 15 % of the contemporaneous global discharge of fluvial sediments into the world oceans (Rao, 1985). Furthermore, these rivers have depositional centres in well-developed deep-sea fans extending several thousand kilometres offshore (Ittekkot and Arain, 1986). These factors could have influenced the observed abundance of arabinose and glucose in the suspended particles of the Bay of Bengal.

The observed relatively higher abundance of glucose in the suspended particles from the deep waters of the Bay of Bengal was comparatively less than those obtained from the deep waters of other seas and oceans (Liebezeit, 1984; Ittekkot *et al.*; 1982; Tanoue and Handa, 1987). This was surprising since it is the dominant sugar in all forms of terrestrial and aquatic matter (Degens and Mopper, 1976). Thus a low content of glucose points to a selective enrichment in the other sugar fraction, or to a preferential degradation of glucose, or to an increased contribution from sources poor in glucose (Cowie and Hedges, 1984; Liebezeit, 1984).

Glucoronomannan of diatoms and glucomannan in terrestrial plants are probably the major sources of mannose of suspended particles (Timmell, 1957; Ford and Percival, 1965; Sjostrom, 1981). The abundance of mannose at various depths suggest that the polymers containing mannose were resistant to biological degradation. Mannose abundance in suspended particles from other oceanic waters has also been observed (Tanoue and Handa, 1987).

The relative abundance of rhamnose, fucose, ribose, arabinose, and galactose also showed large variations with depth. Their concentrations generally decreased with depth and a fairly high contribution from these sugars to PCHO even at greater depths was observed. These facts point either to selective enrichment of these sugars in the suspended particles or to their resistance to biological degradation.

A very high contribution of rhamnose, fucose and ribose was noticeable below 50 m at stations SK 09 and SK 014. These sugars are relatively abundant in bacteria and also in some diatoms such as *Chaetoceros*, *Thalassiosira* and *Corethron* (Handa and Yanagi, 1969; Haug and Myklestad, 1976; Cowie and Hedges, 1984). Diatoms such as *Chaetoceros* and *Thalassiosira* were present at these locations. Thus the higher contribution of these sugars to PCHO suggests a greater contribution from such organisms to suspended particles.

Suspended particles from the deeper waters of SK 09 were poor in galactose and other hexoses and relatively enriched in ribose and deoxyhexoses. The obtained monosaccharide composition was very different from that observed in the surface suspended particles at the same station. This indicates a different source of monosaccharides of suspended particles from the deeper waters of SK 09. Bacteria are relatively rich in ribose and deoxyhexoses and are generally poor in galactose and other hexoses. This implies that bacteria were the major source of PCHO of suspended particles from the deeper waters of the SK 09. Intense microbial growth, diagenetic transformation and mineralization processes associated with small suspended particles have been reported as taking place in the mesopalagic zone of the sea. These microbial processes in the mesopalagic zone can give rise to large scale production of fine (0.3 to 1.0 μm) non-sinking particles rich in bacteria (Cho and Azam, 1988). Such microbial processes could perhaps explain the paucity of galactose and other hexoses as well as the abundance of ribose and deoxyhexoses in the suspended particles of the deeper waters of SK-09.

The monosaccharide composition of suspended particles obtained from the surface and 1,000 m is nearly the same, especially at SK 014 and SK 015. This points to the fact that the carbohydrates did not undergo any degradation during their transport to greater depths. This is very unlikely. Alternatively, suspended particles at these stations were perhaps influenced by large particles (>50 μm). Although large particles such as fecal pellets, fecal matter and aggregates of small particles are present in sea water (McCave, 1975; Asper, 1987), these particles are rare and not effectively collected by conventional water samplers. Occasionally, however they are trapped in the water samplers, thus influencing the composition of suspended particles (Harrison *et al.*, 1987).

In summary, suspended particles collected from surface to 1,000 m were analysed for POC and monosaccharide composition. Higher concentrations of POC and PCHO were observed in the northern than in the southern region of the bay. Both POC and PCHO generally decreased in the offshore direction. The vertical distribution of PCHO implies that the content generally decreased with depth at most of the stations. Monosaccharide composition suggested that glucose, mannose, galactose, fucose and rhamnose were generally the most abundant sugars, followed by ribose, arabinose and xylose, in the suspended particles collected from the surface waters of these stations. The relatively higher contribution from hexoses and some deoxyhexoses suggests the abundance of phytoplankton in the surface waters. The concentration of these sugars generally decreased in the upper 100 m. This was followed by higher abundance of rhamnose, fucose and

ribose and paucity of hexoses at intermediate depths (>100 m) for the station SK 09 and SK 014. This probably suggests intense microbial activity in the mesopelagic region of the bay. Glucose content generally increased with depth and was also associated with higher abundance of arabinose. The abundance of these two sugars is indicative of the contribution from terrestrial higher plants. Thus the monosaccharide composition data indicate that carbohydrates of suspended particles were derived from phytoplankton, bacteria and terrestrial higher plants.

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