Distribution of Dissolved Carbohydrate in the Indian Ocean*

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Abstract: For sea water samples collected during the Umitaka-Maru cruise, December 1962-January 1963, of the International Indian Ocean Expedition Program, the content of dissolved carbohydrate was measured by using the phenol sulfuric acid method on which the author intends to report in a succeeding issue of this Journal.

It was shown that low values 0.21–0.39 mg/l were observed at upper levels, while higher values were obtained at levels below 100 m.

The values are compared with those hitherto obtained in the Pacific Ocean.

Some discussions are made regarding the possible cause of these low and high values and the unequal vertical distribution of the content of dissolved carbohydrate as observed in the Indian Ocean.

1. Introduction

The need of determination and identification of organic compounds in sea water has been stressed for understanding their role in biochemical processes of biological materials in the sea. Thus, several organic compounds such as carbohydrates, acids and especially fatty acids, amino acids and proteins as well as vitamins have been reported of their occurrence and quantity in sea water.

Several reports have been made on the distribution of dissolved carbohydrate in sea water. WANGERSKY (1952) first reported the rhamnose occurrence in a concentration up to 1 mg/l in the inshore water of Gulf of Mexico. COLLIER *et al.* (1953) determined carbohydrate in sea water samples of the estuary of Gulf of Mexico by N-ethylcarbazole sulfuric acid method and showed the maximum value 20 mg/l in arabinose equivalent. In the Pacific Ocean, LEWIS and RAKESTRAW (1955) gave values 0.14–0.45 mg/l for the samples collected from the Eastern Pacific Ocean off the west coast U.S.A. They also showed that the recovery of carbohydrate was higher for the anthrone sulfuric acid method than for the N-ethylcarbazole sulfuric acid method. ANDERSON and GEHRINGER (1958)

reported the carbohydrate content as 0.0–2.6 mg/l in the South Atlantic Ocean. In samples from the continental shelf of Gulf of Mexico, COLLIER (1958) obtained values 0.0–3.0 mg/l by using N-ethylcarbazole sulfuric acid method. Recently, ANTIA and LEE (1963) preferred the anthrone sulfuric acid method for the total dissolved carbohydrate to the N-ethylcarbazole sulfuric acid method which was shown to be interfered by the presence of other organic compounds. They also showed that the anthrone sulfuric acid method is applicable to the differential determination of hexose, pentose and hexuronic acid using the differences in the absorption maximum of different sugar-anthrone chromophores.

Considering the present situation of the organic chemistry of sea water as stated above it is urgent to extend methodological researches of carbohydrate determination on the hand and on the other to increase the number of determination in wider areas of the ocean to draw the map of the distribution of this kind of substance.

In the present paper the author reports the data of determination of dissolved carbohydrate of the samples of sea water from the tropical and subtropical areas of the Indian Ocean collected during the December 1962–January 1963 Umitaka-Maru cruise of the International Indian Ocean Expedition Program.

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Carbohydrate determination was made by the phenol sulfuric acid method on which the author intends to report in the form of a separate paper expected to be published in a succeeding issue of the present Journal.

Despite that the number of data is not very big, the discussion on them are believed to be useful to give clues along which the research shall be extended further.

2. Methods and stations

Sampling: Sea water samples were collected with Nansen water sampler. Just after having been collected the samples were filtered through millipore filter (HA). The filtrate was allowed to be kept in a deep freezer for later use.

During the cruise, photosynthetic rate, chlorophyll-a, temperature, oxygen and inorganic nutrients were measured by the Japanese National Working Group of IIOE at all stations.

Procedure of dissolved carbohydrate determination: After frozen samples were made to melt at room temperature, the obtained sea

water (10 ml) was evaporated to dryness with rotary evaporator using a ground round-bottom flask. To the distilled water (1 ml) was added to dissolve the dry material. Then phenol solution (1 ml, 5% W/V) and concentrated sulfuric acid (5 ml) with stannous chloride (2.5% W/V) were added. The color intensity was measured at 490 m μ using Coleman colorimeter with a 5 cm-cell in light path.

Stations: Four stations distributed to the south of the equator along 78°E in the Indian Ocean as follows:

Station 8	5°52'.2S,	78°01'.6E
Station 14	10°54'.6S,	78°07'.0E
Station 16	15°10'.2S,	78°02'.8E
Station 17	17°31'.8S,	78°08'.2E

The salinity and density distributions are shown in Fig. 1. From the temperature-salinity diagram, three different water masses, Equatorial Water Mass (A), Indian Ocean Central Water Mass (B) and Subantarctic Water Mass (C) are discriminated. Station 8 is in the area of Equatorial Water Mass and Station 16 and 17

Fig. 1. Salinity profile along 78°E of the Indian Ocean showing the location of unattenuated Equatorial (A), Indian Ocean Central (B) and Subantarctic (C) Waters.

are mainly in the Indian Ocean Central Water Mass partly in the deeper Subantarctic Water Mass underlying, while Station 10 appears to be located in the mixing area of both Equatorial Water and Indian Ocean Central Water Masses.

3. Results and discussion

Sea water samples collected at the four stations were subjected to the determination of dissolved carbohydrate by the phenol sulfuric acid method. The results are shown in Table 1. Dissolved carbohydrate ranges 0.19–0.66 mg/l in the area. The values are almost comparable to those obtained by LEWIS and RAKESTRAW who reported 0.14–0.45 mg/l in the samples from the Eastern Pacific Ocean and by ANTIA and LEE who also reported 0.11–0.40 mg/l of the sample from depths of 5 and 3,000 m of North-eastern Pacific Ocean. However, the Indian Ocean appears to differ from the Pacific Ocean as to the vertical distribution of carbohydrate. While the content of dissolved carbohydrate is uniform through different layers in the Pacific Ocean, it is not in the Indian Ocean where the content

is low and rather uniform in the upper 100 m layers and then tends to increase toward deep. Thus at Station 8 the content was 0.23–0.30 mg/l with no significant variation from the surface to 106 m. Then it started to increase to 0.43–0.66 mg/l down to a depth 2,400 m. A similar distribution pattern was found at Station 14 where the carbohydrate was 0.30–0.39 mg/l in upper layers and increased to 0.43–0.50 mg/l from 113 m towards 2,400 m deep. At Station 16 in layers 0 to 104 m the content was 0.26–0.32 mg/l while it increased to 0.30–0.49 mg/l in layers underlying. Different from the preceding three stations, the distribution at Station 17 was somewhat away from the fundamental pattern. The discontinuity near 100 m deep is not distinct. Low values 0.20–0.30 mg/l continue down to 763 m and higher values 0.35–0.41 mg/l were found first at depths 1,671 and 2,080 m.

Here it will be worth to discuss the cause of the observed distribution of dissolved carbohydrate in the light of the knowledge of dissolved carbohydrate in the light of the knowledge of the source of carbohydrate and other ocea-

Table 1. Dissolved carbohydrate distribution in the Indian Ocean.

Station 8		Station 14		Station 14		Station 17	
Depth(m)	mg/l	Depth(m)	mg/l	Depth(m)	mg/l	Depth(m)	mg/l
0	0.28	0	0.31	0	0.32	0	0.25
8	0.23	8	0.35	7	0.23	8	0.23
16	0.24	17	0.37	15	0.33	16	0.23
25	0.24	26	0.30	23	0.36	25	0.25
42	0.23	44	0.30	40	0.30	41	0.20
64	0.25	67	0.39	60	0.30	62	0.30
85	0.25	90	0.31	80	0.29	83	0.30
106	0.30	113	0.31	100	0.26	104	0.21
127	0.43	135	0.45	120	0.30	124	0.19
		182	0.60	161	0.34	170	0.20
212	0.66	229	0.55	166	0.34	216	0.25
252	0.57	272	0.43	200	0.49	287	0.30
328	0.46	363	0.46	264	0.42	359	0.33
411	0.60	453	0.43	329	0.42	432	0.30
494	0.43	544	0.43	395	0.35	591	0.23
657	0.57	726	0.43	550	0.34	619	0.27
821	0.54	906	0.47	670	0.40	746	0.28
983	0.57	1087	0.49	814	0.45	946	0.35
1226	0.57	1360	0.45	1042	0.45	1300	0.36
1625	0.60	1812	0.44	1438	0.45	1671	0.41
2011	0.54	2263	0.45	1855	0.45	2080	0.41
2400	0.56	2720	0.48	2292	0.45		

* Carbohydrate is shown as D-glucose equivalent.

Fig. 2. Distribution of dissolved carbohydrate, temperature and oxygen.
 —: Carbohydrate - - - - - : Oxygen : Temperature

nographic data, which are shown in Fig. 2.

It has been reported by many experts such as ALLEN (1956), LEWIN (1956), FOGG (1952) and WANGERSKY (1958) that living phytoplankton individuals excrete carbohydrate into sea water. Particularly GUILLARD and WANGERSKY pointed to in a bacteria free culture experiment of a unicellular marine algae that carbohydrate excretion is slow at the time when the algae community exponentially grows, while it becomes very active when or after the growth reaches the maximum.

The Japanese IIOE group on photosynthesis-chlorophyll *a* (1965) found that in layers between 75 and 125 m, constituting the upper part of thermocline, the concentration of chlorophyll *a* is maximum and photosynthetic rate is minimum.

Taking in to consideration these facts, the observed vertical distribution of dissolved carbohydrate in the Indian Ocean is understandable as follows: The sharp thermocline as observed at Stations 8 and 14 rather clearly separates the subsurface layers from underlying layers. Naturally the subsurface layers constitute an

arena where young phytoplankton communities are allowed to thrive actively with less enrichment of dissolved carbohydrate in the surrounding water medium, while less active aged or dead plankton individuals tend to move or sink to and through the thermocline. Thus in the thermocline and underlying water layers the production and accumulation of dissolved carbohydrate become considerably great.

At other stations such as Stations 16 and 18, thermocline is not sharp and does not hinder the mixing of water between the subsurface and underlying layers. Naturally vertical distribution of dissolved carbohydrate is not very distinct.

As to the source of dissolved carbohydrate in sea water the supply from decay processes of dead plankton body and its debris must be also taken into account. The observation in the Kuroshio area (1965) showed that the carbohydrate content in particulates does not greatly change between 0 and 100 m. However, it decreased to one third at 500 m. Furthermore, it was found that the carbohydrate is extractable with 80% aqueous ethol and water, and gave

only D-glucose on acid hydrolysis. A fact hinting that the carbohydrate in particulates is possibly of water soluble oligomer or polymer of glucose to its considerable portion and constitutes a significant source of the dissolved carbohydrate in sea water. Excretion by living phytoplankton or production through decay processes of dead plankton body. Which is dominant in contributing dissolved carbohydrate to sea water? This must be a target of future investigations.

Finally the comparison of total organic carbon with dissolved carbohydrate is thought to be worth attention. In a recent report (1964), MENZEL gave total organic carbon as 1.5–2.0 mgC/l for the Indian Ocean Central Water and as 0.6–0.8 mgC/l for the Equatorial Water. When these values are compared with the author's corresponding data for dissolved carbohydrate, the fraction of dissolved carbohydrate carbon in the total organic carbon is 10–20%. Secondly, the difference in total carbon between two different water masses, the Indian Ocean Central Water Mass and the Equatorial Water Mass, is not reflected in the dissolved carbohydrate, the value of which does not differ between the two water masses. The dissolved carbohydrate carbon is 0.09–0.26 mgC/l at Station 8 of the Equatorial Water and 0.08–0.020 mgC/l at Stations 16 and 17 of the Indian Ocean Central Water Mass.

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インド洋における溶存炭水化物の分布について

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要旨 インド洋における溶存炭水化物量をフェノール硫酸法を用いて定量し、その分布を報告する。用いられた試料は 78°E における 5°S から $17^{\circ}30'\text{S}$ に至る四つの station において、 $0\sim 2,500\text{ m}$ (水深) の間で 22 の層より採取された海水をミリポアフィルター (HA) でろ過したものである。この海域における溶存炭水化物量は $0.19\sim 0.66\text{ mg/l}$ であったが従来の報告とは違ってその垂直分布における変化を認められ、特に低緯度における station で著しかった。すなわち、 $0\sim 100\text{ m}$ 層ではいず

れの station においても溶存炭水化物は上下一様に存在し、 $0.21\sim 0.39\text{ mg/l}$ であったが、 100 m 以下の層ではむしろ溶存炭水化物量が増加し $0.19\sim 0.66\text{ mg/l}$ を示した。特に赤道に近い二つの station では $100\sim 200\text{ m}$ 層に溶存炭水化物量の極大値を示す層が見出され、何れも 0.60 mg/l かそれをうわまわる値を示した。しかしながらこのような垂直分布の変化の大きさは赤道から離れるにつれて減少し、 $17^{\circ}30'\text{S}$ の station ではこのような溶存炭水化物量の極大値を示す層は見出されなかった。